



Automatic storage and retrieval system control

by P. R. WITT

IBM Corporation
Endicott, New York

INTRODUCTION

The Materials Distribution Center (MDC) at IBM Endicott, New York, is a new automated warehousing facility (Figure 1). In addition to the conventional facilities, the warehouse contains an Automatic Storage and Retrieval System (Stacker Cranes), a network of pallet conveyors, and an IBM 1800 Data Acquisition and Control System to control the Automatic Storage and Retrieval System and portions of the conveyors.* The warehouse, adjacent to the main manufacturing buildings, is for storage of raw materials, parts, and assemblies.

The computer-controlled portions of the MDC will be discussed in detail. The general background, physical layout, and material flow of the MDC are first presented to describe the environment for the computerized sections.

MDC BACKGROUND

The Endicott plant is responsible for the manufacture, assembly, and test of printers, medium-sized computers, banking equipment, and circuit boards. The manufacturing process is complex, requiring storage of the many levels of subassemblies produced in the plant. In addition to manufacturing for its own use, the Endicott plant produces parts and assemblies for use at other IBM plants and is the central supply for these items.

* The following is a general description of a stacker crane system: The typical installation consists of sets of high rise storage racks, rising to heights of 100 feet or more, and extending to lengths of from 120 feet to over 800 feet, which are arranged in parallel rows in a large room. Each set of storage racks consists of two side panels containing a multiplicity of storage bins. The panels are separated by a narrow aisleway that contains a "guide rail" running along the floor of the aisleway or above the aisleway higher than the height of the highest bin. The storage-retrieval machine or "stacker" moves along the aisleway on the guide rail carrying loads to and from specific, pre-selected bins in pre-selected storage racks. The machine is self-propelled; it functions automatically on the basis of programmed instructions. The design of the stacker is relatively simple: it consists of a "shuttle arm" or shuttle table which extends laterally to pick up and deposit the load; an elevator carriage which raises the load to the proper height (the elevator runs along a "mast" which is a part of the stacker); and the electrical apparatus which controls both the vertical and horizontal automatic movements of the machine.

Prior to the construction of the new MDC, warehousing operations were fragmented and occupied 15 leased, off-site locations spread over the Endicott area. Approximately 60,000 active items were stored in the off-site locations.

The objective of creating the MDC was to bring all warehousing activities—receiving, inspection, storing, order filling, and parts shipping—on site, under one roof, and in a location adjacent to IBM Endicott's manufacturing complex.

Prior to the new Material Distribution Center, our 120,000 parts, of which 60,000 are active at any one time, were stored in over 15 off-site locations. This procedure involved a number of duplicate functions, including extensive transportation between the manufacturing plant and the off-site warehousing locations. The basic reason for building the MDC was to bring the major portion of the warehousing operation under one roof adjacent to the manufacturing buildings.

By using a central location for MDC operations a number of important objectives have been met which provided the justification for building a new warehouse facility.

The first was to substantially reduce Endicott pipeline inventory and resulted in a substantial savings to the manufacturing facility.

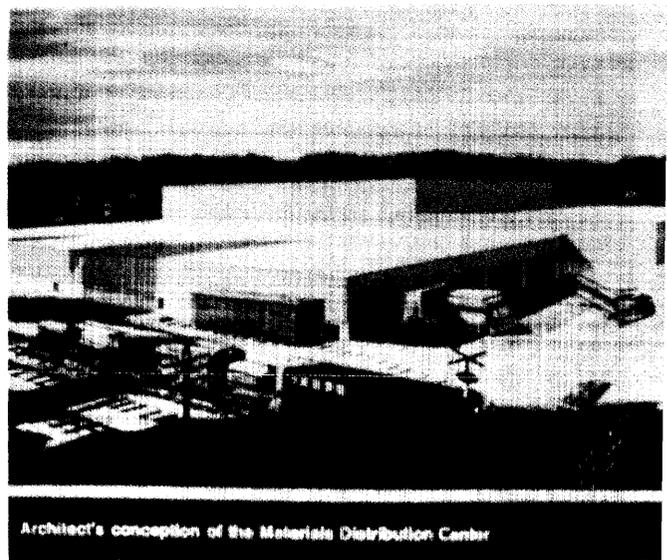


Figure 1—Materials distribution center, IBM Endicott, New York

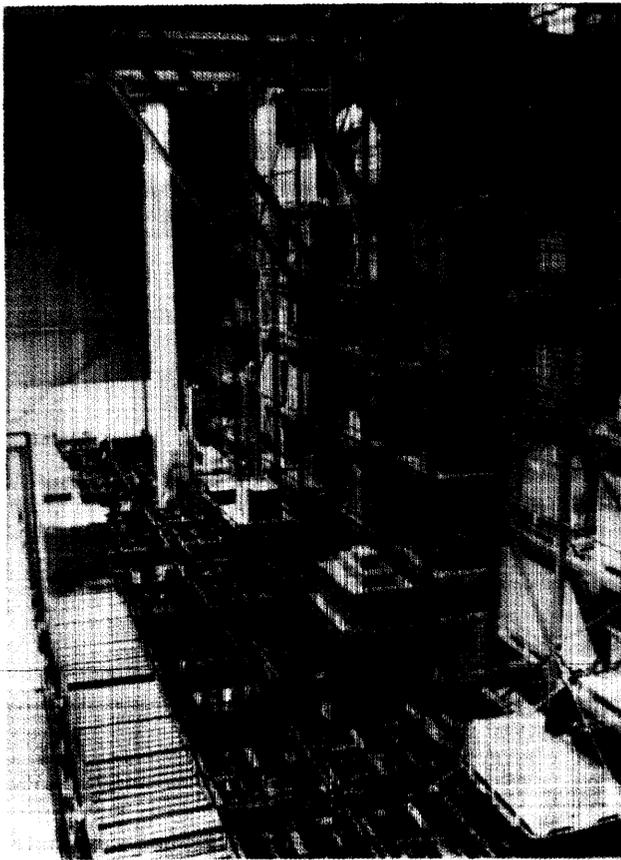


Figure 2—Automated Storage and Retrieval System (ASRS)

The second was to terminate many of the leases on the off-site locations and also have a facility that was designed for our type of warehousing.

During the design stage of the MDC, one of the problems to be solved was the fact of being landlocked in the Village of Endicott. As a solution, the use of a high-rise Automatic Storage and Retrieval System (ASRS) was investigated. A cost comparison (in terms of land, construction, equipment, and operating costs) of the ASRS with conventional truck and rack systems showed the ASRS to be a favorable choice. Because of its narrow aisles and ability to utilize high-rise storage racks, the ASRS (Figure 2) requires substantially less area than a conventional 25-foot warehouse, thereby reducing the land acquisition cost.

The ASRS also reduces manpower operating costs since it moves the product to and from the operator for storage and picking, essentially eliminating the long and unproductive transit time of men going into the storage areas to fill requisitions or store parts. The MDC, as shown in Figure 3, has 235,000 square feet in three basic portions. The first portion is a single level building (First Floor Layout, Figure 3) with 118,000 square feet of conventional warehousing. This building contains:

- an oversize bulk storage area
- bin storage for small parts
- steel and bar stock storage
- an environmental controlled room for storage of printed circuit cards
- a field service area
- parts shipping

The second area (First and Second Floor Layout, Figure 3) is a two-story building with a total of 70,000 square feet. The first floor—two-story portion—of the building contains the CBOSS area (Count, Back Order, and Sample Select). This location is for basic receiving of parts from outside vendors and other plants. Also, there is an inspection area for our quality assurance work on received materials. The second floor area contains:

- the input and picking areas for the ASRS
- the sort and accumulate area which consolidates parts into full loads for delivery to the Manufacturing building

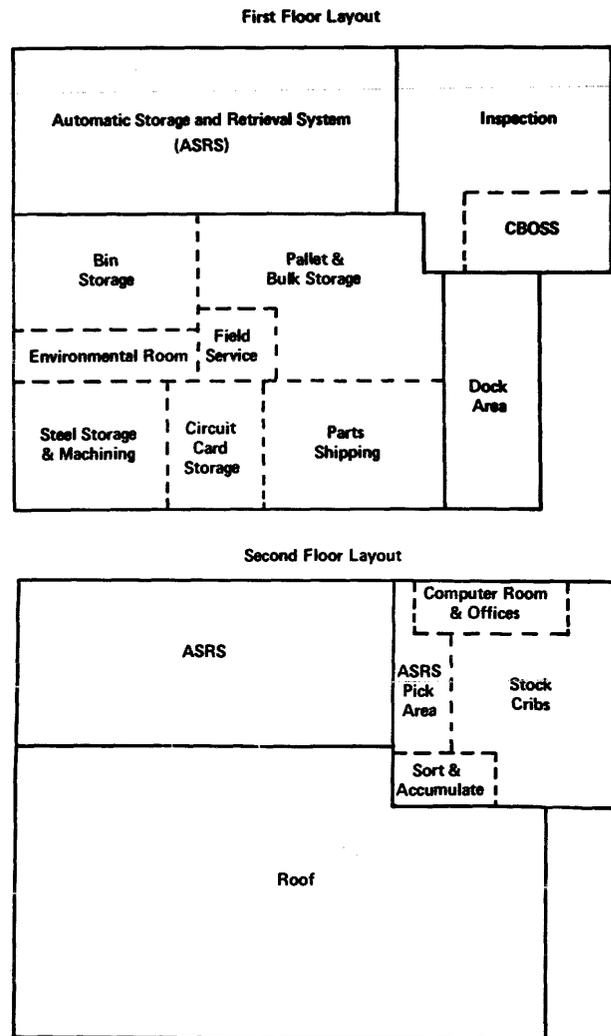


Figure 3—First and second floor layout

- the docking positions for both receiving and shipping

- cribs for special parts and tools
- the computer room and office area

The third area is the ASRS. It is single level, with a clear height of 54 feet, 47,000 square feet, and 2.5 million cubic feet of space. The area has nine 300-foot aisles with a stacker crane for each aisle. There are 18 rows of high-rise racks for storage of pallets; each crane services either side of the aisle—two rows of racks. A more detailed description is given later.

Computer simulations were used to aid in designing the Material Distribution Center. One important simulation was used in designing the ASRS. By knowing the storage and throughput requirements, a model was constructed which analyzed the various costs such as land, construction, equipment, and operating, to obtain the configuration (height, length, number of aisles) which minimized the total cost. The curve in Figure 4 indicates a minimum cost is near to the 55-foot height.

Another simulation model was used to aid in layout of the operating departments within the MDC. Using previously forecasted department space requirements and material movement volumes between departments, the model calculated the total transportation costs within the MDC for proposed layouts. This information was used to select the final layout to minimize operating costs. In addition, this data was used to determine where conveyors would be required and justified, and what throughput capacities were required.

In the ASRS, a single conveyor is used to handle both incoming and outgoing pallets to the stacker cranes. This was simulated to ensure that the single level conveyor was feasible for both control and throughput requirements. This simulation was also used to test and project the hardware system (cranes and conveyors) operation for different diverting and merging rules, partial and total sequencing of

- Satisfy: Storage volume
 Throughput requirement
- Minimize costs: Land
 Building
 Equipment
- Compute: 1. Number of cranes
 2. Amount of racks, building and land
 3. Total system investment

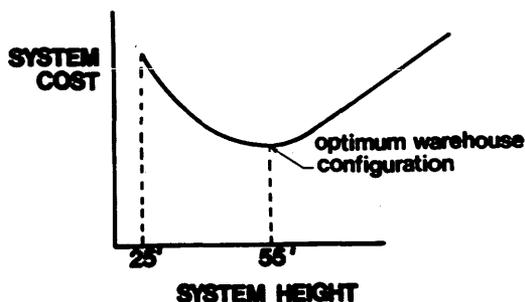


Figure 4—Graph of ASRS model results

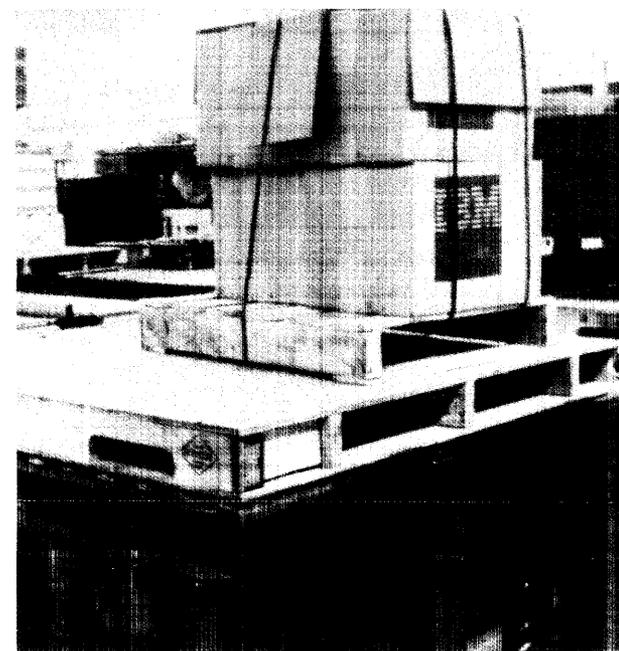
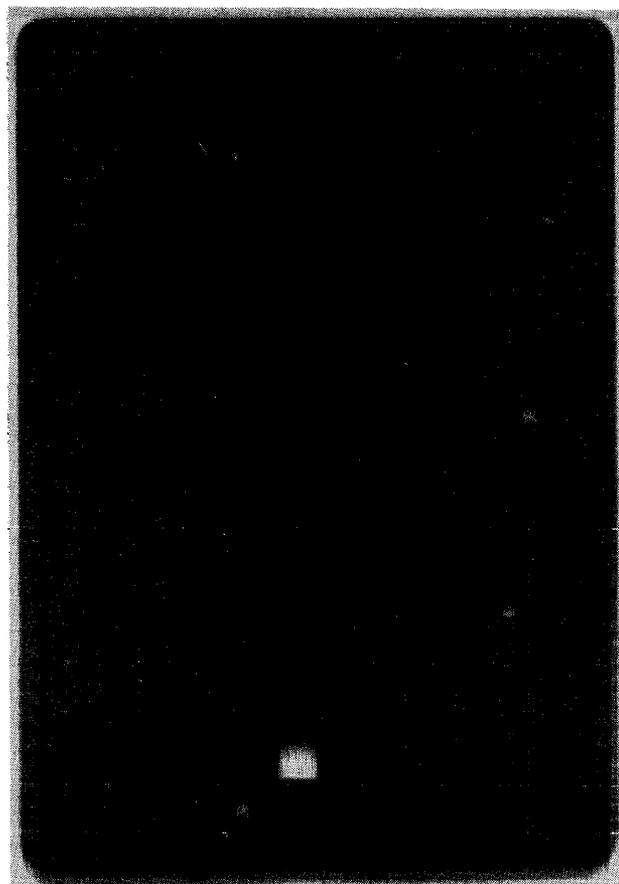


Figure 5—ASRS pallet with badge (lower center) ASRS pallet badge

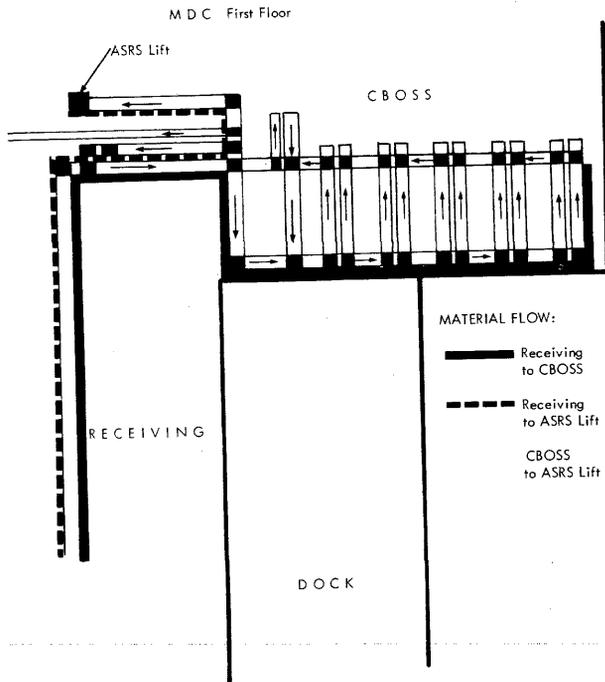


Figure 6—Material flow from receiving to ASRS

output pallets, and different command selection rules prior to actually programming of the control system. Additional programs were written for the IBM/1800 computer to simulate the cranes and conveyors to the control programs and the crane/conveyor control programs to the remainder of the control system. Also, simple programs were written to perform the actual testing of the cranes and conveyors. These programs were developed to separate the initial testing of hardware and software and portions of the application software. By this separation, the testing was simplified and shortened. Simple queuing models were used to develop the docking requirements (number docks, dock space, service times, truck waiting times).

There is material flow, via conveyor or electric truck, between most portions of the MDC. For the purpose of this paper only the flow to and from the ASRS will be outlined.

Incoming parts from vendors or other plants arrive by truck at the receiving dock. The bill of lading accompanying the shipment is used to obtain the proper receiving paperwork in the form of punched cards. These cards indicate if the item is to be sent to the ASRS, bin area, or directly to Manufacturing. The cards are placed on the parts. Parts going to the ASRS are loaded onto the special ASRS captive pallets. These pallets are 40 inches by 52 inches or 40 inches by 62 inches. Each pallet has two badges, which are on diagonal corners (Figure 5).

Each badge has a reflective and non-reflective side to be used for control of the pallet routings through the conveyor network on the first floor. Also, there is a number punched in the badge that is to control the flow through the ASRS conveyor network on the second floor.

The man at the receiving area orients the two badges for the desired routing. As the pallet flows through the network of conveyors, the elective photo-cells check for reflection or non-reflection of the two badges. This information controls the routing through the various portions of the downstairs conveyor.

The flow of ASRS parts from Receiving to the ASRS is shown in Figure 6. Pallets can move directly to the ASRS lift from the dock (dashed line 1). However, most ASRS parts are initially sent through the CBOSS (Count, Back Order, Sample Select) area. In the CBOSS the pallets are directed to one of ten identical spurs.

Here the basic receiving of goods is completed. The parts are counted and the receiving paperwork completed. Back orders are filled. If the parts require inspection, a sample lot is selected and sent to the Quality Department. ASRS parts are then released on the main line conveyor at the end of the CBOSS spurs and directed to a lift which takes them to the second floor. The pallets enter the lift and are brought to the input station for the ASRS (Figure 7). Here data is entered into the terminal describing the parts and pallets entering the system.

The individual pallets flow through a physical-sized sensing for proper matching to the appropriate slot size in the ASRS. Then each pallet moves on the conveyor to the selected aisle and is stored by the cranes.

As parts are required for manufacturing, requests are sent to the warehouse. In the ASRS, parts are retrieved by the stacker cranes and placed on the conveyor which delivers the pallets to one of the seven identical picking spurs in the pick area (Figure 7). The parts are picked and the activity reported through a terminal. Parts that remain on the pallet after picking are recycled back into the stacker crane system for restorage. The parts that have been picked move along the conveyor to a Sort and Accumulate area.

In the Sort and Accumulate, the parts are sorted by location in the manufacturing buildings and consolidated into full loads for delivery to manufacturing. From the sort and accumulate area, pallets move on a conveyor to the manu-

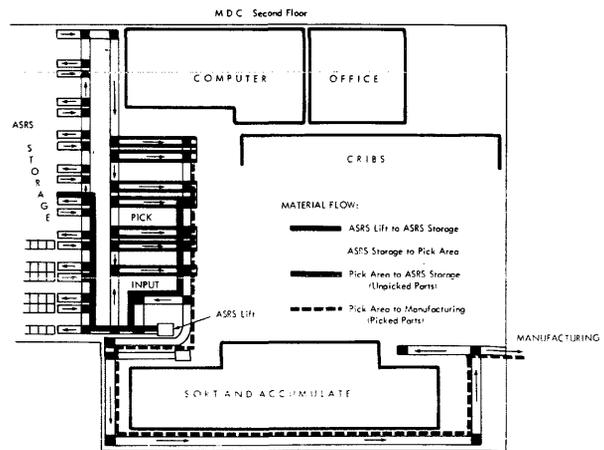


Figure 7—Material flow ASRS to manufacturing

facturing facility. This description briefly summarizes the material movement to and from the ASRS within the Material Distribution Center.

COMPUTER CONTROL—PHYSICAL AREA

The portions under computer control are the ASRS (stacker cranes) and the conveyors on the second floor that service the stacker cranes for both input and output of pallets. These are shown in Figure 8 and consist of four basic areas:

Input area

- As shown in Figure 8, new Pallet Spur (A) enters pallets coming from the receiving dock or CBOSS via the lift from the first floor into the system.
- Recycle Spur (B) returns pallets that have been retrieved and partially picked to the system with the remaining parts.
- Size Sense Station (C) determines pallet load sizes.
- Reject Spur (D) handles pallets failing to meet input criteria—either sizing or data. These pallets are tracked onto Pick Spur S7 for correction of deficiencies and re-entry into the system.

Pick area

- Pick Spurs (S1-S7) handle the retrieved pallets for picking and counting. Each spur has space for seven pallets. An eighth position (SS) on the spur is for 40-inch by 48-inch slip sheets used for taking away parts that have been picked. There is a computer-controlled physical gate between this position and the first pallet on these spurs. This allows for release of pallets from the pick spurs under the proper conditions.
- Take-away Line (V) returns partially picked pallets to the system via Spur B and carries parts to Sort and Accumulate.

Conveyor Area

- As shown in Figure 8, Mainline Conveyor (M) handles pallets going to and coming from the cranes. It carries input and output pallets simultaneously.
- Pick Area Mainline Conveyor (R) carries the pallets to the pick spurs.
- Input Buffers (P1-P9) are conveyor spurs, one for each aisle/crane, that handles pallets going into a crane/aisle. Each buffer has capacity for three pallets going to the aisle. The position furthest from the Mainline Conveyor (M) is the pickup position for a pallet to be stored by the crane. The mainline and input/output buffers are level with the vertical midpoint of the rack structure at the front of the ASRS.
- Output Buffers (D1-D9) are conveyor spurs, one for each aisle/crane, that handle pallets coming out of an aisle/crane. Each buffer has capacity for three pallets. The position furthest from the Mainline Conveyor (M) is the deposit position for a pallet retrieved by the crane. The conveyors operate at a rate of 45 feet per minute.

Stacker crane area

- Stacker Cranes (1-9) transport (store and retrieve) the pallets within the storage-rack structure. There is one crane for each aisle. The crane can be communicated with anywhere in the aisle upon completion of the previous command; there is no home base. The crane travels on rails at a maximum horizontal rate of 300 feet per minute. The shuttle, which carries the pallet, travels vertically at 45 feet per minute.
- The rack structure contains the slots for storage of the pallets. There are 18 rows of racks, with each crane servicing two rows: one row to the right and one row to the left of the crane aisle. Each row is 78 bays long. The racks on Aisles 1 through 7 have 12 tiers. They accommodate pallets 52 inches long by 40 inches wide. Slot heights are 30 inches, 43 inches, and 79 inches, with each horizontal level having the same height. The racks on Aisles 8 and 9 have eight tiers accommodating pallets 62 inches long by 40 inches wide. Slot heights are 62 inches and 89 inches. The weight limitation is 2000 pounds per pallet.

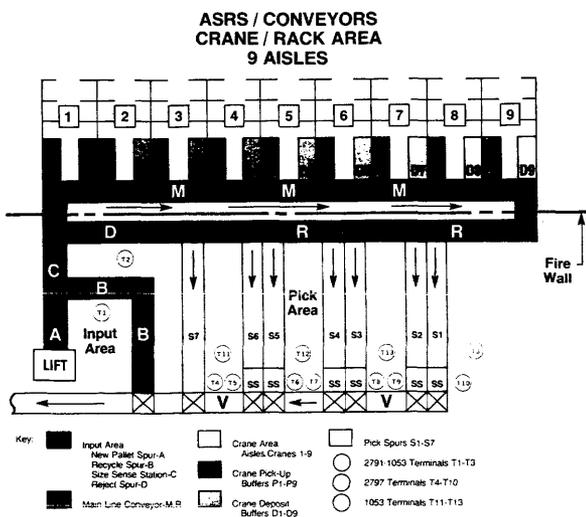


Figure 8—Schematic of areas under computer control

COMPUTER CONTROL—GENERAL

The basic functions of the computer-control system are to direct the conveyor-flow, storage, and retrieval of pallets and to maintain a status of the pallets in terms of contents and location. All controlling and data keeping are done relative to unique pallet numbers.

The first functions of directing pallet flow, storage, and retrieval involve the monitoring and controlling of conveyors and cranes by the computer. This controlling of physical devices requires communication between the computer and the physical devices.* There are approximately 350 sensors

* All hardware/computer communication is in the form of Process Interrupt, Digital Input, and Digital Output. These can be viewed as signals containing one bit of information (on/off, yes/no).

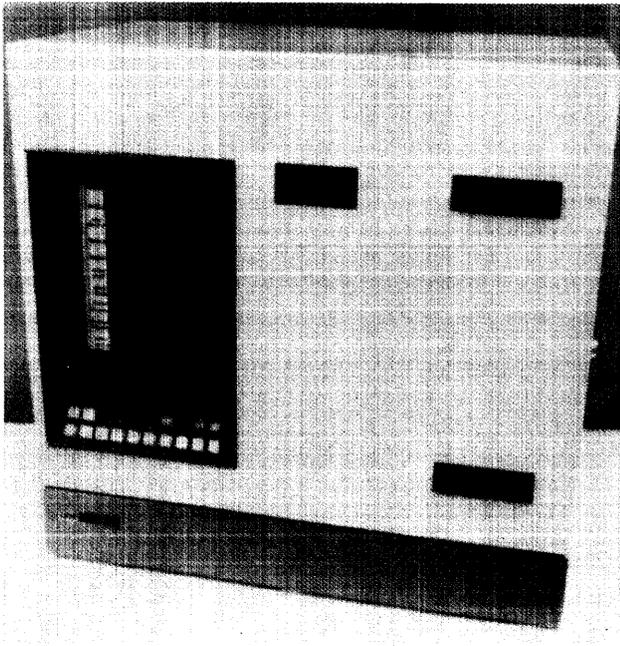


Figure 9—IBM 2791 area station

(switches and photocells) throughout the ASRS and conveyor network. When a pallet activates a sensor (by breaking a light beam, for example), a signal is sent to the computer. The computer analyzes the signal and determines what event has occurred. When the computer wants a device to perform a task, it sends out a signal that causes a physical action, such as raising a pallet stop or causing the pallet to divert onto another conveyor spur.

Signals representing commands are sent to the cranes, the logic circuitry of which interpret and perform the commands. In turn, the cranes send signals to the computer to report what has been accomplished. Simple signals form the communication means of monitoring and controlling the physical devices.

Maintaining the status of pallets in the system requires data files that identify the parts on a pallet and document where they are stored and the quantities on each pallet. Activity affecting the status (picking of parts, change of location, or entering of new parts) must be captured to update the status. To use the cranes and conveyors to meet the varied warehousing tasks effectively in the dynamic ASRS, current data must be continually available. To do this, the files are online to the computer on disk drives.

The updating of the disk files is done online in real-time through the use of terminals. IBM 2791, 2797, and 1053 terminals are used to communicate data between the workers and the computer. The 2791 (Figure 9) accepts badge, punched-card, and keyed-in data. The 2797 (Figure 10) accepts badge and keyed-in data. The 2791s and 2797s are used by the people in the input and pick areas to report activity on the pallets. The 1053s are typewriter terminals

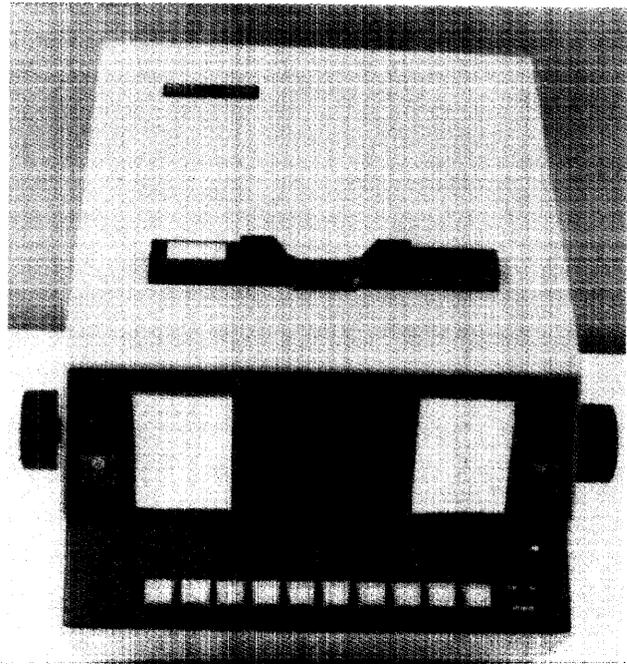


Figure 10—IBM 2797 data entry unit

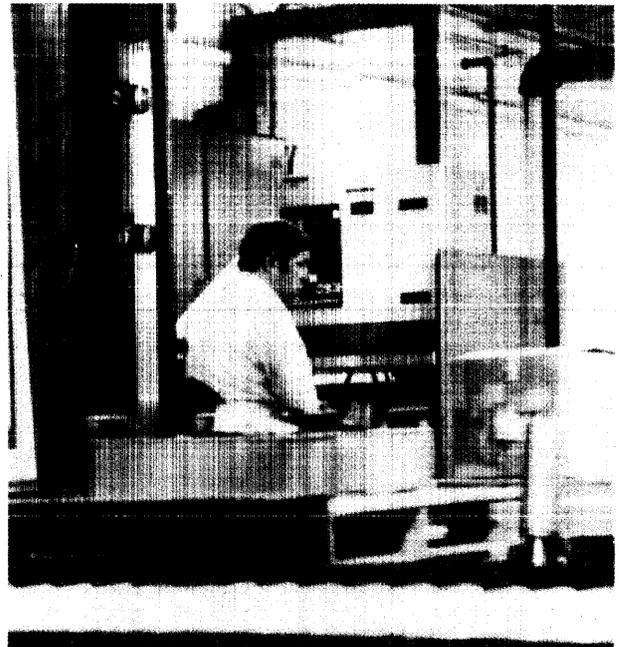


Figure 11—Input operator entering data into the 2791

used to print messages that provide guidance in reporting activities and identifying errors. The placement of the 14 terminals is shown in Figure 8. Online files and update not only substantially improve the physical operation but also improve the integrity of data by immediate reporting and auditing of activity. The need for data integrity is much greater in a stacker-crane system than in conventional warehousing since it is impossible to make an easy visual scan of the storage area.

An IBM 1800 Data Acquisition and Control System provides control and information; it communicates with the physical devices, the terminals, and the files.

Use of a realtime information system to dynamically drive the system controlling the cranes and conveyors is the key to making the ASRS meet the varying warehouse needs. The tendency has been to limit warehouse flexibility in order to simplify the control system. It should be noted that many of the features of the system that will be described do not bear directly on the relatively simple problem of sending commands to the cranes and conveyors. Instead, these features are aimed at dynamic development of control decisions, to increase the productivity of warehouse operating and management personnel.

SYSTEM OPERATION—INPUT

Pallet selection

Pallets arrive for input to the ASRS on the New Pallet Spur (A, Figure 8) via the lift from the first floor and on the Recycle Spur (B). The operator stationed at the 2791 Terminal T1 selects the next pallet to be processed from either Spur A or Spur B.

Pallet identification

The operator removes the badge from the pallet and inserts it into the 2791 (Figure 11). This identifies the pallet being processed.

Part identification

For pallets entering the system with a load not previously stored (normally from Spur A), the operator removes an 80-column punched card or cards from the pallet. The cards identify the parts on the pallet by part number. Two part numbers are allowed on new, non-inspect shipments. Documents accompanying the cards indicate the quantities of each part and the type of load. These documents are in the form of a two-part card. One part stays at the input station for keying in data and for later auditing of the input transaction after the working shift. The second portion remains with the pallet for identification of the parts during picking.

Transaction selection

The operator then enters the type of transaction. This indicates the data to be expected, the audits to be performed on the data, how the data are to be processed, and which files are to be updated.

- New receipt: This pallet contains parts of one or two part numbers to be stored in the system and is available for retrieval as soon as desired.
- Parent: The pallet is to be stored in the system but is to be "bin-locked" (made unavailable for retrieval) until the sample has passed inspection and shipment has been accepted. The bin-lock of the pallet is done under the part number and purchase order number, found in the punched card identifying the part, and the keyed-in shipment number.
- Sample: This pallet contains a sample that has been accepted. It is to be stored in the system, and any pallets previously locked under that same purchase-order number and shipment number are to be unlocked.
- Recycle: This pallet is returning from the pick area for reentry into the system. Because the files have been previously updated, no other data except from the badge is needed for this transaction.
- Reject: The operator wants to reject the pallet for some noticeable error condition, such as absence of paperwork or a load that appears unstable. He also keys in a reason code for the rejection.

Data entry

For New Receipt, Parent, or Sample, the operator enters the punched card(s) (receiving document) into the 2791. The part number and qualifiers are read from the card; for samples and parents, the purchase order number is also read. The operator keys in the part-number quantity on the pallet. For parents and samples, the shipment number is also keyed in.

Data audit

At this point the system knows what pallet, what parts, what quantity, and how to process the data. The system does a preliminary audit on the transaction, posing queries such as:

- Is this a valid ASRS part number?
- Is it a valid recycle?
- Has all data been entered?
- Do data fit the limits?

If the transaction fails, the system may request a repeat of the transaction or may set up a rejection of the pallet.

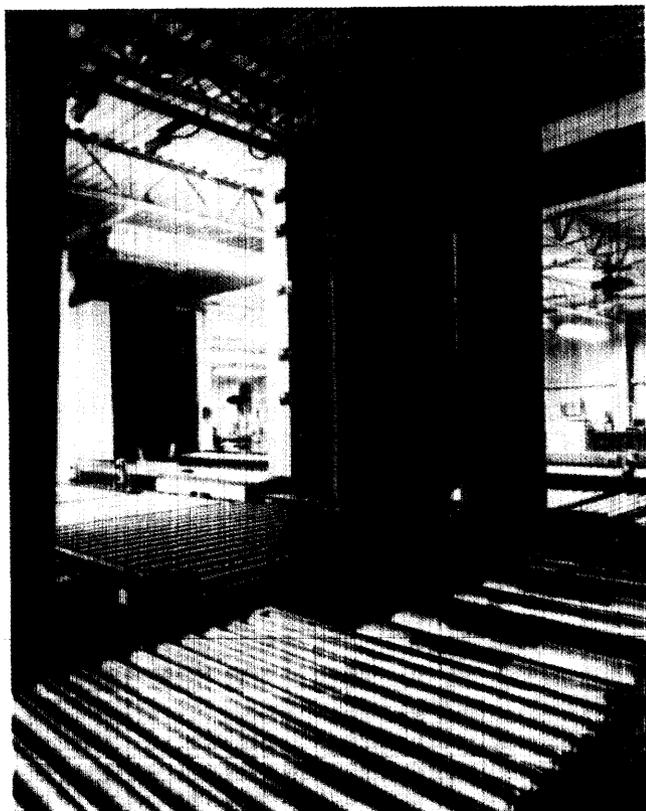


Figure 12—Size sense station

Transaction completion

At the completion of the transaction, the operator replaces the badge and presses a button next to the spur holding the pallet (either A or B). This signals the system that the operator is physically finished with the pallet and indicates which spur the pallet is on.

Pallet movement

When the transfer leading to Size Sense Station (C) is empty, the computer signals either Conveyor A or B to move a pallet. This pallet will move from the transfer area as soon as there is no pallet in the size sense station.

Size sensing

In the size sense station (Figure 12), the physical characteristics of the load are determined. By analyzing the photocell beams that are broken by the load, the computer determines the length of the pallet (52 inches or 62 inches) and the height (including over-height). Signals detecting load overhang on any side of the pallet or overweight (over 2000 pounds) are sent to the computer. The system now

knows the physical size of the load and any out-of-limit conditions.

Pallet rejection

Entry of the pallet will not be allowed into the system for storage if a physical characteristic is out of limits, or if the transaction failed the audit, or if the operator chose to reject. The computer then causes the pallet to be diverted onto the Reject Spur, (D), and onto the Pick Spur (S7), and a message is printed by the 1053 Terminal servicing S7. This reports the pallet number rejected and the cause for rejection. The pallet is then either removed from the system or the problem corrected and entered again via Recycle Spur (B).

Aisle selection

If the pallet is accepted for storage, the location is dynamically selected from all available slots. There is no permanent tie between the physical slots and either pallets or part numbers. Each time a pallet enters the system, a new location which is best for system operation at this time is chosen (recycles will probably not return to their previous slots). To select the location, a number of steps are performed to progressively eliminate aisles from consideration. Some of the steps are:

- For 52-inch-long pallets, Aisles 1 through 7 are considered; 62-inch-long pallets can only be stored in Aisles 8 and 9.
- If a crane is offline, it is eliminated from consideration.
- One of the three input-buffer positions must be free.
- The percentage of proper-height slots still available in the various aisles is also evaluated against certain limits.
- If another pallet holding the same part number is already stored in the system, an attempt is made to put the new pallet into a different aisle. This is done to reduce the risk of parts being unavailable because of crane downtime.
- If more than one aisle satisfies the conditions, a cyclic selection of an aisle is made.

At this point, an aisle has been selected with at least one slot of the required size free. The actual slot will be dynamically selected at the time of storage.

File update

The data files are updated from the information in the transaction.* For newly entering pallets:

- The pallet file is updated with the part numbers, quantities, and status, such as bin-lock and in-transit.
- The pallet is added to the chain of pallets already in the ASRS under the part number only, or under the part number, purchase order, and shipment number (for inspect-locked items).

* See Appendix for details of files.

- The total of pallet quantities in the part-number file is incremented, and indicators are changed to reflect the addition of a new pallet.
- Parent file indicators are changed to reflect the addition of a new inspection bin-locked pallet.

Transaction records

Throughout the various areas whenever a file is modified or an error or potential error is encountered, a magnetic tape record is written. This allows files to be rebuilt if they are destroyed during live operation. The tape is also used to produce batch reports, particularly for auditing.

SYSTEM OPERATION—PICK AREA

Pick-area tasks

Two major functions are performed in the pick area:

- Picking of parts (requisition filling)
- Counting (rotating inventory counts—RIC)

RIC is done in place of a once-a-year total physical inventory in the warehouse. Parts are periodically counted, depending on their dollar value and activity, so that the physical counting is spread throughout the year.

Two minor functions are performed in the pick area:

- Auditing of errors or potential errors found in the actual operation of the stacker-crane system.
- Retrieval of inspect bin-lock items for reinspection by Quality.

Requisition and count requests

Two groups of punched cards are received daily from other systems in the plant:

- Requisitions. Each requisition is for one specific part number and quantity. There can be several requisitions with the same part number but with different departments; these will be on separate requisitions.
- Requests for counts. Each card contains a part number that is to be counted in its entirety. The counts will later be compared against the book record contained in other inventory systems.

Batches

The two groups of cards are kept separate. The requisitions are sorted by part number so that all requisitions for a given part number fall together and will be filled at the same time to minimize pallet traffic. Each group is then separated into

small batches, each batch containing what is estimated to be one to two hours' worth of work at a pick station.

By the use of these batches, the pick area management is able to spread the work and balance the work load across pick spurs. These batches will be assigned to various spurs throughout the day. This is done rather than building up total work for a given spur before starting, and thus possibly resulting in one spur with ten hours' worth of work and a second spur with six hours' worth of work.

Preparation for live operation

Prior to starting daily operations, the batches of requisitions and count cards are processed by the 1800 against the pallet and part-inventory files. Crane commands for retrieval are *not* formatted at this point.

For each batch, a small disk file is built. The disk file for each batch contains the same part numbers as found in the cards within the batch. However, the disk-file records are summary records. For instance, if there were five requisitions calling for Part A, each having a quantity of 10 within a given batch, the disk-file record for Part A would occur only once with a total quantity of 50 needed to fill all requisitions.

For RIC batches, the disk file contains the part numbers and the number of the pallets to be counted for each part number. Pallets to be counted are RIC bin-locked.

These disk files will be used during live operation to determine what pallets must be brought out to fill the requisitions or to satisfy the request for counting. The pallets will be determined dynamically at the time the work is to be done, and the crane commands will be generated at that point.

As the batches are processed against the files, any requisitions that do not have available parts in the system are separated out for the back-order file.

A report for the pick-area technician is produced showing:

- For each batch the pallets that are anticipated for retrieval. They may or may not be the pallets that come out as a result of the changing status of the system during operation.
- Requisitions that may be only partially filled because of lack of parts in the system.
- Conflicts between counting and picking. From this, the technician will attempt to do the counting batch early in the day and the picking late in the day, so that the same part number can be both counted and picked in one day.
- A summary of anticipated crane usage for each batch. The technician uses this data to keep from assigning a number of batches that use one or two cranes heavily, thereby slowing down the system.

The report is used to guide the technician in assigning and balancing work over the seven pick spurs. The data is not used by the pickers or counters in performing their work. They use the actual request-for-count and requisition cards in doing the work.

Batch assignment

The system is now ready for live operation. The pick technician assigns batches of work to the various spurs as follows:

- He hands Batch 20 (a pack of requisitions or count requests) to the worker on Spur #4.
- Through a 2791 terminal, he tells the computer that the punched cards for Batch 20 are a Pick Spur #4.
- The computer searches the disk file for Batch 20 and knows the part numbers and quantities needed to fill the requisitions at spur #4. This information will be used to select and retrieve pallets to satisfy the requisitions.
- The technician may suspend a batch and reassign it to another pick spur in order to balance the work load.
- He may also assign a batch in a pending mode. In this way, when the current batch is finished, the computer will automatically begin allocating work from the pending batch.

By using the above methods, he is able to balance the work and have various numbers of spurs working at different times during the day.

General pick-area operation

The operations performed in the pick area consist of filling requisitions and counting parts.

The operator in a spur works off the first and only the first pallet in the spur (S1-S7, Figure 8). He then reports the activity on the first pallet. If he reports on any pallet other than the first one, the transaction will not be accepted by the system. Until he has completed transactions associated with a pallet and it is physically removed from the spur, he cannot report on the next pallet. This is done to maintain integrity and to smooth the flow in the system. Tremendous peaks and valleys could be created if reporting were to be done on a number of pallets within a spur and then released in a short period of time.

When the man has finished on the pallet, he reports on the 2797 terminal that he has completed pallet processing. At this point, the files are updated with the data he has reported. Once this is done, a signal is sent to drop a physical gate that separates spur position 1 and slip sheet position; this allows the man to remove the pallet. Until he has reported completely on a pallet, he is not able to physically remove the pallet. This substantially aids the integrity of reporting on work completed.

When the gate is dropped, the man physically pushes the pallet out of the spur and onto conveyor segment V (Figure 8) for delivery to either sort and accumulate (if the full load has been picked), or to return the unpicked portion of a pallet to the system via segment B.

As the pallet is pushed out of Position 1, a signal is sent back to the computer indicating there is now a position free

on the spur for another pallet. This signal is essentially a request for the computer to select and retrieve another pallet. Until the first pallet has been physically removed, the new pallet will not be allocated. This is done so that if the man leaves the spur for any reason after finishing reporting on a pallet, another pallet will not be sent to a full spur, causing a jam on the conveyor.

Full pick spur

In each spur, there are seven positions for pallets. When the request for another pallet is initiated, it is really for a pallet seven ahead of where the man is now working. The system attempts to keep each spur as full as possible to smooth the variation in picking time over different pallets. To do this, seven pallets will be allocated to a spur, as long as work is assigned to that spur. The seven will be:

- Physically in the spur
- On Mainline Conveyors R or M leading to the spur (Figure 8)
- In course of being serviced by the crane
- Waiting to be serviced by the crane

Pallet selection

When the signal indicating the release of the pallet is received, the computer goes through the process to allocate another pallet. It relates the signal from a specific spur to the current batch assigned to that spur. Through the disk file for each batch, it determines where in the file it last allocated a pallet. It looks at the summary record of the part number for the previously allocated pallet to determine whether that part-number request has been satisfied. If not, it will look for another pallet with that part number in the system and request retrieval for it. Each time a request for another pallet comes in, it will continue to look for another pallet under that part number until:

- The total quantity for requisitions has been satisfied.
- All the pallets needed for a valid RIC have been retrieved.
- None are left in the system.

If the previous part number request has been completed, the system will look to see if any emergency requests are pending for the spur. If no emergencies are pending, the system goes on to the next part number in the disk file for the batch.

If this was the last part number in the batch, it will automatically go on to the first part number in the next batch assigned to the spur. Once the next pallet has been selected, the appropriate data are passed to the crane control programs, which will set up the appropriate commands to retrieve the pallet.

It should be noted that even if multiple pallets are required to satisfy the total quantity needed, the pallets are

selected and requested one at a time as a space becomes available on the spur.

Smallest quantities first

Pallets retrieved for picking are selected in the sequence of smallest quantity first. For instance, if a total quantity of 100 was needed to fill all requisitions for the part number and there were two pallets in the system, one with 50 and a second with 150 parts, the pallet with 50 would be requested first and the pallet with 150 would be requested second. This is done to empty pallets and conserve space. To call out only the pallet with 150 parts would cause two partially full pallets to be in the system. This pulling of pallets containing the smallest quantity first also eliminates the need to marry parents and samples that have been stored at different times. The sample, normally occupying a small portion of the pallet, is stored later than the parent. However, because of pulling by smallest quantity first, it will be retrieved first and emptied. Thus for a short period of time some storage utilization is lost, but in return, the unproductive and costly work of retrieving the parent to marry with the sample is eliminated. If multiple pallets are retrieved, all will empty with the possible exception of the last.

Partial sequencing

When more than one pallet is being retrieved to satisfy the requisitions for a part number, sequencing is needed. If both the pallet with 50 and the pallet with 150 are called out, the pallet with 50 must arrive first, or the reasons for bringing out both will be defeated. Under these conditions, the pallets must arrive in the sequence they were requested. When single pallets are requested for parts, it is immaterial whether the first pallet requested arrives before the second pallet requested. Sequencing is also done on RIC pallets to make sure that all pallets for a part number arrive together.

Hence, the system performs partial sequencing. The use of partial sequencing, rather than total sequencing, substantially reduces the loss of effective capacity throughout the system. For instance, 50 percent sequencing has only 25 percent of the impact of full sequencing in loss of flow through the conveyor network. This sequencing data is also passed along with the crane commands for use in the conveyor tracking.

Advantages of dynamic retrieval selection

The pallets and the commands are selected dynamically as the parts are worked on, rather than preformatted at the beginning of the day. This provides for better operation in the system; for example:

- Suppose the crane on the aisle containing the pallet that would be first selected is down (out-of-service). If the commands were preformatted, they would be by-

passed. By dynamically selecting, the system automatically looks for any other pallets that are in the system and withdraws any required to satisfy the requisitions.

- Requisitions may be scheduled to be only partially filled because of the number of parts and pallets in the system at the beginning of the day. If new pallets are received and/or released from inspection bin-lock, they will be dynamically allocated, eliminating the partially filled requisitions.
- RIC-locked pallets may be picked from, provided the count is done before picking.
- The effect of emergency requisitions on normal picking can be minimized. If an emergency has been filled from a pallet early in the day, the pallet may no longer have enough parts to fill the planned requisitions. If the commands were preformatted, the planned requisitions would be only partially filled. However, with dynamic selection, the system picks up this condition and allocates additional pallets to fill all the requisitions.

Reporting in the pick area

As an operator works on a pallet, he reports the activity he has completed to the system. He does this by placing the pallet badge in the 2797 terminal and entering type of transaction he has performed. He also fills out the requisition card or count card with the correct data.

For requisition filling the sequence is as follows:

- As an operator fills each requisition, he enters the quantity pulled in the 2797 (Figure 13). A running total of the quantities reported on a pallet is accumulated.
- When he has finished processing the pallet, the operator may find one of two conditions exists: (1) he has unsatisfied requisitions with no corresponding parts on the pallet (the pallet may or may not have another type of part on it) or (2) he has filled the requisitions but there are extra parts of the same kind on the pallet. In the first case he enters a "zero part" transaction. This indicates to the system that he is finished with the pallet and there are no more parts. If the system records show there should still be parts on the pallet, the transaction is questioned by a message on the 1053 Printer. If the operator repeats the "zero parts" transaction, it is accepted. In the second case, he enters a "finished-pallet" transaction. If the system records show that it should be zero, the transaction is questioned. If he reenters a finished-pallet transaction, a dummy quantity of one (1) is placed in the pallet record and the pallet marked for audit by warehouse personnel.
- At the end of a reporting on a pallet, quantities reported are used to update the pallet and part-number inventories.
- If the operator has unfilled requisitions for a part number, but the next pallet does not contain that part number, he knows they will remain unfilled since all

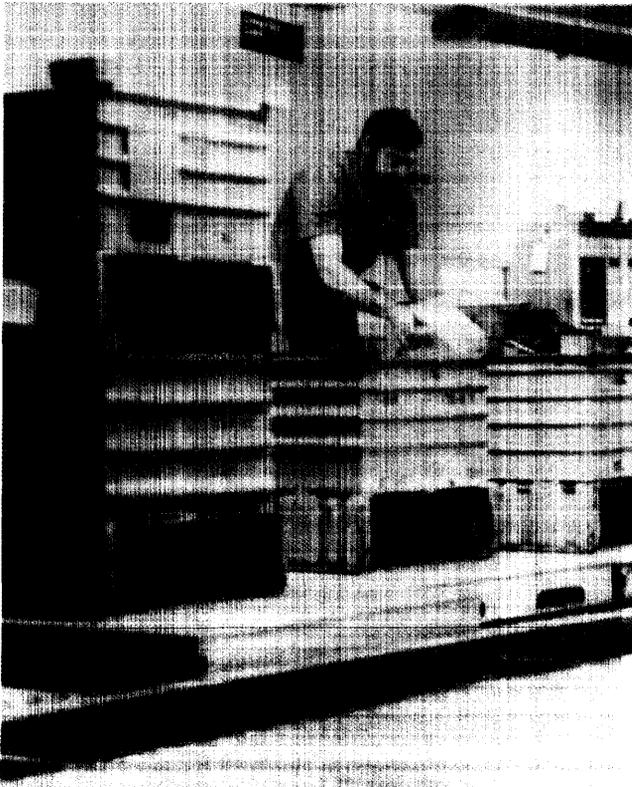


Figure 13—Pick area operation and reporting

pallets with the same part number would have come out together. He puts these aside and works on the requisitions that match the part number on the pallet.

For RIC counting the sequence is as follows:

- The operator enters the pallet badge and the total count for the pallet.
- This is accepted by the system, and file quantities are updated.
- During counting, pallets can be merged by zero-counting one pallet, and incrementing the count on a second pallet containing the merged parts.
- If one or more of the pallets required for a complete count are unavailable, the system cancels the count activity for the part number via a message to the counter.

The operators also enter two other transactions. The first is a "no action" transaction: the operator recognizes the part number but he is not going to do any work on it. For instance, it is the end of the day, and there are one or two pallets he wants to remove from the spur so that it is empty. The second is an "unexpected" transaction. This essentially means that he does not have requisitions or count cards to cover the part(s) on this pallet. This may or may not be recognizable by the system. The pallet may have been erroneously diverted into the spur because of hardware failure. The system knows this and knows the operator has no matching requisition. In another case, the system recog-

nizes the pallet number as being legitimate but the pallet obviously does not contain the part recorded in the file; this is marked for audit.

When a transaction is incorrect or questioned by the system, a light is turned on next to the 2797 terminal to get the worker's attention. A message is printed on the 1053 and the worker takes the proper action.

The pick area technician has a number of 2791 transactions by which he can control the operation in the system and override or add to the planned retrieval of pallets.

- Batch Assign/Suspend. This has been previously discussed.
- Emergencies. He can enter requests to retrieve pallets to fill emergency requisitions, assigning these to any spur that is working on requisitions. The requests for emergency pallets take priority over the planned picking.
- Management Bin-Lock/Unlock. This allows locking or unlocking under 15 separate codes of specific pallets or all pallets under a part number by management directive.
- Inspect. This retrieves inspection bin-locked pallets, which cannot be normally withdrawn, for return to vendor or resampling by quality personnel.
- Retrieve by Part or Pallet. A single pallet or all pallets

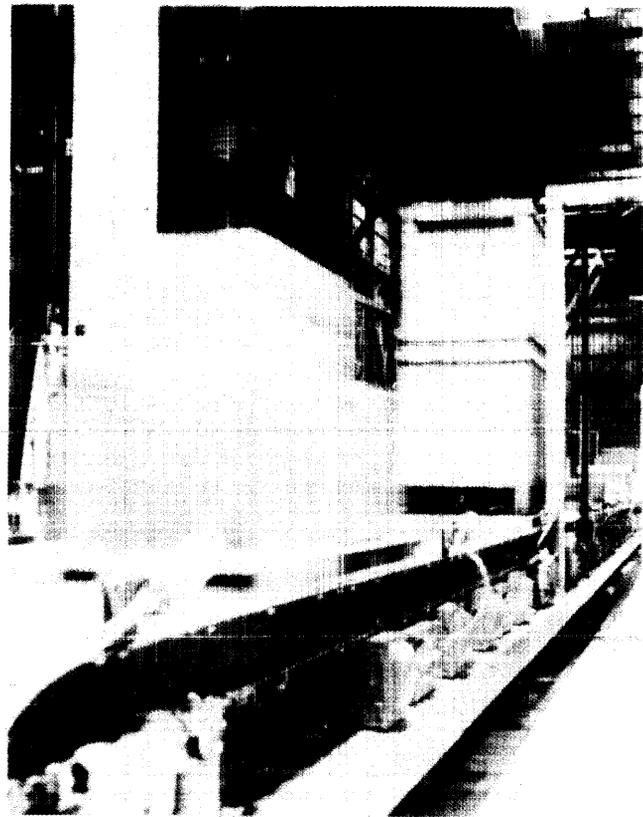


Figure 14—Pallets moving on main line conveyor

containing a part number can be retrieved. This is used to perform auditing of problems or potential problems trapped by the system.

- Inquiry. Inquiry can be made to any of the files on the system.

SYSTEM OPERATION—CONVEYOR CONTROL

Simultaneous input/output flow

The Mainline Conveyor (Figure 8) (M) handles both pallets entering the system for storage and pallets retrieved from the system going to the pick area. Pick Area Mainline Conveyor (R) delivers pallets to pick spurs. Conveyors M and R can be physically viewed as one continuous, moving conveyor.

Data zones

Mainline Conveyors M and R are artificially or logically broken up into 24 segments or data zones. Physically, there is no break or independent control of the zones, but they are logically used by the computer to map and control the movement of pallets through the conveyor network. The zones are delineated by sensing devices, either photocells or switches. A map of the zones is kept in the computer. If a pallet is in one of the zones, the corresponding entry in the computer map contains the associated data for the pallet—pallet number and destination (for input, aisle number; for output, pick spur number). Both the input and output buffers for each aisle have the three positions delineated by sensors for mapping in the computer.

Pallet tracking and mapping

As a pallet moves from one zone to the next, the sensing device is activated and a signal is sent to the computer. The computer determines from the signal which zones are involved and, also, the associated pallet and map entry. The computer updates the map by moving the pallet data from the zone (map entry) the pallet is leaving to the zone (map entry) the pallet is entering. By this means, the computer tracks the physical movement of the pallet through the network and knows the relative position of all the pallets on the conveyor. The relative positioning by zones occupied by the pallets is a key to the control scheme. Zone lengths average about 10 feet, with variations depending on physical characteristics of the conveyor. The computer knows to within a few feet the actual physical position of the pallet by knowing which zone it is in.

Movement from size sense

When processing of a pallet is complete at the size sense station, control is passed to the conveyor tracking programs

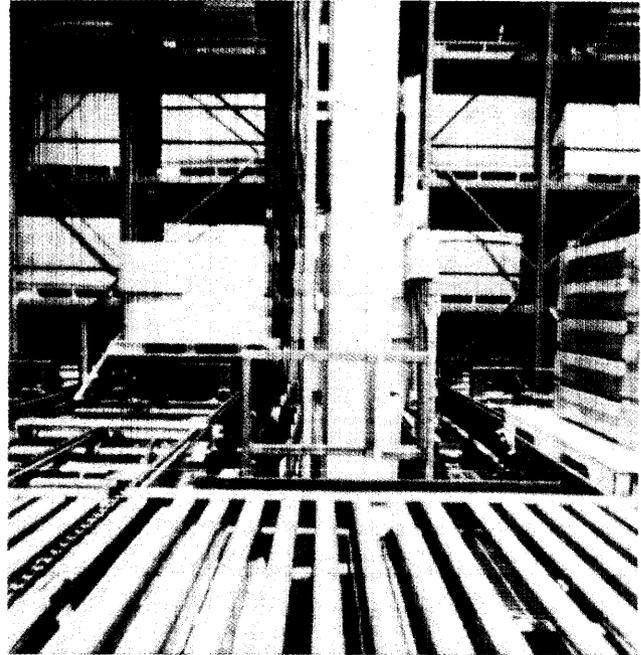


Figure 15—Cranes transporting a pallet

along with the pallet number and destination. The computer sends a signal to release the pallet from the size station. If the pallet is marked for reject, a second signal is sent to divert the pallet onto the Reject Conveyor (D); the computer releases the pallet onto Spur S7 when there is a free space and when no conflict exists with pallets on conveyor R going to S7. The arrival sequence of the pallets is recorded in the map for Spur S7.

Accepted input pallets move into the system to flow on Mainline Conveyor (M). The pallets are tracked as they move through the zones.

Input-pallet diverting (Figure 14)

As an input pallet enters the zone containing the input-buffer transfer, the pallet data is checked to see if the destination matches the aisle being approached. If a match is found, the computer sends a signal to raise the pallet stop on the input-buffer transfer. When the pallet hits the stop, the chain transfer raises and moves the pallet into the first pallet position. Signals indicating start and completion of transfers are sent to the computer; these are used to determine failure conditions and to aid in control during merging of output pallets.

Input-buffer movement

As the pallets are indexed through the input-buffer spur positions, the pallet data is also tracked within the computer. When a pallet reaches the pickup position, a signal is sent to the system that the pallet is ready to be stored, and the

pallet data is passed on to the programs controlling the cranes.

Output-buffer movement

The cranes retrieve pallets from storage and deposit them on the output buffer. When a pallet is placed on the deposit station of the buffer, a signal is received and the crane control programs pass data (pallet number, pick-spur destination, and sequence data) to the conveyor programs.

The pallet indexes and maps through the buffer positions toward the mainline conveyor as the positions become free. When the pallet is in the position closest to the mainline, it is ready for merging.

Output-pallet merging

The computer scans the map entries for the zones both upstream and downstream on the mainline from the merge point (output buffer) to determine whether there is enough free space on the mainline. Pallets are not merged if a pallet collision would occur. This is also true of subsequent transfers from segment M to segment R (Figure 8). The zones may be physically empty or "logically" empty.

A zone may physically contain a pallet that has started to divert into an input buffer, but it can be considered logically empty since the divert will be completed before the merge of the outbound pallet takes place. The use of logically empty zones effectively raises the capacity of the conveyor in pallets per hour.

When the needed free space is found, the computer sends a signal to start the merge. A signal is returned when the merge is complete; the data is then moved to the mainline map. The outgoing pallets on the mainline are tracked in the same manner as incoming pallets.

As pallets divert into aisles, free space is created, which is used by pallets merging out. This replacement basically allows the same rates of pallets in and out on a single conveyor as would be accomplished using separate conveyors for input and output, at the same speed of conveyor movement. Some loss of capacity occurs, however, over short periods of time with a single conveyor when the input and output distributions across aisles do not match, thus preventing total replacement.

Sequence control

Under certain circumstances, it is necessary for pallets to arrive at a pick spur in a certain sequence, that is, pallet 136 must arrive before pallet 35 in Spur S3. The pallets are requested one at a time sequentially for a pick spur. However, because of the physical nature of the system, they may not always arrive in the sequence requested without intervention. For instance, the first pallet requested may be on an aisle that has five output requests already pending (re-

quests for a given aisle are serviced in the order received); the second request (perhaps generated two minutes later) is to an aisle that has no output commands pending. The second pallet will probably be serviced first and arrive at the pick spur first. A second example of this is when the first pallet requested is on Aisle #1 and the second is on Aisle #9.

When a pallet is ready to merge, a check on required sequencing is made. If sequencing is needed (another pallet must precede this pallet to the pick spur), the preceding pallet must have previously entered the mainline and be downstream of the merge point. If this condition is not met, merging is held until the condition is satisfied.

Pick-area tracking and diverting

Outgoing pallets are tracked along Mainline Conveyors M and R (Figure 8). As a pallet approaches the zone containing the transfer into a pick spur, the spur number is matched against the destination of the pallet. If a match is found, a signal is sent to divert the pallet into that pick spur. A signal is received when the pallet has completed the transfer into the spur, and the map of actual arrival sequence is updated. The actual sequence of arrival is used to control reporting in the pick area.

Conveyor rejects

If a pallet takes the wrong divert or misses a divert—as in the case of a stuck relay—the pallet is rerouted by the computer. If a crane goes down while a pallet is on the way to it, the pallet is also redirected. If these conditions occur on the crane buffers or on the mainline, they are routed to Pick Spur S7. Spur S7 handles the rejects from both the input and the mainline as well as pallets for picking. For any reject pallet going to S7, an appropriate message for the operator is printed on the 1053 next to the spur.

Failure trapping and recovery

Control of the conveyors is accomplished by monitoring events involving positive action, such as a pallet tripping a limit switch or breaking a photocell beam. Timing is not directly used in controlling the movement on the conveyors. However, timing is used to trap problems, and more importantly, potential problems on the conveyor. For instance, if it normally takes 12 seconds for a pallet to travel the length of a given zone and the signal of the pallet entering the next zone is not received in 15 seconds, a malfunction is assumed and the conveyor stopped. A flashing red light is turned on in the computer room, and a message is printed describing the type of failure and the location. These problems are checked and corrected by, for example, clearing a pallet jam or replacing a burned-out photocell. An appropriate physical recovery procedure is followed, such as moving the jammed pallet to the next photocell. The associated

recovery code is then entered into a 2791, and the system restarts from the point where it stopped.

Immediate stoppage of the conveyor is intended to avoid major problems, such as would be caused by several pallets piling up behind a jammed pallet. This allows easier physical correction and makes logical recovery (ensuring that the physical condition matches the computer map) possible without the lengthy and costly procedures required to flush the pallets from the mainline, to ensure integrity of the system. Most failures can be corrected in five minutes; whereas, a flush of the mainline and restart of the system requires about one hour.

The detection of failure is done on the mainline, on all transfers, on the size sense station, and on input/output buffers.

Command selection

After successful completion of the previous crane command, the next command is selected if there is either a pallet for storage in the pick-up station or a request pending to retrieve a pallet. If only one of these commands exists, it is done next. If both exist, a selection must be made to either store or retrieve next. The requests for retrieval are placed in a list for each crane as they occur and are serviced in the same order. Communication with cranes can take place anywhere in the aisle once the previous command has been completed. The crane remains at the position of completion of the last command.

Thus, the last command has a considerable influence on the selection of the next command because of the position of the crane. If the last command was a retrieve, the crane is at the head of the aisle as a result of dropping off the pallet; a store will probably be done next since it does not involve crane movement to pick up the pallet. If the last command was a store, the next will probably be a retrieve, since the crane is already down the aisle. In this manner, the normal operation will consist of alternate stores and retrieves, the stores/retrieves being effectively paired. This limits unnecessary, unproductive movements of the crane, that is, movement when the crane is not carrying a pallet (time is really the factor limited).

This pairing is logical. Commands are sent individually; "dual" commands (where both the store and retrieve commands are physically sent to the crane at the same time) are not used. Dual commands make practical error recovery impossible, lessen flexibility, and do not gain any advantage in capacity when the crane can be communicated with anywhere in the aisle.

Under certain circumstances, this pairing may be overridden. For instance, the last command may have been a store just several bays down the aisle. A retrieve just requested may be at the end of the aisle. If a pallet is waiting for storage, another store command is given; this will further limit unnecessary movement. If a large number of retrieves are pending and there are only a few stores, the retrieves will be given priority to help balance the system.

Slot selection

If the command selected is a store, the actual location must be selected. This selection is dependent on the height of the load. The aisle was chosen at the input. If no retrieves are pending, the slot closest to the front of the system is selected to minimize the time required for the command.

Since vertical and horizontal motions are performed at different rates, each portion of the command must be considered and balanced to select the best slot. For instance, a slot one vertical level above and five horizontal bays from the pickup station is closer in terms of time than one five vertical levels above and one horizontal bay from the pickup station. The horizontal and vertical motions and the associated times are the key elements in minimizing total time from the present or future anticipated points.

If there is a retrieve command pending, the store slot is chosen relative to the retrieve slot. Ideally, the store slot would be selected exactly opposite the slot for the next retrieve, so that unnecessary motion and time would be totally eliminated. This elimination has more significance than may be anticipated. The movements in the last ten feet and in the final positioning are slow compared to the rest of the motion and comprise a large percentage of the total command time. For example, if the distance is doubled from 100 to 200 feet, the travel time is increased by only 20 percent.

Elimination of the final positioning on one of the commands substantially reduces the total time for both commands. Selection of a storage slot exactly opposite the slot for the next retrieve is, of course, impossible most of the time, but the correct choice can minimize the unproductive time. The empty slot that minimizes movement time relative to the retrieve location is therefore chosen.

This elimination and minimization substantially raises the effective capacity of the cranes over the nominal capacity obtained by random selection of the storage location. It also increases the response and improves the balancing of the system and aids in overcoming downtime of the cranes.

Command transmissions and execution

Once the command has been selected, it is formatted and sent to the crane. The command describes crane number, type of command (store, retrieve), and location (horizontal, vertical, left/right). Once the crane accepts a command, it is no longer under direct control of the computer. The local logic on the crane directs the crane until it completes the command or detects an error.

Command completion

When the command is successfully completed a signal is sent to the computer, and the location file is updated to show whether the slot is full or empty. The pallet file is also updated to show the pallet is in transit to the pick area or is in storage, with the new location.

Error detection and recovery

If an error is detected, an error-alert signal is sent to the computer. The computer, in turn, formats a special sense command and sends it to the crane. This causes the crane to return status data to the computer. The status data describes the error(s) detected and indicates whether the pallet is on board the crane. From this data, it can be determined whether the error is recoverable. If it is recoverable, a new command to finish the operation is formatted and sent to the crane. This new command is based on the previous command, load-on-board data, and where the failure occurred in the command.

This may be the same or a different command. When a retrieve is being performed and the error indicates that no pallet is on board, the pallet has not yet been removed from the slot and the retrieve command is reissued. If the pallet is on board, it has been removed from the slot. The command is then changed to a store, designating the deposit station on the output buffer as its store address.

If the error is not recoverable, as in the case of an overhanging load, the flashing red light is turned on, and a message describing the problem is printed.

The computer takes the crane logically offline to prevent further use until corrective action has been performed. The pending requests for output are cancelled so that output is not totally stopped while waiting for a sequenced pallet from the crane that is not operating.

When the problem is corrected, the crane is reactivated to the system via a 2791 transaction.

At the end of the daily one-shift picking operation, the picking area is cleared and all pallets are returned to storage. Approximately 20 minutes before the end of the shift all of the active batches are terminated by the pick-area technician so that no new work is generated by the system. Just before the end of the shift, the workers release the pallets for re-storage. Any unfilled requisitions are included in the batches for the next day.

SYSTEM OPERATION—BATCH REPORT

A number of reports in various categories are produced to aid in monitoring and managing the system. Some of the major reports are discussed below.

Physical activity

Crane & Conveyor Activity—Several reports are produced showing stores and retrieves done by each crane, the number of good commands and number of errors by type, the number of offline conditions by crane, and the total time each crane is inoperable during the period covered by the report. The conveyor reports cover all malfunctions on the conveyor by device for both errors which stopped the conveyor and errors filtered by the software. The total up time is reported.

Pick-Area and Input-Area Activity—These daily reports

show the number of pallets passing the input station by tape such as new, recycle, parent, and sample. The number of pallets processed in each pick spur are shown by type such as count, requisition, no-action, and unexpected. These reports are not used to measure people, but rather to show activity trends that may reveal potential problems.

Storage Utilization—Periodically a report showing a percentage of slots used by size, by aisle, and by total system is produced. This is used to predict either over- or under-utilization of the system storage.

Inventory status

Part-Number Inventory
Pallet Inventory
Pallet Inventory in Slot Sequence
Aisle and Part-Number Inventory

This provides a listing for specified part numbers for all the pallets in slot sequence. This is used to audit and count part numbers that have many pallets in the system, rather than retrieve the parts for counting. This is done particularly with part numbers where each pallet contains a quantity of one.

Auditing and tracing

Daily Pallets In and Out—This records all pallets that are new to the system for the day and those that have physically left the system (zeroed out). This provides additional tracing of movement of any particular pallet.

Pallet in Transit—As pallets move through the system (from input to storage, in storage, from storage to pick, from pick back to input for recycle), the transit status is changed. Since the conveyor network is cleared at the end of the working shift, no pallets should appear on the in-transit report. They should be either physically out of the system or be in storage. Any pallets on the report are flagged as errors, and a physical check of the warehouse areas is made to find them.

ASRS Audit—The receiving documents, requisitions, and count cards are compared to the transactions that have been keyed in through the terminals; any discrepancies are noted and investigated. This makes it possible to correct common errors such as keying in the quantity 90 instead of 9.

System Error—This report shows all potential errors or errors trapped during realtime operation such as unexpected full bins, unexpected empty bins, or quantity discrepancies discovered in the picking area. Each item is audited by the warehouse personnel.

Inventory activity/management

Bin-Lock—This is a report of all pallets that are bin-locked, under either inspection or management lock, showing the number of days they have been locked.

Part-Number Activity—This report lists all part numbers and shows the number of times each part number has been accessed during that reporting period.

Inactive Part Number and Pallet—This shows any part number and/or pallet that has not been accessed during a management-specified period of time. This, in conjunction with a part-number activity report, is used to determine whether the correct parts are stored in the stacker-crane system.

File recovery

A set of programs rebuilds the files to the current status using the transaction-tape records and previous disk files so that the data is not lost if files are accidentally destroyed during realtime operation.

CONTROL SYSTEM—MAJOR FEATURES

The following is a recapitulation of the major features in the system:

- Control of nine individual cranes
- Closed-loop conveyor system
- Total pallet tracking throughout the conveyor network
- Handling of both inbound and outbound pallets on the same conveyor
- Partial sequencing of outbound pallets
- Ability to handle up to 133 pallets in and 133 pallets out per hour
- Detection of crane/conveyor malfunctions, with dynamic restart capability
- Automatic size sensing
- Storage of variable-size loads in five different-size slots
- Both dynamic selection of slots for storage and selection of pallets for retrieval
- Storage and accounting of pallets in 15,600 individual slots
- Accounting for 8,000 part numbers
- Handling of multiple pallets for a part number
- Handling of two parts per pallet
- Ability to perform partial- and full-load picking
- Recycling of partially picked pallets
- Ability to perform counting functions
- Operator guidance for all man/machine interfaces
- Dynamic recording of all activity on the pallets and parts, with realtime update of data with appropriate auditing
- Ability to logically lock pallets for inspection, counting, or management review
- Emergency requests for parts for picking or resample
- Dynamic assignment and reassignment of pick-area work
- Tape backup for disk-file updates and file-rebuild capabilities

Benefits of computer control

Total computer control of the ASRS with the 1800, is the most technically feasible and most economical control system available, considering the volume and complexity of operation. The online 1800 control system was compared with two other possible methods:

- **Manual Control**—all control done by people in the system; this includes manual recording and updating of data.
- **Semiautomated**—extensive vendor control logic to aid people in controlling the hardware, with data maintained offline on a small disk computer.

Online control is economically superior to either of the other alternatives in both initial investment and continuing operating cost. The major advantage in initial investment is realized in the reduction of vendor-provided control hardware.

Some of the major benefits derived from total computer control of the ASRS are briefly discussed in this section.

- **High-Volume Handling**—The ability to handle a high flow of pallets in the conveyor network and on the cranes. Better handling of peaks of activity, which are natural in an ASRS environment.
- **Reduced Hardware Investment**—Reduction of vendor-provided hardware, especially for control, such as:
 - Card readers on the cranes
 - Shift-registers on the conveyors
 - Separate conveyors for input and output to the ASRS (this also eliminated construction costs)
- **Improved Efficiency**—Significant improvements in efficiency, particularly in control, data recording, and auditing.
- **Improved Space Utilization**—Accomplished by:
 - Dynamic update of slots being freed for immediate reuse
 - Easy handling of multiple parts per pallet
 - Resizing and reselection on recycles
 - Pulling smallest quantity first
- **System Integrity**—Reduction of exposure to “lost” loads and data errors as a result of:
 - Elimination of many repetitive manual decisions
 - Elimination or reduction of data recording and transcription
 - Forced total reporting
 - Online auditing of data
- **Better Exception Handling and Increased Flexibility**—Increased ability to dynamically meet changing requirements of the warehouse, in order to meet their customer needs without wasted effort, by easily handling:
 - Emergency requests
 - Bin-locking
 - Hardware failures
 - Changes in work assignment
- **Effective System Usage**—Smoother and more effective use of the system and the hardware as a result of:

Control decisions made from a total-system viewpoint
 Matching of crane commands and slot selection
 Immediate trapping of potential hardware problems,
 with dynamic recovery

APPENDIX I

Disk files

In order to utilize and support the use of automated cranes and conveyors, it is necessary to maintain a current picture of all inventory in the system. This is done by updating the status of a pallet, part number, slot location, or request for output, as a change occurs. To accomplish this, it is necessary to maintain six basic files: the pallet file, part number, location, parent, requisition work queue and work queue directory.

The part number file contains records defining all inventory in the system. Each part number authorized to be stored in the ASRS has one unique record which summarizes the total quantity and status of that part. Also included are pointers to pallet records, which contain additional information about the associated part number. Part-number history and statistics are also accumulated on the record, such as the date of last activity against the part number and a counter of the number of requests for pallets containing the part number.

Each physical ASRS pallet has a unique corresponding pallet record. Pallet records are not created or deleted when pallets enter or leave the ASRS, instead the status is updated to reflect its current location and availability. Pallet records are used to describe the specific characteristics and status of the parts on the pallet. This includes actual location, quantity, part number(s), current status (in-storage, empty, in transit, etc. . . .), and pointers to other pallets that contain the same part number. In this way, pallet records of like

part numbers are chained together, with pointers of the first and last pallets in the chain contained in the part-number record.

The location file provides an indication of which slots are full/empty. It does not include which pallets or part numbers are stored in a particular slot. The file is organized by aisle, level, and size of slot to provide easy access to available information.

The parent file, like the part-number file, points to chains of pallet records. All pallets in the chain contain parts that are currently being inspected. That is, a sample is taken from newly received parts and inspected, while the balance of the parts (the parent) are stored in the ASRS unavailable for requisition filling until the sample has passed inspection. When the accepted sample enters the ASRS, the associated chain of parent pallet records is added to the part-number chain. The part-number record is then updated to reflect the availability of the accepted parts. Purchase-order number and shipment number are also used as qualifiers, to link samples and parents of like part numbers. In this way, a sample will only release those parts that were contained in the original shipment.

The requisition work queue (REQWQ) provides a summary record (macro) of the total requirements against a part number for a given day. All normal requisitions to be filled are sorted by part number and the gross quantity requirements are maintained on a REQWQ record. The record is then assigned a unique sequential number—the macro number. These macros will then be exploded into specific requests for pallets when needed. In this manner, changes in the real time environment will be taken into account.

A second file, the work-queue directory (WKQDR), indexes the REQWQ macros and groups them into "batches of work." Each work-queue directory record has a starting and ending macro number, and the number of the next macro to be "worked on." The pick-area technician can now assign or activate any given "batch of work" and the macros

Basic Operating Files

Name	Size		Organization	Information
	REC/File	Words/Rec		
Pallet (PALET)	20,020	24	DIRECT-Sequential by Pallet Number	Pallet number, status, location, part number, P/N status quantity, date of entry, date of last transaction, next pallet pointer, previous pallet pointer, entries for 2nd part number.
Part Number (PART #)	10,440	11	Index Sequential By Part Number	Part number, status, quantity first pallet pointer, last pallet pointer, date of last transaction activity counter.
Location File (LOCFL)	9	320	Sequential by aisle number	Aisle number, number of full locs for size, number of locs Size N, SLOT status (empty or full), error log by crane number.
Parent File (PARFL)	1,050	9	Indexed Sequential by PO & Ship & P/N	Part number, purchase order number, shipment number, first pallet pointer, last pallet pointer.
Requisition Work Queue (REQWQ)	1,050	9	Sequential by Part Number	Macro number, part number, quantity, first pallet, RIC count, status.
Work Queue Directory (WKQDR)	80	4	Sequential by Batch Number	Starting macro number, ending macro number, status, next macro pointer

associated will be processed by the computer. This, in turn, will generate specific requests for pallets until the macro is completely satisfied or all existing parts in the ASRS are exhausted.

IBM 1800 software

Multiprogram Executive Operating System (MPX Version 3) is used unmodified for the 1800 computer operating system. This system provides all of the non-application software support. It has the required capabilities to service:

- Interrupts
- Multiprogramming Levels and Priorities
- 2790/1053 Terminals
- Disk and Tape Files

The application programs are written in both 1800 Assembler, Fortran, and 2790 Macro Languages. These are mixed

within modules and individual programs. The crane and conveyor control programs are predominately Assembler. The other areas are predominately Fortran and 2790 Macro. The number of installed programs by area are shown below:

Real Time	
Conveyor Control	22
Crane Control	12
Pick Area	31
Input Area	32
File Support	18
Miscellaneous	4
Batch	42
	161
Total	161

Additionally, over 60 uninstalled programs were written for test purposes.

