For Release:

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At the ASTME Exposition...

IBM DEMONSTRATES COMPUTER CONTROL OF MANUFACTURING

CHICAGO, May 5 ... An IBM exhibit here demonstrates how all phases of plant operations can be integrated into a total, computer-managed system.

A stamping press, stacker crane and other plant-floor equipment are part of the exhibit at the annual exposition of the American Society of Tool and Manufacturing Engineers in the International Amphitheatre here.

The equipment is linked to an IBM 1800 data acquisition and control system, which monitors and directs the "make, move and test" operations of the simulated plant. The demonstration shows how the "product," a plastic gear box, moves from parts inventory to final assembly and testing.

The computer in the IBM exhibit:

-- Directs the stacker crane to store and retrieve parts;

-- Monitors the operations of the stamping press;

-- Instructs a worker assembling the gear boxes;

-- Controls an IBM 1627 plotter tracing a new gear;

-more-

-- Tests products and reports defects to responsible areas;

-- Measures output of each work station against production plans, alerting supervisors to problems, and

-- Produces end-of-shift reports on each production area.

Information is transmitted in and out of the computer via IBM 1053 printers and terminals that read badges.

"We are demonstrating how the computer can integrate information handling and equipment-control into a single system for plant management," said Nathan Chiantella, program administrator of plant automation systems for IBM's Data Processing Division.

"The IBM exhibit turns the clock ahead," he said. "The technology and the equipment for such a total system are already here. Various companies have implemented parts of it. What we've done is put it together."

# # #

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5/5/69

Advances in Manufacturing
Materials Distribution Center IBM Endicott

This publication describes the computer-controlled (IBM 1800) Materials Distribution Center at the IBM plant in Endicott, N.Y. Each area of the center is covered, photographs and schematics of the conveyor lines and the Automatic Storage and Retrieval System are provided, and justification is discussed. Substantial detail concerning the conveyors, etc., is provided in an appendix.

Foreword

IBM has successfully utilized computers to improve, monitor, and control actual production processes for many years and, as a result, has accumulated a large store of experience concerning their use as a manufacturing tool. The Advances in Manufacturing (AIM) series of publications is an effort to share this experience with others and, possibly, to assist them in finding solutions to similar situations.

Each publication in the AIM series discusses an advanced manufacturing application/system that is currently operational within IBM. In each instance the computer utilized is either a standard IBM product or a modified standard product. For readers desiring more information than is contained in a particular AIM publication, a demonstration of the application/system may be arranged through your IBM representative or the IBM branch office serving your locality.

CONTENTS

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.

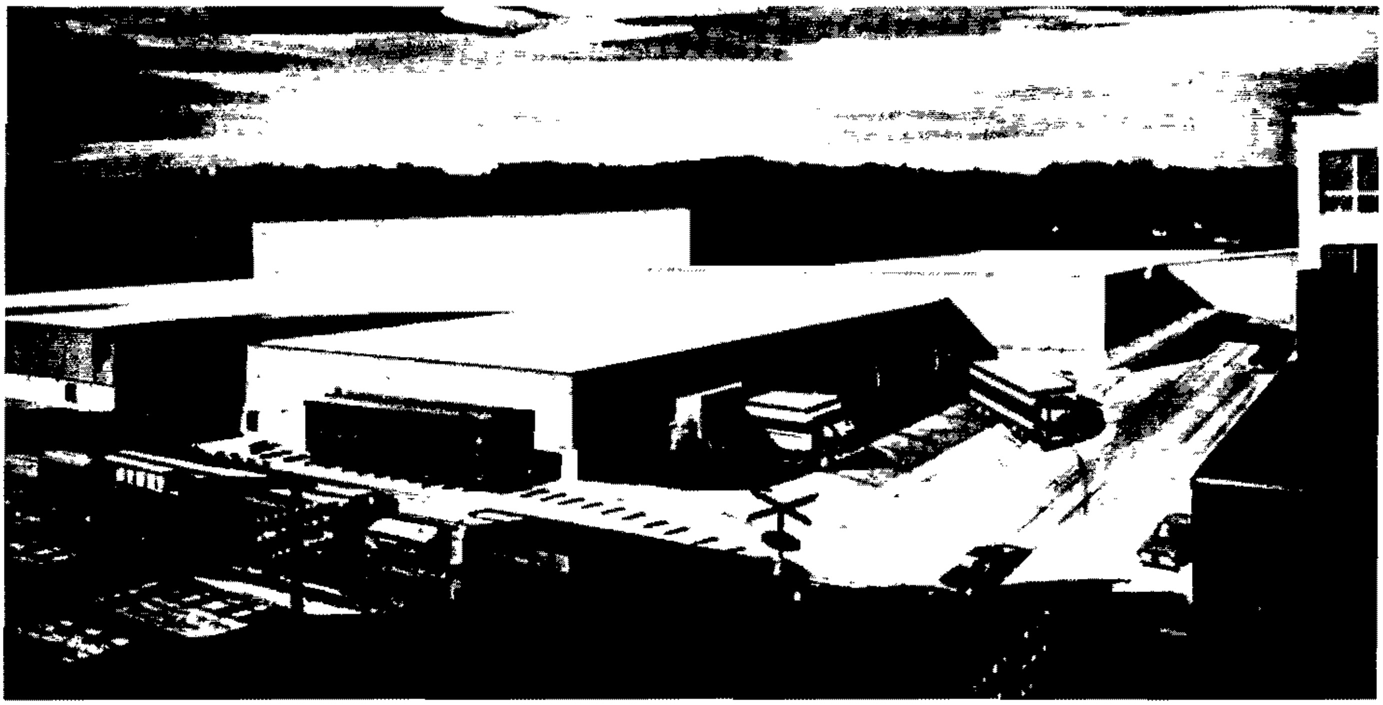

Figure 1. Materials Distribution Center, IBM Endicott, New York

MDC BACKGROUND

The Endicott plant is responsible for the manufacture, assembly, and test of printers, medium-size 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.

Prior to the construction of the new MDC, warehousing operations were fragmented and occupied fifteen leased, off-site locations spread over the Endicott area. Approximately 35,000 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 (Figure 2). By doing this, the following benefits would be realized:

- Reduction of the "pipeline inventory". This was done by substantially reducing the time between withdrawal from stock and arrival at manufacturing.
- Termination of leases on 15 warehouses. Many of these were physically inefficient for storage of the required types of items.
- Consolidation of the operation and people on-site for improvements in efficiency, control, and security.
- Substantial reduction of the operating costs through automation and computer control, elimination of duplicate functions and associated manpower, and elimination of internal transportation to and from remote warehouses.
- Reduction of departmental work-in-process inventory. As a result of the closeness of the facility and the use of automation, not only is the pipeline inventory cut, but variations in the time from request until arrival and in the time for filling emergencies are substantially reduced. This reduces the need and the tendency to have "manufacturing-floor warehouses" to cover these contingencies.

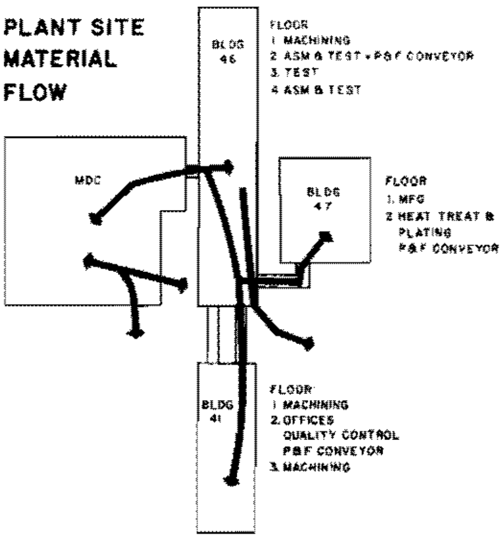

Figure 2. General plant material flow; MDC adjacent to the plant

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.[1] Because of its narrow aisles and ability to utilize high-rise storage racks, the ASRS (Figure 3) 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.

Additionally, it was found that total online computer control of the ASRS area was the most efficient and economical solution to the control problem. Controlling the physical devices of the ASRS by computer, with an online realtime inventory file, allows dynamic modification of ASRS operation to most effectively meet changing warehousing needs.

Total computer control proved to be economically superior to any alternative in both initial investment and continuing costs. The benefits of computer control are discussed more fully in the section "Benefits of Computer Control" but, briefly they are:

- High-volume handling
- Reduced ASRS hardware investment
- Improved manpower efficiency
- Improved space utilization
- System integrity
- Better exception handling
- Effective systems usage

[1]Simulation models were used in designing the warehouse to compare various ASRS configurations, other equipment needs, and alternative layouts of operating departments.

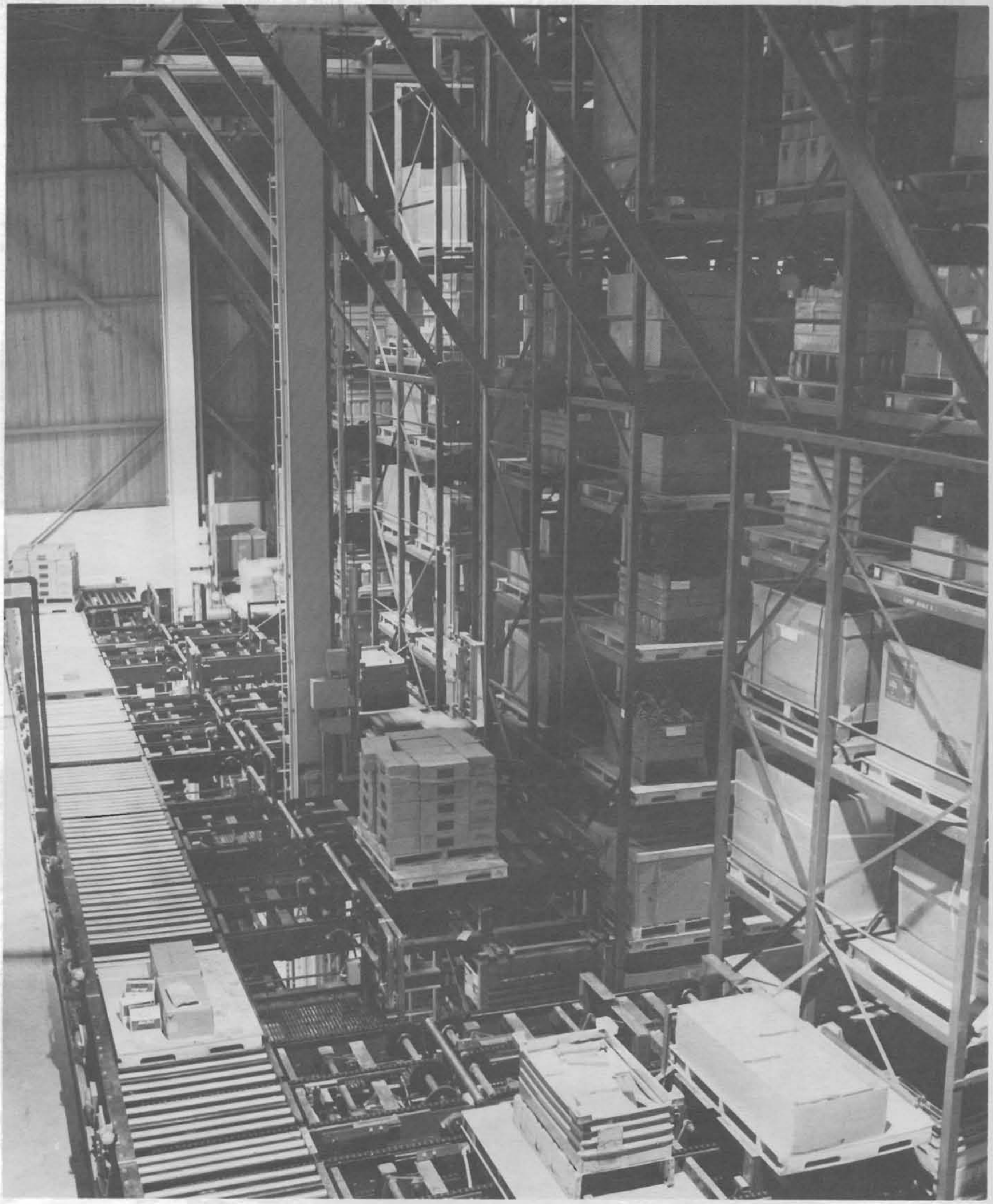

Figure 3. Automatic Storage and Retrieval System

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. [5] There are approximately 250 sensors (switches and photocells) throughout the ASRS 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 on the conveyor. When the computer wants the conveyor 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 random access storage devices (disk drives).

The updating of the disk files is done online in realtime 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 16) accepts badge, punched-card, and keyed-in data. The 2797 (Figure 17) 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 (Figure 18) print messages that provide guidance in reporting activities and identifying errors. 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; signals communicate with the physical devices, the terminals, and the files tied to the 1800.

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 in other systems 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.

[5] 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). See Appendix.

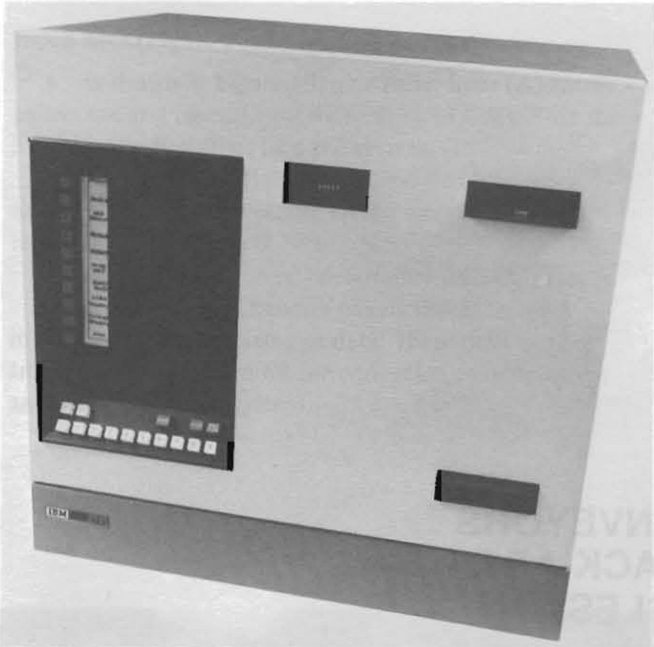

Figure 16. IBM 2791 Area Station

Figure 17. IBM 2797 Data Entry Unit

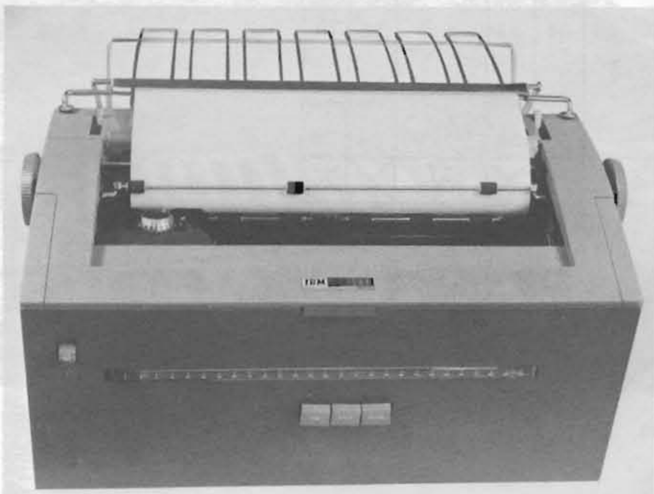

Figure 18. IBM 1053 Printer

BATCH REPORTS

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 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.

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 (Figure 31)

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.

ASRS PALLET INVENTORY REPORT

DATE 12/15/7X

REPORT UT129

PAGE 130

PALLET NUMBER	TR1	TR2	TR3	RIC	INS	REI	PART NUMBER	RAW	AFR	RIC	MGT	QUANTITY	PO QUALIFIER	SHIP	MGT CODE	ENTRY DATE	DATE LST TRANS	LOCATION S	A	V	H
5662	-	-	-	-	-	-	005298179	-	-	-	-	10.			0	2 278	2 321	R	4	2	30
5664	-	-	-	-	-	-	000856032	-	-	-	-	21.			0	2 325	2 342	L	7	5	47
5665	-	-	-	-	-	-	000317131	-	-	-	-	396.			0	2 277	2 347	R	4	6	66
5666	-	-	-	-	-	-	002471737	-	-	-	-	584.			0	2 278	2 318	R	3	4	2
5667	-	-	-	-	-	-	000810583	-	-	-	-	54.			0	2 272	2 325	R	4	11	3
5668	-	-	-	-	-	-	000852015	-	-	-	-	215.			0	2 301	2 301	L	6	7	8
5669	-	-	-	-	-	-	002638514	-	-	-	-	6.			0	2 306	2 321	L	2	13	6
5671	-	-	-	-	-	-	005298868	-	-	-	-	15.			0	2 278	2 340	R	4	11	28
5672	-	-	-	-	-	-	000123430	-	-	-	-	398.			0	2 278	2 347	L	3	7	48
5673	-	-	-	-	-	-	000123430	-	-	-	-	285.			0	2 278	2 347	L	6	4	32
5674	-	-	-	-	-	-	000155247	-	-	-	-	675.			0	2 278	2 336	L	3	10	32
5675	-	-	-	-	-	-	000175376	-	-	-	-	580.			0	2 278	2 278	R	4	5	13
5676	-	-	-	-	-	-	000175376	-	-	-	-	560.			0	2 278	2 278	L	7	5	16
5677	-	-	-	-	-	-	005298196	-	-	-	-	17.			0	2 278	2 333	R	5	3	10
5678	-	-	-	-	-	-	000210450	-	-	-	-	480.			0	2 291	2 340	L	7	2	41
5679	-	-	-	-	-	-	002471603	-	-	-	-	139.			0	2 269	2 318	R	1	6	52
5680	-	-	-	-	-	-	002495731	-	-	-	-	359.			0	2 337	2 342	L	6	5	47
5681	-	-	-	-	-	-	002532197	-	-	-	-	3771.			0	2 271	2 346	L	6	7	52
5682	-	-	-	-	X	-	002495706	-	-	-	-	100.	04199830	1	0	2 269	2 269	L	5	5	1
5683	-	-	-	-	X	-	002495706	-	-	-	-	100.	04199830	1	0	2 269	2 269	L	5	5	6
5684	-	-	-	-	X	-	002495706	-	-	-	-	100.	04199830	1	0	2 269	2 269	L	2	5	11
5685	-	-	-	-	X	-	002495706	-	-	-	-	100.	04199830	1	0	2 269	2 269	R	7	9	11
5686	-	-	-	-	X	-	002495706	-	-	-	-	100.	04199830	1	0	2 269	2 269	L	5	5	7
5688	-	-	-	-	X	-	002495706	-	-	-	-	100.	04199830	1	0	2 269	2 269	R	5	5	13
5689	-	-	-	-	X	-	002495706	-	-	-	-	100.	04199830	1	0	2 269	2 269	L	6	12	13
5690	-	-	-	-	-	-	000833873	-	-	-	-	378.			0	2 304	2 339	L	4	4	43
5691	-	-	-	-	-	-	000454355	-	-	-	-	125.			0	2 343	2 343	L	7	2	62
5692	-	-	-	-	-	-	002646275	-	-	-	-	1572.			0	2 291	2 348	R	3	3	44
5693	-	-	-	-	-	-	002525788	-	-	-	-	216.			0	2 326	2 337	R	4	6	47
5694	-	-	-	-	-	-	002641190	-	-	-	-	76.			0	2 314	2 321	L	2	11	38
5695	-	-	-	-	-	-	002526443	-	-	-	-	161.			0	2 276	2 318	R	5	6	5

Figure 31. Pallet inventory report

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.

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 disklike 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

MDC SQUARE-FOOT STATISTICS

AREA 1:		SQUARE FEET
Receiving & Shipping Docks, Truck Wells		21,400
Bulk Area		26,500
Bin Area		26,000
MES		11,200
Steel		14,200
Shipping		18,800
	TOTAL	118,100
AREA 2:		
Receiving		3,600
CBOSS		11,500
Quality		14,700
Cribs		7,500
Computer Room & Offices		6,700
Sort & Accumulate		10,000
ASRS Input & Pick		5,600
Miscellaneous		10,700
	TOTAL	70,300
AREA 3:		
ASRS Racks		48,000

CONVEYOR HARDWARE

To facilitate the moving of material in the MDC, a network of conveyors is used, some of which are controlled by the IBM 1800. Those areas that employ computer control do so because of the large number and the complexity of diverts/merges required to direct the pallet to its destination. They include (see Figure 19 in the main text):

- ASRS Input Conveyors A, B, C, and D
- ASRS Mainline Conveyors M and R
- Crane Deposit/Pickup Buffers D1-D9 and P1-P9

All other conveyors are controlled by local hardware logic utilizing:

- Operator pushbutton panels
- Retro-reflective tape (GO/NO-GO Gates)
- Photoelectric scanners
- Electromechanical memory
- Local interlocks

The type of conveyor used also varies through the MDC. The conveyors in the ASRS under computer control are of five basic types:

- Accumulating (APC)
- Live-roller, chain-driven
- Indexing
- Chain
- Belt-driven, roller-type

Accumulating conveyors are located in the Input Area (Conveyors A, B, C and D) (Figure 19), the Pick Spur S7, and the Mainline Conveyor R preceding Pick Spur S1. They use air pressure to deactivate rollers immediately behind the load, thus preventing pallets from colliding. As the first pallet advances along the conveyor, the trailing deactivated sections of the conveyor are activated, thus moving the following pallets forward.

Mainline Conveyor M consists of two sections of a chain-driven, live-roller conveyor. The sections form one continuous line that does not stop unless an error condition is detected. All diverting and merging onto the mainline is done while moving. Power is carried from roller to roller by short loops of chain running over sprockets mounted on each roller.

The third type of conveyor, the Indexing conveyor, is used to move pallets into and out of the crane pickup and deposit buffers. Two sets of chains are used to advance a pallet to the farthest available position.

The fourth type of conveyor uses no rollers; instead two chains traveling in a track carry pallets to the appropriate Pick Spur, (Mainline Conveyor R). Pallets traveling on the continuous moving chains are diverted into the pick spurs without the conveyor stopping. Like Mainline Conveyor M, the Pick-Area Mainline (R) does not stop unless an error is detected.

The last type of conveyor is a belt-driven roller conveyor, located on Pick Spurs S1-S6. Power is supplied to the rollers from friction contact with a continuous belt traveling beneath the rollers. The drive force exerted on the pallet is continuous and thus requires a stop gate to halt the forward motion of the pallet when it reaches the end position in the Pick Spur.

All conveyors in the ASRS are heavy duty, designed to handle loads up to 2000 pounds. The loads travel on wooden pallets of two sizes, 40 X 52 or 40 X 62 inches, and travel at an average speed of 45 feet per minute. The total network in the ASRS can accommodate 133 pallets per hour in and 133 pallets per hour out of the system, with both input and output areas capable of handling three pallets every minute under peak conditions.

In addition to the above types of conveyors, pallet diverts and elevator lifts are used to move pallets. The two basic types of diverts used are:

Ninety-degree roller-driven transfers in the Pick Area

Ninety-degree chain-driven transfers on the Mainline Conveyor M

The roller-driven transfer diverts pallets into the pick spurs by raising moving rollers between the mainline chain to lift the pallet load. This removes the drive on the pallet from the chains and transfers it to the rollers, thus diverting the pallet 90 degrees. When the transfer is completed the rollers lower to their original position below the mainline chains. The same procedure is used to divert a pallet on the Mainline Conveyor M, except that moving chains are substituted for the rollers.

Elevator lifts are used to move pallet loads between the first and second floors. They are capable of moving one pallet at a time, with a cycle time of 60 seconds.

CONVEYOR COMPUTER CONTROL

To control pallet movement in the conveyor network, photocells and limit switches are used to signal the computer that an event has occurred. For instance, as a pallet moves along the mainline conveyor, it will break photo beams and trip limit switches at strategically placed points. These actions are translated into unique Process Interrupts (PI's) that are recognized by the computer and cause associated programs to be executed. The computer, in response, may issue a signal that will cause a transfer device to raise and divert the pallet into a crane pick-up buffer. These output response signals are called Digital Outputs (DO's). Another type of signal, a Digital Input (DI) is used to monitor the current state of switches in the environment. A change of state in the switches (ON or OFF) does not initiate an event in the computer, as does the PI. Instead the computer initiates the reading of the DI status and, in turn, determines an appropriate response. The following table summarizes the number of points monitored or controlled by the IBM 1800:

Figure 32 lists the types of conveyors used in other areas of the MDC.

Area	Type of Conveyor	Basic Control Mechanism
Receiving & CBOSS	Accumulating APC Gravity feed 90-degree power curve Chain transfers 90-degree transfer table 3-story lifts	Manual pushbutton panel Electromechanical memory GO/NO-GO gates Photo scanners
Bin Area	Incline/decline belt Accumulating live roller 210-degree curve Gravity feed	Local interlocks Photoelectric scanners
Sort & Accumulate	Powered transfers Accumulating	Manual pushbuttons Local interlocks
Inclined Conveyor	14.5-degree-decline special conveyor 4-story lifts Accumulating Indexing 14.5-degree incline Chain transfers	Manual pushbutton panel Photoelectric scanners

Figure 32. Types of conveyors used in other areas.

ASRS CONVEYOR SIGNALS			
	Signal Type		
Area	PI	DI	DO
Input Conveyor	6	10	5
Pickup/Deposit Buffers	45		10
Mainline	55	30	20
Pick Area	25		35
Miscellaneous	6	10	5
Total	137	50	75

Error Detection

To ensure the conveyor network is operating properly and to prevent out-of-control conditions, the computer monitors all signals and compares them to anticipated actions. To do this, the elapsed time between the anticipated signal and the actual signal is compared. If the signal arrives too soon, it is disregarded as a "bounce". If it arrives too late, or not at all, an error condition is generated. This causes an error message to be printed, identifying the error and its location. Other action may be taken to stop all conveyors or to bypass a local section of conveyor automatically. This allows corrective action to be taken and permits recovery action without flushing or clearing the entire system. Types of error conditions monitored include:

Jammed Pallet	No downstream signal received.
Unexpected PI	Extraneous signal received or valid signal received early.
Indexing Failed	Pallet(s) failed to advance on input or output buffer.
Transfer Failed	Pallet failed to divert.
Wrong Transfer	A pallet diverted that was not scheduled to divert.
Overhang	Pallet load overhanging or pallet skewed on conveyor.
Local Flow Control	A section of conveyor is stopped to prevent a collision.
System OFF	Power off or operating mode changed to manual.
Controls Not in AUTO	One of the five control panels or one of the 18 buffer-control boxes not in AUTO.
Emergency Stop	Emergency condition on conveyors.

CRANE HARDWARE

ASRS Stacker Crane Characteristics

Physical

Cranes-9 (1 crane per aisle)
Double MAST design
Horizontal movement via monorail trolley
Vertical movement of shuttle only
Aisle dimensions – 54' X 335' X 60" or 70"
Unique addresses – 15,600
Horizontal speeds – 300, 150, 75, and 10 fpm
Vertical speeds – 45 and 15 fpm
Shuttle speed – 60 and 20 fpm
Loads stored on pallets – 2 sizes (52' X 40" and 62" X 40")
Various – height slots – 5 sizes, 30" to 89"
Various number of levels/aisle
Load limit – 2000 pounds

Operating

Single commands – Store, Retrieve, Sense, Reset
Dual commands – Store and Retrieve
Transfer in aisle – Retrieve and Store
Local or Remote Operation
Manual or Computer (AUTO) Operation
Average throughput – 306 pallets stored and retrieved per hour. Consisting of 12 dual and 10 single commands per hour per crane

Controls

Local control from on-board crane
Remote control from manual interface
Remote control via 1800 computer
Non-homing cranes
On-board control logic
Communication in aisle via collector bar system
Absolutely addressed slots via optically scanned targets
Error/out-of-limits sensors (Bin Full, etc...)
Automatic squaring of loads
Extensive error monitoring/recovery
Detection of invalid addresses
Verification of signals

CRANE COMMANDS

The following types of crane commands are used by the 1800 computer to control and monitor the operation of the nine stacker cranes:

Single Commands - Store or Retrieve

Store – Pick up load at input buffer position and deliver to bin address.
Retrieve – Pick up load at bin address and deposit on output buffer.

Dual Command* – Store/Retrieve

Store/Retrieve – Pick up pallet at input buffer position and store at bin address location, then retrieve pallet from bin location and deposit on output buffer.

Dual Command* – Retrieve/Store (Transfer-in-aisle)

Retrieve/Store – Retrieve pallet from bin location X and store in bin location Y.

Single Command – Sense or Reset

Sense – Sense the current error status of crane X and display on 16-bit digital input bus.
Reset – Reset all status indicators to zero.

CRANE CONTROL

The several modes of operation of the cranes are controlled by:

Local Manual Control – Onboard crane
Remote Manual Control – From interface control panel
Remote Automatic Control – Computer

Local manual control consists of an on-board operator panel from which commands are entered via manual switch settings. Information such as mode of operation, type of command and store/retrieve address are interpreted by on-board crane logic. The appropriate signals are then generated to control the movement of the crane. Status and error conditions are displayed on motion and error-indicator lights.

Remote manual control consists of operating the cranes from the crane interface control panel located in the computer room. Again, commands are generated from manual switch settings or from a card reader. In addition to the information entered in local manual control, the crane number must also be supplied. This permits one man to control the operation of all nine cranes simultaneously.

Remote automatic control utilizes the 1800 to generate the crane commands and monitor the operation of all cranes. To accomplish this, an interface is used between the 1800 and the crane interface control panel. The interface consists of:

32 bits of digital output – command information
16 bits of process interrupt – data-accept and cycle-complete information
16 bits of process interrupt – data-reject and error-alert
16 bits of digital input – error status

*Not normally used in computer operation.

The functions performed and sequence of events are as follows:

Requirements Determined by Computer	The computer determines the next operation to be performed by the crane, and all associated data: Crane Number Type of Command (Store, Retrieve...) Location (horizontal, vertical, side)
Command Issued to Crane	The computer issues a command to the crane interface panel via the 32-bit DO bus. It includes the following information: Device number Horizontal address Vertical of command Side Sense/Reset function Continuation/Complete indicator Parity bits
Command Interpreted by Interface	The crane interface then analyzes and interprets the command – checking for proper parity and valid data.
Computer Informed of Command Accept or Reject	Upon completion of the interface, it will respond with a data-accept or data-reject process interrupt (PI). If accepted, the computer will wait for the crane to physically complete the operation. If rejected, the computer will attempt to recover or issue instructions requesting manual checklist.
Command Executed by Crane	At this time, the crane interface issues the appropriate commands to the local logic on-board the selected crane and verifies that it was received correctly. The crane then executes the command, monitoring and controlling all physical movement.

Computer Informed of Successful Completion of Command	Upon completion of a command, an operation, or a cycle, process interrupt will signal the computer that the operation was completed successfully. The computer will then update the associated pallet file record to reflect its new status/location.
Crane Detects Error & Informs Computer	Should an error occur during the execution of the command, the crane interface will respond with an error-alert process interrupt. The computer will then request the corresponding error status to be loaded on a 16-bit digital input bus.
Computer Determines Specific Error Condition	This triggers the computer sensing of the DI BUS, which communicates the specific error encountered. Possible errors include: Device Busy Invalid Address Communication Error Bin Full Bin Empty Load Overheight Sequence Error Over-Travel Skewed Load Controller Error Load-on-Board Man-in-Aisle Time-out
Recovery Action Determined	The computer will then analyze the error and determine the appropriate recovery action. If necessary the computer will request manual checkout of the crane.

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: 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 that summarizes the total quantity and status of that part. Also included are pointers to pallet records that contain additional information about the associated part number. Part-number history and statistics are also accumulated on the record; examples of these are 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 indicate 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 and thus rendered 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 realtime 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 associated macros 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.

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)	1050	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)	1050	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.