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The role of bar coding in implementing computer integrated manufacturing /

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THE ROLE OF BAR CODING IN IMPLEMENTING COMPUTER INTEGRATED MANUFACTURING

by

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ABSTRACT

This thesis examines the role that bar coding plays in implementing Computer Integrated Manufacturing (CIM). The first half of the report focuses on the fundamentals of bar code technology. The second half discusses definitions of manufacturing, automation, and CIM, culminating with a description of bar code's role in the scheme of modern manufacturing systems.

Various alternatives to bar code are compared, including optical character recognition, radio frequency identification, and magnetic stripe. A discussion of bar code symbology is conducted using Code 39 to demonstrate nomenclature and various characteristics of bar code technology. A review of bar code equipment covers printers, readers, and systems; applications and trends concludes the first half.

The second portion addresses manufacturing, automation, and CIM. Particular attention is paid to the material flow cycle and the tracking of materials and work-in-process (WIP). From there, a two-pronged path toward achieving CIM is developed. One path is concerned with the planning and control aspects of CIM, including WIP and inventory control. Materials Requirements Planning (MRP) and Manufacturing Resources Planning (MRP II) are shown as routes between manual control and CIM. The other prong is

concerned with automating production processes and linking automated equipment with communications interfaces. CIM is achieved when the two paths are completed and integrated with one another.

The role of bar code in the progression is illustrated and discussed. Essentially, each prong on the CIM path has two areas where bar code data entry is a useful tool. On the control side there is bar code identification of items to assist in controlling the material flow cycle. Also, for facilities using MRP or MRP II, bar code is seen as a way of improving database integrity to ease CIM implementation. On the equipment side, bar code can be used as an interface between islands of automation as well as on a single piece of equipment for verification applications. In all applications, bar code data entry provides accurate, timely information which is essential for Computer Integrated Manufacturing.

I. INTRODUCTION- The World of Bar Coding

Automatic Identification encompasses a wide array of technologies involving the identification of items and the entry of this data into systems requiring the data. Prior to modern automatic techniques, these tasks were accomplished manually using for example, simple hand written index cards and a filing cabinet. The advent of the digital computer has replaced the filing cabinet with the capability for rapid data storage and manipulation. However, the typical method of data entry is still manual using labor intensive keyboard entry.

Keyboard data entry has developed into a major effort with many computer systems. Employees who provide this service have become very proficient, yet are prone to errors. Furthermore, it is the occasional and untrained user that is typically found in manufacturing. As such, manual data entry is time consuming, error-prone, and a necessary evil for most users.

Automatic data entry has developed to address these issues. Technologies are diverse and include such things as bar coding, magnetic stripe, optical character recognition, and voice recognition. Each of these will be described later and their capabilities and shortcomings will be compared. Different data collection environments have different needs, so an understanding of the various technologies is necessary in order to choose the most appropriate system.

The most dominant automatic identification technology is certainly bar coding. Bar codes are the familiar black and white stripes on packages in grocery stores. The pattern of alternating lines and spaces is translated by a bar code scanner which converts the code into usable data. The scanner uses a light source and a light detector as it passes over the code. The relative widths of the elements are measured and their pattern is compared to a standard in order to be translated.

The coding pattern used in the grocery industry is called the Universal Product Code, or UPC. Written documents describe the exact interpretation scheme of the bar code. Many other systems, or Symbologies, have been developed to meet various needs. The most popular symbology for industrial use has been Code 39, also known as Code 3 of 9. Others in common use include Interleaved 2 of 5 (I-2 of 5), Codabar, Telepen, Code 93, Code 128, MSI, Ames, Plessey, and Nixdorf. If bar coding is chosen as an appropriate automatic identification technology, the next step is to choose the symbology. In many industries, there is a standard, such as the UPC in the grocery industry. In other cases, the users must evaluate the various differences between symbologies and choose the one best suited for the application.

The growth of automatic identification can be attributed to the dramatic speed and accuracy improvements over manual data entry. A few quick sweeps of a bar code scanner can decode several bar codes with ease. For example, an 8 character bar code can be scanned less than a second. Keypunch operators on the other hand generally operate at 2 characters per second.

The accuracy of keypunch operators, with one error for every few hundred keystrokes, is not acceptable. Naturally, the error rate for unskilled operators will be even higher. Bar code scanning on the other hand, has been shown to reduce errors to somewhere in the order of one error in 3 million characters scanned [2]. Errors can be virtually eliminated with the use of a "check character" to verify the encoded information. This is described in detail later.

Another advantage to automatic identification systems is that they can be used in real time systems interactively. With manual systems, the data typically would be hand written and collected for batch entry by a keypunch operator. There is a time lag for the data to enter the system and for the system to respond if immediate action is necessary. Using bar coding, it is possible for an operator to enter a transaction and to have the system respond with instructions immediately. The keypunch method also has problems because the hand written data could be misplaced. When it finally arrived for data entry, there is still the possibility of problems due to poor legibility.

Auto ID has been successful in a variety of industries from groceries to health care to banking. Perhaps the greatest potential for bar coding is in manufacturing. Auto ID and bar coding in particular has been successfully utilized for tracking of work in process material, production control, inventory management, warehousing, attendance reporting, labor tracking and tool control. In material handling alone, there is potential for tremendous savings as 30 to 90% of product cost can be attributed to material handling.

A recent survey of manufacturing uses for bar code revealed three main application areas currently in use [8]. The most common use was for inventory management and control, closely followed by work in process monitoring and control. Both of these functions deal with the handling of materials as they move through the manufacturing system. They are not involved in the direct fabrication of the product, but rather the overhead of keeping track of it. This is also true of the number three application, shipping. Among the other applications mentioned are production counting, data entry, process control, automated warehousing, receiving, and document processing.

The benefits of automatic identification systems are varied. They facilitate improved decision making by providing timely information on people and products. They offer low likelihood of errors in data input. They offer a constantly updated database and accurate maintenance of inventory records. There are labor savings through the elimination of slow manual methods. There is improved quality control, tool management, and customer service.

This report will examine the role that bar coding plays in implementing Computer Integrated Manufacturing (CIM). A history of bar coding will be presented first followed by a discussion of other methods of automatic identification. The review of bar code technology continues with a discussion of symbology and nomenclature followed by a summary of various types of bar code equipment. Several case studies of successful bar code projects conclude the first half. The material up to this point is intended to provide a solid understanding of bar code technology so that its role and use in manufacturing can be better understood.

The focus next turns to developing an understanding of automation and the manufacturing process. Particular attention is paid to the material flow cycle and the potential problems in tracking material. A progression toward CIM is presented culminating with a presentation of where bar code is an important tool in this progression.

II. HISTORY, CURRENT MARKET, FUTURE MARKET

Bar coding is a fairly new field existing only in the latter half of this century. The first application of bar code technology appeared in 1949 when a patent was issued to Norm Woodland for a circular bar code [2]. In the 1960's, bar codes were used for rail car identification, while in 1963 Control Engineering described various bar code techniques. The first company to use a bar code reader in conjunction with a computer was Rust-Oleum. This 1969 application was designed to maintain a perpetual inventory file.

The 1970's saw the formation of the U.S. Supermarket Ad Hoc Committee on Universal Product Coding. This culminated in the 1973 adoption of UPC by that industry. Meanwhile the Plessey Code was being applied in European libraries and the Codabar and I-2 of 5 codes were developed. In 1974, Code 39 was developed by Intermec Corporation and grew in popularity due to its alphanumeric capabilities.

By the 1980's the technology was being refined and improved. Industry organizations were beginning to see the payback in bar coding. In 1981, the Automatic Equipment Manufacturers (AIM) published Uniform Symbol Descriptions to standardize certain codes. Further impetus to standardization that year was supported by the circulation of the ANSI draft bar code standards. The Department of

Defense published the Military Standard on bar coding in 1982 and began requiring Code 39 on all its shipments as part of the LOGMARS program. The Health Industry Bar Code Council also endorsed Code 39 with its 1984 standard. Other standards came from such industries as automobiles, paper products, and aluminum.

The growth of UPC in the grocery industry in the late 1970's [1] was followed by a growth in bar coding in manufacturing and services. The potential uses of automatic identification are enormous. Thus the total size of the market is expected to increase rapidly from an already respectable size. The 1986 market for bar code products was estimated to be $511 million according to Ross Associates of Needham, MA [25,26]. This is expected to increase at a strong 19% per year to reach over $1 billion by 1990. The market was divided into three segments by Ross: reading equipment, printing equipment, and labels. Currently, all three segments are about equal in sales dollars with printing equipment having a slight edge. This lead is expected to grow to the end of the decade primarily at the expense of bar code labels.

The Ross estimates of market size are small when compared to other studies. Venture Development Corporation of Natick, MA estimates a 1986 market of $936 million and projects 18.6% growth to $2.6 billion in 1992 [26]. Their study included input devices, printers, labels, software, systems integration, and miscellaneous products. The software and systems inclusion may account for some of the difference with Ross.

A third study, this one by Frost and Sullivan, offers similar results. The New York based market research firm claims a 1986 market of $750 million with a staggering 30% growth rate to $2.3 billion by 1990 [25]. Bar code scanner sales reached $43.8 million in 1985, with 63% of the sales going to only four manufacturers. Conversely, the top four companies in the $450 million printer and terminal segment accounted for only 38% of the market. This segment is known for its value added retailers using equipment from various manufacturers.

The users of bar code are as diverse as U.S. commerce itself. Manufacturing is by far the largest user segment with 52.3% of the users [9]. This is followed by services, such as banking and insurance at 14.4%. Close behind is distribution (8.7%) and government (7.6%). General retail and health care are among the remaining segments. Other methods of automatic identification (OCR, radio frequency) are far behind bar code, which represents 85% of the automatic identification market.

As manufacturers feel the effect of offshore competition, they are looking to bar code to improve their efficiencies and output. It is primarily the larger companies which have turned to bar code initially they seek greater international competitiveness. Smaller companies are now beginning to become aware of the advantages of auto ID. In some cases they are being forced into it as suppliers to certain industries such as the automobile industry. These industries require bar codes on incoming shipments, so the vendors are exposed to the technology and begin to look for their own applications.

The dominance of the manufacturing sector in bar code applications is evident in examining which bar code symbology dominates the label market. Code 39 is by far the leading choice for industrial applications. In 1986, Code 39 labels accounted for 45% of the total label market, well above Plessey at 17% and Codabar at 15% [25]. This dominance is predicted to continue with Code 39's share expected to increase to 53% by 1990. Much of this gain is at the expense of Codabar which is expected to drop to 7% of the market. Also of note is the projected drop of "other" from 8% to 4% indicating the growth of industry standards using the most popular codes.

III. ALTERNATIVES TO BAR CODE

Although bar code offers many advantages, there are other technologies in automatic identification. None of them have seen the widespread success that bar code has, however each has advantages in certain conditions. In this section we will review these technologies and compare applications and relative advantages.

TRADITIONAL KEYBOARD ENTRY- Although this is not an automatic identification technique, it is the standard for comparison as it has been the predominant method. Users range from full time data entry clerks with refined skills to shop floor workers with little training entering occasional information. The speed of data entry can range from less than one character per second to several characters per second depending on equipment, operator, and data complexity.

It is interesting to note that the format for the traditional "QWERTY" keyboard was developed to slow down the rate at which users could type. The commonly used keys were put in awkward locations to prevent rapid typing and the consequent mechanical problems. Modern keyboards and typewriters no longer have such problems, encouraging the development of the Dvorak keyboard with its ergonomic layout. Because QWERTY is so ingrained in our system however, the Dvorak has not become popular. Thus top speeds are limited for both experienced and inexperienced users. This, coupled with error rates of approximately 1 in 300 keystrokes, have shown the need for fast, accurate methods of automatic identification.

MAGNETIC STRIPE- The use of this technology is familiar to the public for its use on credit cards and banking machine cards as well as on checks and other financial documents. The medium is similar to that used for recording on audio tape. Magnetic stripe offers continuous read write capabilities. This is useful for commuter tickets, but certainly not for systems where data security is vital. One of the advantages over bar coding is its potential for densely packed data which can be revised. Furthermore, the stripes are resistant to environmental problems. Accuracy is maintained even with moderate amounts of heat, dirt, grease, and other contaminants. On the other hand, the magnetic stripe can only be scanned at close range and the tags are relatively expensive to produce. As a costly alternate, magnetic stripe is not a common automatic identification technology.

RADIO FREQUENCY- One of the most rapidly growing auto ID technologies is radio frequency identification (RF/ID). Bidirectional radio signals are employed in systems using a tag, an antenna or scanner, and a reader. The tag receives radio frequency signals and outputs a code to the reader. Tags consist of an integrated circuit chip on a printed circuit board and can be either "active" or "passive".

Passive tags only receive the RF signals and output a code, generally of 8 to 128 bits. Active tags use a long life lithium battery and hold 48 to 512 bits of data. They have the ability to receive, store and transmit data. This read/write capability is one of RF/ID's main advantages. The size of the tag can range anywhere from a grain of rice to a brick depending on its capabilities. Naturally the price varies considerably as well. Passive tags cost $5-$50 while read/write tags can cost three times that. The cost of the reader and antenna is approximately an additional $10,000.

Radio frequency identification can operate at a longer range than other techniques, offering an advantage where proximity scanning is more convenient than contact scanning. Additionally, there is not a line of sight requirement involved and RF can penetrate nonconductive materials such as wood, water, and concrete. Perhaps one of the strongest arguments for RF is its suitability for harsh environments where other ID systems would fail. RF/ID has been used in high temperature, highly corrosive, poorly lit, and explosive environments. Paint, dirt, coolant, and other contaminants have not affected these systems.

Because of these characteristics, RF/ID is commonly used in automobile assembly lines, particularly in spray painting areas. It is also popular for animal identification, namely cows and pigs. Agricultural applications involve automated feeding, milking, and weighing and the appropriate data collection and control mechanisms associated with these activities. For example, feed levels can be adjusted for specific animals and production levels can be monitored.

In addition to high cost, there are other issues to consider with radio frequency. These include the range and reliability of data, battery reliability, and industry standards. There are currently no industry standards and there are compatibility problems between vendors. With about 40 such companies, there is a need to develop these standards so that an open system can exist between vendors.

OPTICAL CHARACTER RECOGNITION- As another optical technique, optical character recognition (OCR) is a direct competitor to bar code. The symbols are stylized human readable numbers and letters scanned with a light source. A pattern is recognized and data is converted to electrical impulses for transmission to computer. There are currently two fonts- OCR-A and OCR-B, which are deliberately restricted to a narrow range of sizes and shapes for machine recognition.

An OCR reader looks at differences in reflectivity between ink and paper (or between etched and virgin material) then decodes using either matrix matching or feature analysis. Matrix matching involves dividing each character location into pixels. Each pixel is either "on" or "off" depending on whether there is ink in the pixel. The confidence level, or degree of matching, is preset by the reader software. In feature analysis, each character is analyzed in terms of horizontal, vertical, and diagonal lines and various curves. The number of each of these features in a character is matched against the software's list of characters and their features.

Optical character recognition is common in retail applications and for document control. Industrial uses tend to focus on production control applications such as on work orders and routing slips. Generally, OCR is a good choice when a code and human readable information are both needed on a small space, such as a price tag. Furthermore OCR is easy to print and can employ relatively inexpensive labels.

The accuracy of OCR is much less than that for bar codes (see Figure one). A single printed ink spot or void can render an OCR tag useless. This is not true with bar codes because of "vertical redundancy", or the fact the scanning can be done anywhere across the height of the code and still yield the same results. Optical character recognition needs careful alignment, is slower, and sometimes requires several attempts at decoding. Hence, it is not generally used when high speed and accuracy are critical.

MACHINE VISION- Strictly speaking, machine vision is not an automatic identification technology, however in many applications, it performs the same function in addition to its other capabilities. Machine vision is a computerized image processing technique used for such tasks as character reading, sorting by shape or markings, finding defects, and other inspection functions. Vision systems consist of a television camera, monitor, keyboard, and processor. The camera converts the image to an analog signal and sends it to the processor. The signal is then converted to a digital matrix and compared to matrices stored on memory.

Usually, characteristics visible to the human eye are suitable for machine vision inspection. Lens changes are used to accommodate depth of field changes. The speed of the system depends on the type of object, the number of features to be identified, and environmental conditions. Vision systems are complex, and hence expensive. A low end figure is $20,000 for a microcomputer based system.

VOICE RECOGNITION- Again, this is a complex system which has many uses including automatic identification. Naturally it is useful when the operator's hands or eyes are occupied.

Applications include inventory control, circuit board inspection, and material processing. The operator's words are recognized from a preprogrammed vocabulary. They are converted to analog voltages which are sampled thousands of times a second. A conversion is then made to digital data and into a matrix of numbers. This is compared to the matrices stored in memory.

Trade-offs in voice recognition involve flexibility, vocabulary size, and price. Systems are speaker dependent and have difficulties differentiating voices, accents, or variations from normal speaking. Not surprisingly, prices are high due to the complexity. On the positive side, accuracy is improving. The most expensive systems are best of course, reaching as high as 85-99% accuracy.

Figure one summarizes the key parameters of the various automatic identification technologies. The relative advantages of each can be used to choose the appropriate method for a given environment. Sometimes the choice is easy; for example radio frequency is the only option for use in certain harsh environments. Also, certain industries tend to prefer one method, such as OCR for the banking industry. None of the methods come close to the popularity of bar coding. Among it's characteristics are low to medium cost, immediate data entry, excellent accuracy and reliability, and widespread acceptance.

SUMMARY OF MAJOR AUTO ID ALTERNATIVES

METHOD	PRICE	DISTANCE	SPEED	ERRORS
keyboard	low	contact	slow	1 in 300
mag stripe	med	contact	fair	1/3,000,000
OCR	med	contact	fair	1 in 10,000
RF/ID	med-high	to 30 ft	immed.	almost zero
vision	high	to 10 ft	good	varies
speech	high	to 1 ft	fair	varies

COMMENTS

<u>keyboard</u>- training required for proficiency

<u>mag stripe</u>- read/write, environment resistant, good density

<u>OCR</u>- easy to print, proper alignment required, good density

<u>RF/ID</u>- read/write, good for harsh environments, no standards

<u>vision</u>- complex, many capabilities

<u>speech</u>- complex, hands-free usage

FIGURE ONE

IV. BAR CODE SYMBOLOGY AND QUALITY CONTROL

There are dozens of bar code interpretation schemes, known as symbologies. These have developed over the years to meet various user needs. Among the properties which a bar code symbology may possess are the following:

a. a large character set
b. loose tolerances between characters
c. self-checking
d. constant character width
e. structural simplicity
f. generous tolerances

The characteristics have conflicting objectives and a symbology develops as a result of trade-offs to satisfy the needs of the intended environment.

Perhaps the code which best meets current needs in manufacturing is Code 39. It was developed in 1974 by Intermec Corporation and was the first symbology to offer alphanumeric characters rather than numeric only. Because of its popularity, it will be used here to demonstrate the mechanics of symbology and to define the nomenclature of bar coding.

A Code 39 character is composed of 5 bars and the 4 included spaces. Each of these bars and spaces is referred to an <u>element</u>. Of these 9 elements, three are wide and six are narrow. The name of Code 39 (or Code 3 of 9) derives from the fact that three of the nine elements are wide.

Specifically, it is two bars and one space that is wide, giving a total of forty possible combinations.

In addition, four special characters are defined with all the bars narrow and three spaces wide. These 44 characters include the 26 letters, 10 digits, and several special characters. A unique stop/start character represented by an asterisk rounds out the character set. Figure two illustrates the full Code 39 character set, demonstrating the pattern of three wide elements of the nine total elements.

An advantage to Code 39 is its property of being self-checking. Because of the interpretation scheme of two wide bars and one wide space (or three wide spaces for special characters), a single printing error will not result in misinterpreting a character. For example, if one of the narrow bars was misinterpreted as a wide bar due to a spot, the code will be rejected rather than accepted as an incorrect character. The extra wide bar of course is not acceptable.

A Code 39 symbol is a string of these nine element characters. The space in between the characters is known as the intercharacter gap and is more loosely toleranced than the elements. Symbologies with this intercharacter gap are known as discrete codes. There are some codes where all the spaces are a part of the code. They are referred to as continuous codes.

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CHAR.	PATTERN	BARS	SPACES	CHAR.	PATTERN	BARS	SPACES
1		10001	0100	M		11000	0001
2		01001	0100	N		00101	0001
3		11000	0100	O		10100	0001
4		00101	0100	P		01100	0001
5		10100	0100	Q		00011	0001
6		01100	0100	R		10010	0001
7		00011	0100	S		01010	0001
8		10010	0100	T		00110	0001
9		01010	0100	U		10001	1000
0		00110	0100	V		01001	1000
A		10001	0010	W		11000	1000
B		01001	0010	X		00101	1000
C		11000	0010	Y		10100	1000
D		00101	0010	Z		01100	1000
E		10100	0010	-		00011	1000
F		01100	0010	•		10010	1000
G		00011	0010	SPACE		01010	1000
H		10010	0010	★		00110	1000
I		01010	0010	$		00000	1110
J		00110	0010	/		00000	1101
K		10001	0001	+		00000	1011
L		01001	0001	%		00000	0111

The ★ symbol denotes a unique start/stop character which must be the first and last character of every bar code symbol. Note that the start/stop character is distinct from the "asterisk" defined in Table 6.

CODE 39 CHARACTER SET [2]

FIGURE TWO

A complete Code 39 symbol has several characters as well as the start/stop character at each end. The stop/start character is to indicate where the symbol begins and ends as well as which end of the symbol is being scanned first. This ability to read the code from both ends makes it <u>bidirectional</u> and is a useful feature to have.

In addition to the characters, a symbol must have blank space before and after it known as <u>quiet zone</u>. It must be at least ten times the width of the narrow element. Also, since it is difficult for people to read a bar code symbol, the <u>human readables</u> are printed below the bar code symbol. This is a character by character interpretation of the symbol.

Code 39 has only two element widths while other codes may have as many as four. The ratio of the element widths in Code 39 is referred to as "N" and must be in the range of 2.2 to 3.0. The "X" dimension is the width of the narrow element. Both N and X are critical dimensions when examining printing and scanning tolerances. Naturally, increasing either of these will provide for easier printing and more reliable scanning. The size of Code 39 is variable over a wide range provided that tolerances are maintained. Thus Code 39 is able to meet a wide range of character densities depending on the printing and scanning processes being used in a given application.

The accuracy of Code 39 is excellent in part because of the self-checking feature. Even further accuracy can be obtained through the use of a check character, although only applications needing extremely high data security would need this. The health care field is one such application due to potential fatalities in medication errors. Essentially a check character works by assigning a numerical value to each of the Code 39 characters. When a symbol is scanned, the value of its characters is summed and the total is divided by 43. The remainder of this division is the numerical value of the check character. This is encoded between the last element of the code and the stop character. The reading device must be instructed to look for the check character.

An additional characteristic of Code 39 allows it to encode all 128 characters of the ASCII character set. When the reader is put in "full ASCII" mode, the special symbols are used as precedence codes with the 26 letters. These paired characters are decoded together and converted to the ASCII equivalent based on the published standard.

Code 39 is fully specified by ANSI standard MH 10.8M-1983 as well as by documents from the Automatic Identification Manufacturers. Additional support comes from the Department of Defense, the automobile industry, the health care field, and widespread use throughout industry. Code 39's popularity stems from the extensive capabilities

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Code 39 is fully specified by ANSI standard MH 10.8M-1983 as well as by documents from the Automatic Identification Manufacturers. Additional support comes from the Department of Defense, the automobile industry, the health care field, and widespread use throughout industry. Code 39's popularity stems from the extensive capabilities it has compared to other symbologies. Reviewing some of these, we see that Code 39 is variable length, alphanumeric, discrete, self-checking, bidirectional, of variable size, and has a simple structure. Furthermore it is compatible with the use of a check character and is capable of encoding the entire ASCII character set.

In addition to Code 39 of course, there are other symbologies which are common. The choice of a symbology is sometimes dictated by industry standards. Examples include Code 39 for automobiles and health care, UPC for retail, and Codabar for the blood industry. In other situations the choice can be made based on the attributes of the various codes. A comparison of three of the more popular codes is shown in Figure three.

A discussion of bar code standards is not complete without covering the quality of the printed symbol. When a bar code symbol is scanned, the desired result is for the correct data to be decoded and transmitted with one pass of the scanner. Occasionally, a pass of the scanner will not be able to decode at all and another attempt will be necessary. The percent of successful scanning on the first try is referred to as the <u>first read rate</u> (FRR) and is indicative of print quality. Another possible scanning result is that the scanner successfully reads a bar code, but interprets it incorrectly. This is the least desirable result of course, and is called the <u>substitution error rate</u> (SER).

	CODE 39	UPC	I 2-OF-5
standards	AIM,ANSI	UPCC,IAN	AIM,ANSI
corp. sponsor	Intermec	-	comp. identics
applic. area	industry	retail	industry
variable length	yes	no	no
alphanumeric	yes	no	no
discrete	yes	no	no
self-checking	yes	yes	yes
simple structure	yes	yes	no
# of characters	43/128	10	10
max CPI	9.4	13.7	17.8
toler. @ max CPI	.0017	.0014	.0018
data security	high	moderate	high

CHARACTERISTICS OF THREE SYMBOLOGIES

FIGURE THREE

The goal of bar code printing should be a high first read rate and a low substitution error rate. These rates are correlated. When the first read rate is high (85-100%), the errors are reduced greatly. Low first read rates lead to operator frustration and wasted time. A no-read of course, would require a return to error prone manual data entry. Substitution errors result in a contamination of the data base and destroy the benefits of an accurate bar code system.

There are four basic attributes which must be checked when evaluating the quality of a bar code: layout, encodation, print contrast, and bar/space dimensions. Layout verification is a simple visual check to assure that the correct number has been assigned to the code, that the proper code format has been followed, that the human readables are properly printed, and that the quiet zone is acceptable.

After the correct layout is confirmed, the correct encodation must be verified. The symbol is scanned and the decoder's interpretation is compared to the actual intended value. If the values are not identical, the code must be rejected.

The optical properties of a bar code symbol are critical to it's scanability. This includes the color of the bars and spaces as well as the amount of contrast between them. Specifications call for measurement of contrast using two specific wavelengths designated B633 and B900. Band B633 is visible red with a wavelength of 633 nanometers, corresponding to the wavelength of light from a helium-neon laser. This is the light source of many scanners while the others are designed to scan in this wavelength as well. The Band B900 corresponds to scanners using a gallium arsenide based light source.

Background reflectance for industrial bar codes can be as low as 25%, which is suitable for printing on corrugated containers. Higher density codes with a narrow element dimension of 0.02 inch or less require a minimum background reflectance of 50%. Additionally, a print contrast signal of at least 75% is required. Essentially this means that the space reflectance must be at least four times the bar reflectance.

The fourth attribute to be evaluated is the dimensions of the bars and spaces. Because Code 39 is a discrete code, the intercharacter gap is not part of the decoding. Rather, each character is analyzed by measuring each element and comparing them to a specific fraction of the overall character length of nine elements. The tolerance on the dimensions is calculated using the following formula:

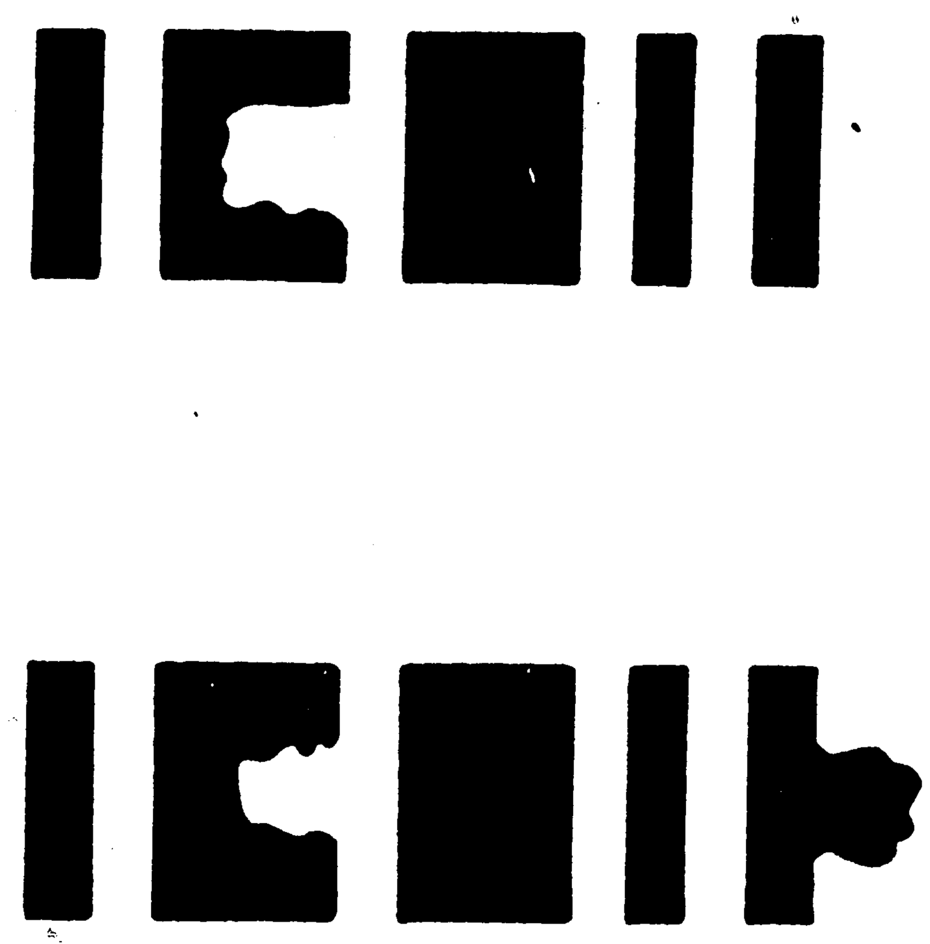
$$T = \frac{\pm 4X\ (N - 2/3)}{27}$$

where N is the wide to narrow ratio and X is the narrow element width.

The total tolerance for a bar code symbology is specified according to the limit at which the decoding algorithm will break down. This tolerance must then be broken down into a portion for the printed symbol and a portion for the scanner, The scanner tolerance is to account for difficulties in locating the bar edges, rounding errors during processing, and velocity changes of the scanning beam. If the scanner tolerance is not accounted for, poor read rates will result and error rates will rise. Conversely, if the scanner's portion of the tolerance is too generous, the symbol tolerance will be too tight, making printing difficult. Code 39 allocates 44% of the total tolerance to printing, and 56% to scanning.

Many applications for Code 39 involve a need for printing symbols at high densities. This is measured by the number of <u>characters per inch</u> (CPI). Unfortunately, as the symbol gets smaller, the tolerance get smaller as well. This makes printing difficult and may require a more complex printing process. If dimensional difficulties arise, the first recommendation is to increase the wide to narrow ratio to the maximum 3:1. If necessary, the nominal element width could then be increased as well. Naturally, both actions would increase symbol length.

The area of localized printing defects such as edge roughness, spots and voids is important to print quality. Figure four illustrates such defects. If the scanner path passes through one of these defects, the symbol may not scan or may scan incorrectly. For example, a void can transform a wide bar to a narrow bar while a spot would do the opposite resulting in a substitution error. If a re-scan is performed in another part of the symbol, the correct interpretation should result due to a lack of defects. This is due to the vertical redundancy of the bar code, one of it's strong advantages.



PRINTING DEFECTS

FIGURE FOUR

The specifications call for limitations on the magnitude of these printing defects. Specifically, spots and voids should occupy no more than 25% of the area of a circle whose diameter is 0.8 times the size of the narrow element. The size of the scanning beam itself should be no smaller than 0.8X. A smaller diameter would not be tolerant of defects. On the other hand, too large a diameter would not be able to distinguish the elements.

Because of the small dimensions and tolerances, special equipment is needed to inspect for bar code quality. The simplest equipment is an optical comparator or microscope. This requires human judgement and does not offer consistency from operator to operator. Further disadvantages to this method include time and labor intensive nature and the fact that generally not all of the bars and spaces are checked. Furthermore, there is no determination of encodation or print contrast.

Another quality control method involves the use of wand scanners. They are portable, easy to use, and require little operator training. Usually there is a display for a check on encodation and the scanning process indicates a degree of machine readability. Unfortunately, these devices cannot measure individual element dimensions or print contrast. Using a scanner as a quality control tool require caution, as various scanners tend to have different performance characteristics. A symbol which is decoded by one scanner may not work with another.

Recently, more complex instruments known as verifiers have been introduced as quality control tools. These are high precision instruments using microprocessors to measure and store the data for comparison with specifications. Measurement of the elements is performed to a precision of 0.0001 inch. Verifiers are capable of decoding the symbol, measuring all elements, measuring the reflectances of bars and spaces, calculating the print contrast signal, and calculating the tolerances.

Verifiers are fast and provide a thorough examination of all the key attributes of a bar code symbol. proper use of these devices ensures high print quality and therefore a high first read rate and low substitution error rate. Generally they are used for statistical trend analysis rather than as absolute judges of the acceptability of individual symbols. As such, they are a cost effective tool for maintaining the integrity of a bar code system. Although expensive at $1000 to $4000, there is a payback in terms of avoiding costly substitution errors in data entry.

V. BAR CODE EQUIPMENT

A. PRINTING SYSTEMS

One of the first areas to consider in a bar code system is the printing of the bar code labels. There are many ways to produce a label and the choice of a process depends on many factors. These include but are not limited to the following:

1. equipment and process cost
2. materials cost
3. print quality
4. printing speed
5. possible code density
6. flexibility in formats and sizes
7. lead-time requirements
8. ease of use

Printing processes can be divided into two categories: on-site and off-site. Various types of each will be discussed in this section.

Off-site printing involves a batch operation of large quantities of labels which are printed well before they are needed. This is typically done by an outside vendor who may be printing text and other graphics along with the bar code symbol. Consumer packages with the UPC symbol are typical of this arrangement.

A condition known as average ink spread is a natural occurrence in these off-site commercial printing processes. It results from the printing plates pressing against the label material and is a predictable growth of the printed elements. The amount of growth depends on the printing press, the condition of the plates, ink viscosity, substrate material, environmental factors, and plate pressure. In order to print the bar code symbol within specification, a <u>bar width reduction</u> factor must be used. The bars on the printing plate are made narrower by this factor to compensate for the growth due to ink spread.

Traditional wet-ink techniques such as off-set, lithography, letterpress, and gravure are the most common commercial off-site printing processes used. All of these apply ink selectively to a substrate (paper, foil, mylar) in accordance with an image contained on a printing plate. The plate is produced photochemically from a film master. Generally, these processes allow for a narrow element width of 0.010" or greater.

In the photocomposition process, a photosensitive substrate is exposed to computer controlled light from a flat faced CRT or a laser projection system. After development, a very high quality symbol results. Reliable narrow element widths of 0.0075" are not uncommon. It is an expensive process, but necessary if high quality, high density labels are required. Generally speaking, commercial printing is used when bar code printing is to be done directly on the package, if there is static, or incrementing data, and there is a several week lead-time available.

On-site printers are also known as demand printers, because of their ability to provide labels "on demand". These printers can receive instructions from a keyboard and produce a unique label with individualized information. They are characterized by the ability to print random data with little lead-time and are capable of changing codes or formats.

One of the most common types of demand printers is the dot matrix printer. These contain a printhead with a bank of wires in a 5 x 7 or 7 x 9 matrix. A microprocessor causes the pins to fire in the correct sequence striking the paper through an inked ribbon. Wire diameter is typically 0.010"-0.020" although the printed elements are wider due to ink spread. The amount of ink spread varies as a function of ribbon wear. Overlapping dots create elements whose edges are not well defined. Dot matrix printers are capable of printing 30-50 symbols per minute and are known for their high flexibility in formats and sizes of data. Only low to medium density symbols can be printed with dot matrix due to low print quality and poor definition.

Formed font impact printers have characters etched in reverse on a rotating drum. A one pass ribbon (yielding consistent ink spread) and a substrate pass between the drum and a hammer. The hammer strikes the drum causing the image to be transferred from the ribbon to the substrate. Formed font printers can produce 40-100 symbols per minute with excellent edge definition and high density. Because of the nature of the drum, formed font printers offer little flexibility in formats, fonts, and sizes.

A thermal printhead with special heat activated paper is used for thermal printing, a quiet and inexpensive option. The printhead has an array of square or rectangular dots which are heated under microprocessor control. Since no ink is involved, there is no ink spread or splatter. However, the labels are sensitive to ultraviolet light, causing fading in sunlight. Speeds range up to 120 labels per minute using a wide range of symbol densities. There is excellent print quality and edge definition as well as much flexibility depending on the software.

A similar but newer process is called thermal transfer printing. This uses a heat activated ribbon with almost any substrate. The ribbon releases ink when heated by pins under microprocessor control. Dots as small as 0.003" are used with a single pass ribbon. Speeds of up to 300 symbols per minute are possible at all densities. There is a great deal of flexibility, excellent quality, and excellent edge definition.

Ink jet printers use a very thin semi-continuous stream of ink pulsed one drop at a time from a nozzle. The drops receive an electric charge, pass through deflector plates, and are deposited on the substrate. There is not precise placement of the ink and splatter is common. Low density symbols and poor edge definition result. Advantages are speed, with line speeds of up to 250 ft/min and high flexibility. Costs are relatively high but justifiable on high speed packaging lines.

In electrostatic printing, patterns of electrical images are charged onto the paper using 7-10 mil dot sizes. Particles of dry solid ink, called toner, are attracted to the charged areas. The characters are permanently fixed by pressure rollers or by heat. Electrostatic printers can print 200-300 labels per minute at medium to high symbol density. Flexibility is very good as is the quality.

Laser printers are very similar to electrostatic printers. A laser beam forms dots in a matrix on a rotating photosensitive drum. Toner is attracted to the imaged areas of the drum and transferred to the paper. The toner is fused by heat or pressure. Laser printers are only used as page printers not as label or tag printers and are useful for printing bar coded work orders. Speeds range up to 180 pages per minute. Excellent symbol quality and edge definition are possible. Commercial systems are expensive, however office-type equipment is competitive with other on-site printers. Lasers have also been used for etching directly on products, most notably in the electronics industry.

Figure five summarizes some of the important characteristics concerning demand printers. In addition to choosing a printing method, an important but often overlooked decision involves the choice of a bar code media, be it a label, a tag, or a document. The media must be compatible with the printer as well as the scanner and the environment in which the components will be used. In designing a bar code application, it is not uncommon to conduct performance evaluations of several alternatives.

SUMMARY OF DEMAND PRINTERS

	symbols per min.	flexi.	density	edge def.
dot matrix	30-50	high	med	low
formed font	40-100	low	high	excel.
thermal	10-120	high	high	excel.
therm. trans.	25-300	high	high	excel.
ink jet	200-400	high	low	low
electrostatic	200-300	good	med-high	good
laser	n/a	page only	med-high	excel.

FIGURE FIVE

Optical characteristics are critical with the most important factor being reflectivity. Ideally, the media should reflect at least 70% of the scanner light. The ideal is not always achievable, such as with fiberboard shipping containers, which puts more emphasis on the contrast between bars and spaces. Also a dull surface is recommended as opposed to a glossy one to ensure that an acceptable reflectance pattern exists. Finally, the media should not be at all transparent as the material underneath may affect the scan reception.

Another factor to be considered when choosing the media is the material's durability. The number of times which a contact scanner will be used on the symbol determine the need for a durable label. In some cases a cheap paper label is acceptable. In applications involving repeated scanning, dirt, moisture, solvents, and temperature extremes, a transparent protective coating should be used. This could involve such things as a clear plastic report cover over a bar code template or a laminator used in conjunction with a demand printer.

B. BAR CODE READERS

The interface between the bar code symbol and the computer system is the bar code reader. Assuming that the symbols are printed within specifications, it is the performance of the reader which determines the first read rate. A controlled study using supermarket type scanners yielded a first read rate of 99%. In practice, good symbols seem to generate a FRR of 80-90%. This seems to be an acceptable rate for user satisfaction. Lower rates lead to operator frustration and abandonment of bar code use [2].

Bar code readers consist of two components: the input device and the decoder. The input device operates the electro-optical activities of reading a symbol. The reflectivity of the elements produces an output signal proportional to the reflectivity. The result is a time varying electrical signal with the relative widths of the elements determined by the time differences.

Input devices illuminate an area of the symbol and collect a portion of the reflected light with a photodetector. This generates an analog signal which is converted into a square wave. This is known as signal conditioning or digitizing. The signal is then amplified and transmitted to the microprocessor for decoding.

The decoder logically separates the symbol from background noise and tests for validity. The decoder then determines which elements are bars and spaces and calculates their widths. This information is decoded using the rules of the particular symbology programmed. The data is then either transmitted or stored.

The most common light source used for bar code readers is Light Emitting Diode, or LED. It is reliable, low cost, and low power. They are of limited use in applications involving scanning at a distance and require careful alignment. Also, they are poor performers if a large <u>depth of field</u> is required. This refers to the range of distances over which scanning can be done.

An optical lens focuses the scanning beam to a small enough size the resolve the elements. The beam has it's smallest diameter at a specified distance and the depth of field is located around that point. A larger X dimension will allow for a larger depth of field. An X dimension of 7.5 mils results in a depth of filed of about 5 inches, while a 12 inch depth of field can be obtained with a 20 mil element.

Scanners using charge coupled devices (CCD) are useful for reading symbols with surface irregularities. Like LED, they have a small depth of field and <u>optical throw</u>, which is the maximum scanning distance. CCD scanners have high cost and require high power. Their advantage is in the ability to scan over surface irregularities including symbols covered with glass or laminates.

Scanning over distances requires the use of laser diodes or helium-neon (HeNe) laser tubes. The laser diode has a large depth of field but cannot be used with some inks because it is an infrared light source. A carbon based ink must be used. Maximum depth of field and optical throw is obtained with the HeNe scanners. Unfortunately, they have limited life, high voltage, and are expensive.

There are several options available in choosing a bar code reader. Some readers are on-line with the computer system with a direct connection powered by an AC power line. Other readers are portable and battery operated. The data is stored in local memory and downloaded in batches. Both on-line and portable devices may have displays for receiving prompts and a keyboard for entering non-bar code information.

Another feature which some readers may have is autodiscrimination. This is the ability to determine which symbology of several in memory is being scanned and decode using the appropriate algorithm. This is useful in warehouse environments where more than one symbology is accepted, such as medical supply house whose suppliers use both UPC and Code 39. It has been suggested that the use of too many symbologies causes the substitution error rate to rise. This is because of the possibility that a printing defect will transform a no-read of one symbology into a valid character in another symbology.

Another reader option involves the amount of "intelligence" in the reader. In non-intelligent systems, the decoded data goes straight to the computer and messages go directly to the display. The computer is a part of every transaction. With an intelligent reader, the application program is executed in the reader itself. The mainframe computer is not involved in every transaction, thus improving system response time. The local program can edit, validate, and reformat the data without the host computer.

Bar code readers which touch the symbol during scanning are called contact scanners. They are commonly referred to as wand readers or light pens. Some skill is required for proper alignment and speed of the wand during scanning. A 20 mil depth of field is provided in order to read through protective coverings. Wand readers are compact, lightweight, and low cost.

Wand readers also fall in the category of fixed beam readers, meaning that there is a single stationary beam of light from the light source. The relative motion between the light and the symbol must be provided by moving the light source past the symbol or moving the symbol past the light source. Fixed beam readers can also be non-contact readers. The principal is similar to the wand but they are used a few inches away from the symbol. They are slightly more expensive and require some operator skill to align at a distance. Fixed beam, non-contact scanners can also be mounted on a conveyor to scan symbols moving past it. Good registration is needed to ensure proper alignment of beam and symbol. There is generally a rectangular aperture to provide greater immunity to localized printing defects.

The final category of readers is moving beam readers, which use an internal mechanism to automatically rescan the symbol rapidly. Rescanning rates are as high as 2000 scans a second, allowing symbol to be read reliably when passing on a conveyor at up to 1100 feet per minute. Moving beam scanners are always non-contact and usually use a laser light source. Little skill is required to operate the units and the multiple scanning makes it easier to read poorly printed codes and those with uneven surface textures. The higher cost of these readers can often be justified by their higher performance and productivity.

C. DATA COLLECTION SYSTEMS

The bar code readers discussed in the previous section become part of the data collection system. In addition to the readers, the system contains computers, communication devices, and software. There are many ways in which this system can be constructed. The three main categories are interactive, batch, and preprocessing systems. They will be discussed here along with some information on portable data collection terminals.

The first category is on-line interactive systems also known as fully integrated systems. Data from the reader is immediately transferred to the host computer, and responses are immediately sent back to the reader or terminal. The CPU becomes a part of every transaction.

One of the primary advantages of on-line systems is the ability to update the data base in real time. As soon as a transaction is complete, that information is available for all authorized users on the mainframe. The set-up eliminates the need for maintenance of multiple data bases and limits problems associated with data obsolescence.

Real-time systems also offer the ability for programming checks on data content validity. For example, a check can be made to ensure that the number of components just arrived matches the number called for on the purchase order. These systems are generally managed by the Data

Processing or MIS functions as they can appreciate the scope and details of a large computer related capital investment. These functions can also provide on-going support for the project if problems arise or changes are needed.

A disadvantage of on-line systems is the long planning and implementation time required. This can be aggravated by shifting priorities on the mainframe computer system. Also, the response time during transactions can be slow at peak hours as the host computer is a shared resource. Finally, the host may need an upgrade due to the added load of the data collection system.

At the opposite end of the spectrum is the batch or stand alone system. This uses a dedicated computer resource such as a minicomputer or a desktop microcomputer. The system collects the data, checks the format, and updates the local database independently of the host. Data files are transferred in batch mode between the stand alone system and the mainframe computer via physical media such as diskettes or via direct connections.

Batch systems can offer very fast response times as they are dedicated to the data collection function. A further advantage lies in the ability to make hardware and software changes without disturbing the mainframe system. This is useful during implementation as well when debugging the system is done independently of the host. Implementation is typically done by the user group. As the cost of microcomputers becomes less, this type of system is becoming very attractive.

A significant drawback to independent batch systems is that there are no real time updates of a central database. This prevents the continual checking for logical inconsistencies and the ability to immediately alert the users of problems. Batch systems require the control and maintenance of multiple data bases: the corporate systems and each of the batch systems. It is difficult to perform verifications on the parallel databases and the time lag in updating the central database can create confusion.

The third type of data collection system is the preprocessing system. The preprocessor performs local editing and interactive instructions downline from the host. Applications programs are run directly at the terminal level. They are typically stored in the host and downloaded to the terminal. Several scanner events are stored in the local memory. After a "complete transaction" of several scans, the properly formatted information is sent to the host.

Preprocessing systems provide a front end for the mainframe system, allowing the benefits of close to real time interaction with the central database without sacrificing response times. Extensive data validation is possible due to the real time aspects. Also, there is a minimum impact on the host system hardware or programming.

A disadvantage of the preprocessing systems is their complexity as well as their higher cost. Furthermore, there is the need to maintain parallel databases and there is a problem of host level data trapping. This refers to the one way communication which prevents the host from downloading error detections to the terminal.

An important component of many data collection systems is the portable data entry terminal (PDET), which permits data to be collected from any point in the facility using a hand carried device. Some portable systems simply collect the data, while other are extensively programmed for a specific data entry function. There is usually a keyboard and a display and most are batch oriented.

Of particular interest are those portable terminals with a radio link which allows immediate transmission of the data to the host. They are on-line , permitting two-way communication between host and terminal. Data verification and editing is possible. The data is carried over a low power FM radio link to a base station which collects the data and sends is to the host.

These units typically use rechargeable nickel-cadmium batteries and can be hand carried or mounted on equipment such as a forklift truck. A common arrangement consists of a truck with a mounted terminal used in conjunction with a moving beam scanner. This permits the operator to perform put-away tasks and data entry functions without getting off the truck.

Keyboards on portable terminals can be either numeric or alphanumeric. Furthermore, the alphanumeric keyboards can be either "QWERTY" or alphabetic depending on user skill and preference. Displays use either light emitting diodes (LED) or liquid crystal displays (LCD). The LED display offers more crisply formed letters, but consumes more power and is temperature sensitive. The LCD displays use less power, thus extending the battery life and can be used in direct sunlight where LED cannot be used.

VI. APPLICATIONS AND TRENDS

Applications of bar code technology have been implemented in a wide variety of industries. Virtually any environment involving information processing can use bar coding to enter that information quickly and accurately. Almost any business enterprise can benefit by identifying and tracking materials, documents, equipment, or people. In this section a few common applications will be discussed with an emphasis on manufacturing.

One of the more popular application areas is inventory control. Bar code can help in knowing what materials and supplies are available, what has been backordered, and what is surplus. Items are easily identified and controlled by appropriate programming.

Production control applications involve tracking of work in process materials. Bar code data entry can provide the status of every job on the shop floor. A user has access to which jobs are current and which jobs are behind. Complete job histories can be maintained by automatically recording production data.

Parts identification involves identifying an item and indicating it's location. Tools needing resharpening can be identified and recalled using bar code. Similarly, tool management applications can identify tools to aid in their automated selection and verification. As a tool is delivered to a machining center, a scanner can read a tag to verify that the correct tool has been delivered.

A popular application involves labor tracking and attendance reporting. Bar code terminals can replace time clocks to mark the arrival of workers at various workstations. An extension of this would be in security situations where only employees with authorized bar codes would be allowed to enter.

As automatic identification becomes more well known, more diverse user groups will develop. Management Accounting recently listed some bar code applications of interest to accountants in a manufacturing enterprise. The list included inventory control, asset management, receiving functions, record keeping, tool crib checkout and record control, and time and attendance data collection. The benefits include improved customer service and reduction in idle time in production via effective production scheduling and control [28].

General Motors Corporation has implemented a successful warehouse control system using bar codes. Four hundred containers arrive daily from GM suppliers, many on a Just-in-Time basis. A radio frequency terminal is used with bar code labels on the containers to feed the inventory control software. Forklift operators are equipped with laser scanners and with computer terminals mounted on the trucks.

As materials arrive from suppliers, the operator can immediately learn it's destination by scanning the label. The destination can either be a warehouse storage location or the staging area for immediate shipment. The age of shipments is monitored so that a strict FIFO inventory system can be maintained. With this system, warehouse management has greater control over meeting customer needs and over activities on the warehouse floor [29].

With a $9 million tool inventory, the General Dynamics Land Systems Division is benefiting from a tool inventory control system. This is an on-line menu driven system capable of supporting multiple sites. The facility involves a machine shop operation and laminated labels are used for protection from the environment. Laminated ID badges with a bar code ID number are also used.

Employees bring a tool requisition form to the crib window along with their badge. The badge is wanded and the attendant goes to the tool location to retrieve the tool. The bins have a bar code label to identify the tool while quantity codes are located on top of the cabinets. Wands with extension cords are located throughout the crib. When items are returned, an appropriate code is scanned to indicate if the tool is broken, lost, or returned in good shape. There has been increased service to the plant by being more efficient at the window. Better tracking of tool use is possible as well. This is important because many materials from the crib are billed to the customers account which requires accurate recording of tool and supply use [26].

A timekeeping application is illustrated by the system at Endevco, a supplier of accelerometers and transducers. The products are produced on a job shop basis with as many as 150 discrete steps involved. Direct labor accounts for up to 50% of product cost, so close tracking of employee activity is imperative. Each worker has a menu with has employee number, stop, start, and quantities in both bar code and text form. Work orders and part numbers are bar coded on cards attached to the products.

A wanding sequence is done at the start of the day and at the completion of each work order. The data entered through the wands is fed to a microcomputer which calculates the time spent on the job. Codes for rework, absence, and indirect labor are printed on the back of each bar code menu. Supervisors have access to information on the previous day's activities and payroll gets information on attendance. As a result of the system, information is available quickly on job status and employee productivity [5].

In addition to manufacturing applications, there are numerous applications in other fields. One of the more visible examples is at point of sale registers in retail outlets. The National Retail Merchants Association (NRMA) has endorsed UPC for source marking of retail products.

Optical character recognition has much support among retailers as well, so an environment of dual marking technologies will exist as OCR is phased out in favor of UPC. Sears and J.C. Penney are two of the largest users of OCR in the retail industry.

Bar coding and UPC in particular was chosen in part because of its success in the grocery industry. Both fields often utilize commercial printing of packages, computerized inventory control, and sales to the general public. Bar codes have achieved mainstream acceptance with the buying public. As long as the pertinent information such as price and size are clearly visible, there is generally no objection to the addition of a bar code symbol. The increased speed and accuracy at checkout lends additional customer support.

The liquor industry has also followed suit by adding UPC to its labels, and videotape manufacturers have as well. Apparently, the trend is for all consumer related segments to follow the lead of the grocery industry. The recording industry has been bar coding records and tapes and publishers have been printing bar codes on books and magazines.

Service industries have seen the advantages of bar coding also. Many libraries are computerized and have added bar code data entry for borrowing transactions. Paperwork and filing systems have potential applications as well. The

U.S. Patent Office is one of the largest of these applications with its vast amounts of information to process. Four hundred applications are received each day. A bar code tracking system is used as applications proceed through the lengthy multi-step approval process [12].

An interesting application involves the use of bar codes in conjunction with video cassette recorders. Some owners have had difficulties in programming their VCRs to record at specific times. A sheet is provided which lists the more popular movies and their bar coded start and stop times. Users simply scan the codes next to the desired selection and the machine is ready to record at the correct time [22].

The future of bar coding is strong as indicated in a prior section. In addition to market growth, there are some specific trends which are developing. Among them is the trend toward smaller equipment. Devices will be of lighter weight and be more power efficient. The result will be more memory and intelligence available at the transaction point.

Another trend centers around other identification technologies such as radio frequency identification and communication, which is becoming more refined and affordable. The result will be integration of these technologies with bar code systems. In fact the systems approach which will become dominant in the not to distant future. Companies will need to integrate an entire control system utilizing automatic identification as one important resource. Currently, the automatic identification industry is dominated by companies that concentrate on one or two types of components, but it is transforming to a situation of mostly full service systems integrators.

A final trend is towards increasing the density of bar codes. More information is being required in smaller places. This is especially true in health care and electronics. A recent development in this regard came with the announcement of a new symbology by Intermec Corporation. The new high density Code 49® is a two dimensional code as opposed to other codes which just use element widths to distinguish characters. It is essentially a stack of bar codes one on top of another. Code 49 can encode all 128 ASCII characters and can be intermixed with other symbologies on conventional reading equipment [17].

VII. AUTOMATION AND COMPUTER INTEGRATED MANUFACTURING

In order to understand how bar code systems can become an integral part of manufacturing systems, it is first necessary to develop a framework to describe the manufacturing process. Within the scope of manufacturing are other terms which are relevant to modern production systems. These terms include automation, CAD/CAM, and Computer Integrated Manufacturing. This section will attempt to define these terms and illustrate their differences, similarities, and relationships.

Harrington [13] defines manufacturing as the "conversion of naturally occurring raw materials into desired end products." To be more specific, he generally uses this definition to describe discrete products manufacturing. This is opposed to the to the extraction of the naturally occurring materials from the environment and conversion to a specialized form in bulk. In this definition, the mining of ore is not considered a manufacturing system, but it's subsequent use to produce steel is as well as it's conversion to automobile parts.

There are four major functions which a manufacturing enterprise must perform according to Harrington. They are:

-manage the enterprise

-manufacture the products

-market the products

-support corporate activities.

Managing the enterprise includes planning how to meet the corporate objectives as well as developing strategies, policies, and programs. Manufacturing the products involves producing the corporations products in a continuing operation. Marketing operations include informing potential markets of the products and contracting for delivery and service. Supporting corporate activities includes legal council, financial services, personnel management, and data processing. There is much more to manufacturing than the physical fabrication of the product. There are other functions and the interaction of these various functions is critical to the success of a manufacturing enterprise.

Modern manufacturing facilities use some sort of mechanization and automation of equipment and information processing. Thompkins and White [30] describe an automatic factory as essentially a factory without people. They are so highly automated that human interaction is not required for their normal operation.

More typical is the automated factory. Automation and mechanization are dominant, however people perform a limited number of direct tasks as well as a greater number of indirect tasks. Most facilities in the industrialized world fall into this category by utilizing various levels of automation. Very few automatic factories exist however.

They are characterized as having products with high volume and low variety. Such is not the case with the vast majority of products.

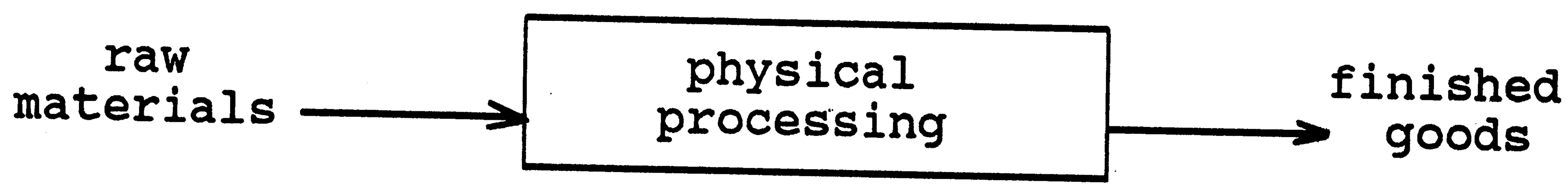
As a facility uses more and more pieces of automated equipment, the system can develop what is known as <u>islands of automation</u>. As the name implies, each component is operated in an automatic fashion independent of any other component in the system. There is no communication between any equipment or computers to allow real time control of the system as a whole.

Islands of automation are frequently used to make a transition from a conventional factory to an automated factory. Equipment is purchased one piece at a time and justified by the cost savings projected by tradition payback analysis. Examples of some of the potential islands in a system are numerically controlled machines, automatic storage and retrieval systems, and industrial robots.

The ultimate goal after obtaining the various islands should be to develop them into an integrated factory system. This is accomplished by linking several machines together. The extent of this linking can vary from the workstation level up to an entire facility. The larger the system, the more complex the tasks of linking the components. The objectives of the control systems include integrating the material handling information with shop floor control information, assigning and scheduling material handling resources, and providing real time control of material move, store, and retrieve actions.

Another view of automation is provided by Groover. His definition of automation is a "technology concerned with the application of mechanical, electronic, and computer based systems to operate and control production [10]." Devices included in this definition are automatic machine tools, automatic assembly machines, individual robots, automated material handling systems, automated inspection systems, and computer systems for planning and decision making to support manufacturing activities.

To visualize manufacturing, the Groover model shows manufacturing as a pipe containing the physical activities such as processing, material handling, assembly, and inspection. Into one end of the pipe flows raw material. Out the other end of the pipe flows the finished products (Figure six). This is the basic model of a manufacturing system.



PIPE MODEL OF MANUFACTURING

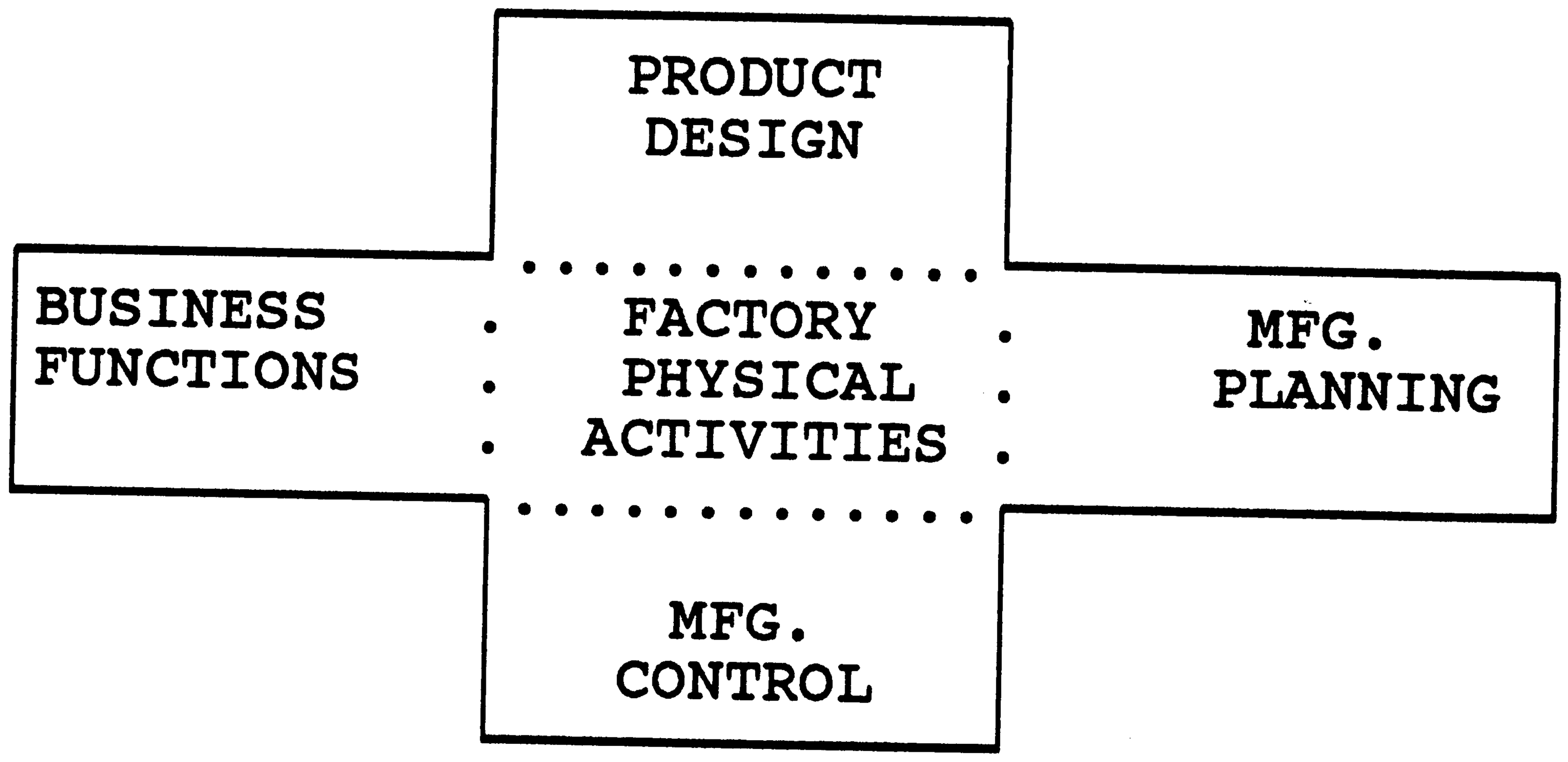
FIGURE SIX

A more advanced systems involves Computer Integrated Manufacturing (CIM) which has many different definitions from various business persons and scholars. The Groover definition refers to the "pervasive use of computers to design the products, plan the production, control the operations, and perform various business related tasks needed in a manufacturing firm [10]." As a comparison, automation is concerned with the physical activities in a manufacturing facility, while CIM is concerned with the information processing functions utilized to support production.

To incorporate the CIM definition into the pipe model, a ring of information processing activities envelopes the pipe. The four sectors of this ring are business functions, product design, manufacturing planning, and manufacturing control (Figure seven). The business functions include sales, marketing, order entry, and billing. Design includes product development, engineering drawings, and bills of materials. Planning involves the process plan, the master schedule, and capacity planning. Finally, manufacturing control includes shop floor control, quality control, and inventory control.

Popular nomenclature for modern manufacturing systems also includes Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). The union of these two concepts is commonly called CAD/CAM, implying that the two are related.

Groover defines CAD as "any design activity that involves the effective use of the computer to create, modify, or document an engineering drawing [10]." The term is generally used to describe an interactive computer graphics system. Referring to the outer ring of the pipe drawing, it is evident that the product design sector is where CAD would fit if implemented by an organization.

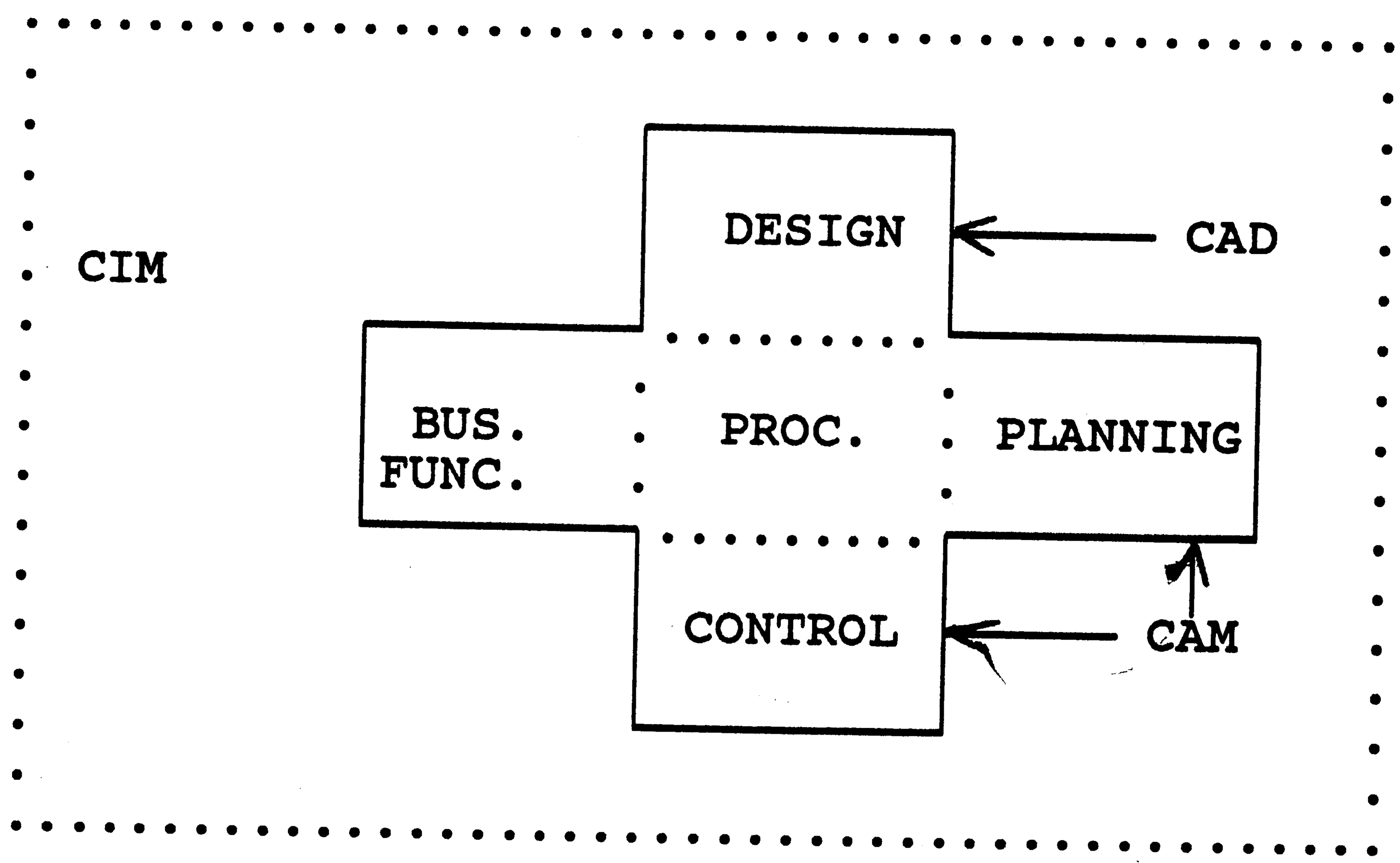


EXPANDED PIPE MODEL

FIGURE SEVEN

The definition of CAM on the other hand is "the effective use of computer technology in planning, management, and control of the manufacturing environment [10]." This fits the planning and control sectors of the pipe ring. The planning activities of CAM would include such activities as computer aided process planning, computer assisted NC part programming, and production and inventory planning. The CAM control sector applies to managing and controlling the physical operations in the facility via process control, quality control, shop floor control, and process monitoring.

The term CAD/CAM thus envelopes three of the four sectors of the ring. By including the business functions as well, one defines the scope of CIM. From the previous definition, it is apparent that CIM must include all of the sectors to be complete. However, implementing several CAD/CAM and computerized business functions independently does not connote CIM. All of these activities must be integrated into a complete system to manage the enterprise. This omnipresent view of CIM is represented in Figure eight.



CAD, CAM, AND CIM RELATIONSHIPS

FIGURE EIGHT

VIII. MATERIAL FLOW AND WORK-IN-PROCESS

As evident in the previous section, manufacturing is concerned with much more than the actual fabrication of the end products. A manufacturing entity must design the products, plan the production, monitor the process, control the inventory, finance the operations, and perform a myriad of other tasks. None of these functions operates independently. The CIM concept calls for a harmonious interaction of the various elements. An appropriate place to begin analyzing this interaction is the material flow cycle and the extensive data that follows it.

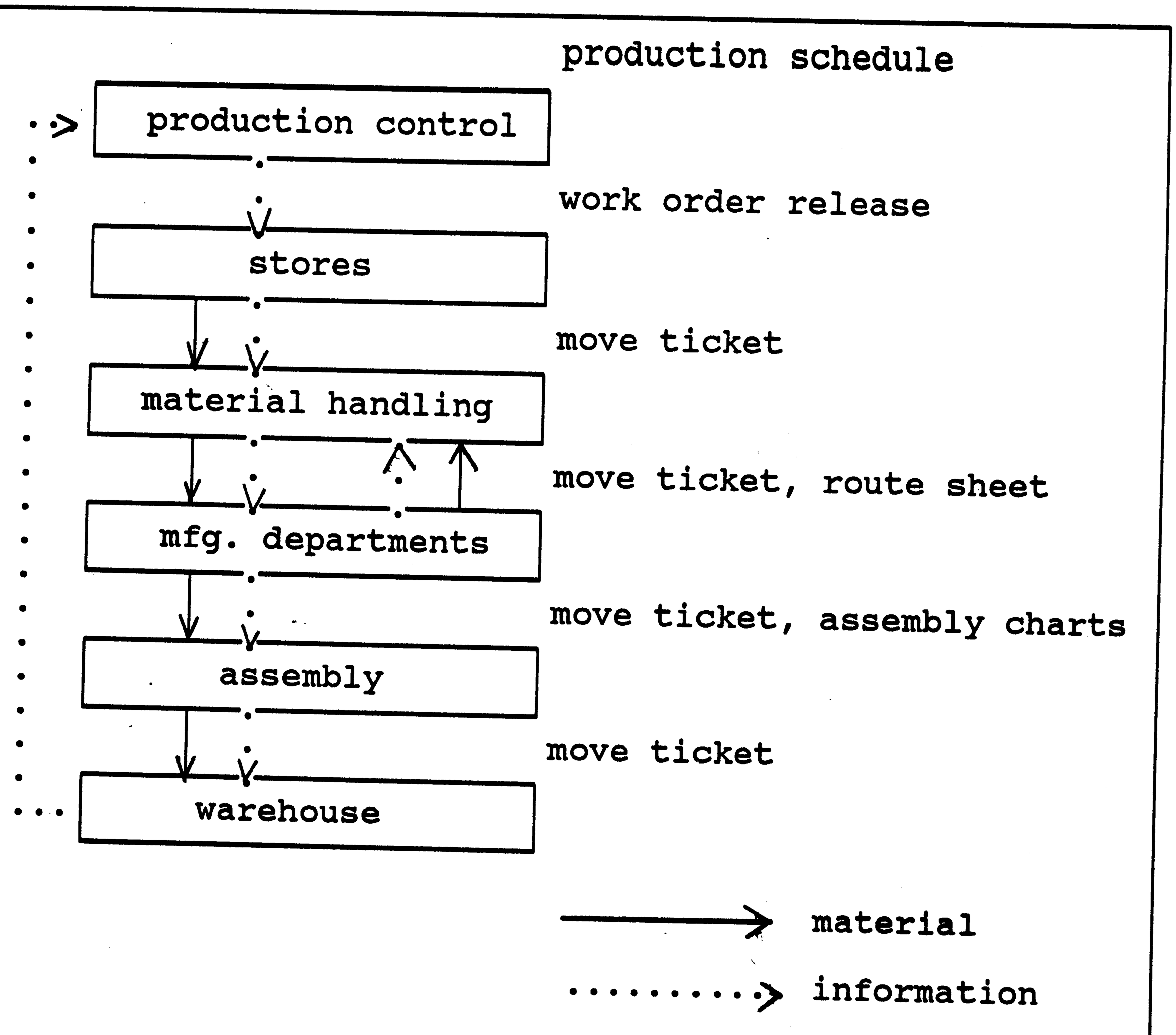
Any manufacturing facility requires extensive movement of raw materials, subassemblies, and finished goods. There are a multitude of potential moves within a facility, and a corresponding amount of paperwork to monitor those movements and material depletions. Raw material is stored in the warehouse until a move ticket and route sheets call for its removal. It is then moved by the material handling staff who deliver it to the various manufacturing departments. While some of this movement may be accomplished by automated material handling systems, there is still a need to initiate, control, and document the movements.

After various moves through the production departments, there could be further moves to such areas as inspection, assembly, and quarantine. Each move warrants another move ticket and perhaps other items such as assembly charts or inspection sheets. A final move ticket sends the finished product to the warehouse and distribution. Monitoring this procedure is some sort of production control mechanism which includes warehouse records, production schedules, and work order releases. Figure nine, adapted from Thompkins and White, illustrates this cycle by indicating both the physical material flow and the communication which accompanies it.

Following the intra-facility material/information flow lies the physical distribution system with it's own logistics and communications. A document trail indicates a sales order, a pick list, a shipping release, and one or more bills of lading. In addition, there is a shipping report, an invoice, and a payment. The material itself moves from the warehouse to material handling to transportation and generally to a distributer on its way to another transporter for delivery to the end user.

The overall material logistics system includes both the material flow system of Figure nine and the physical distribution system. Also included are the vendor, the customer and a material management system. Figure ten, also from Thompkins and White, illustrates the complete logistics system.

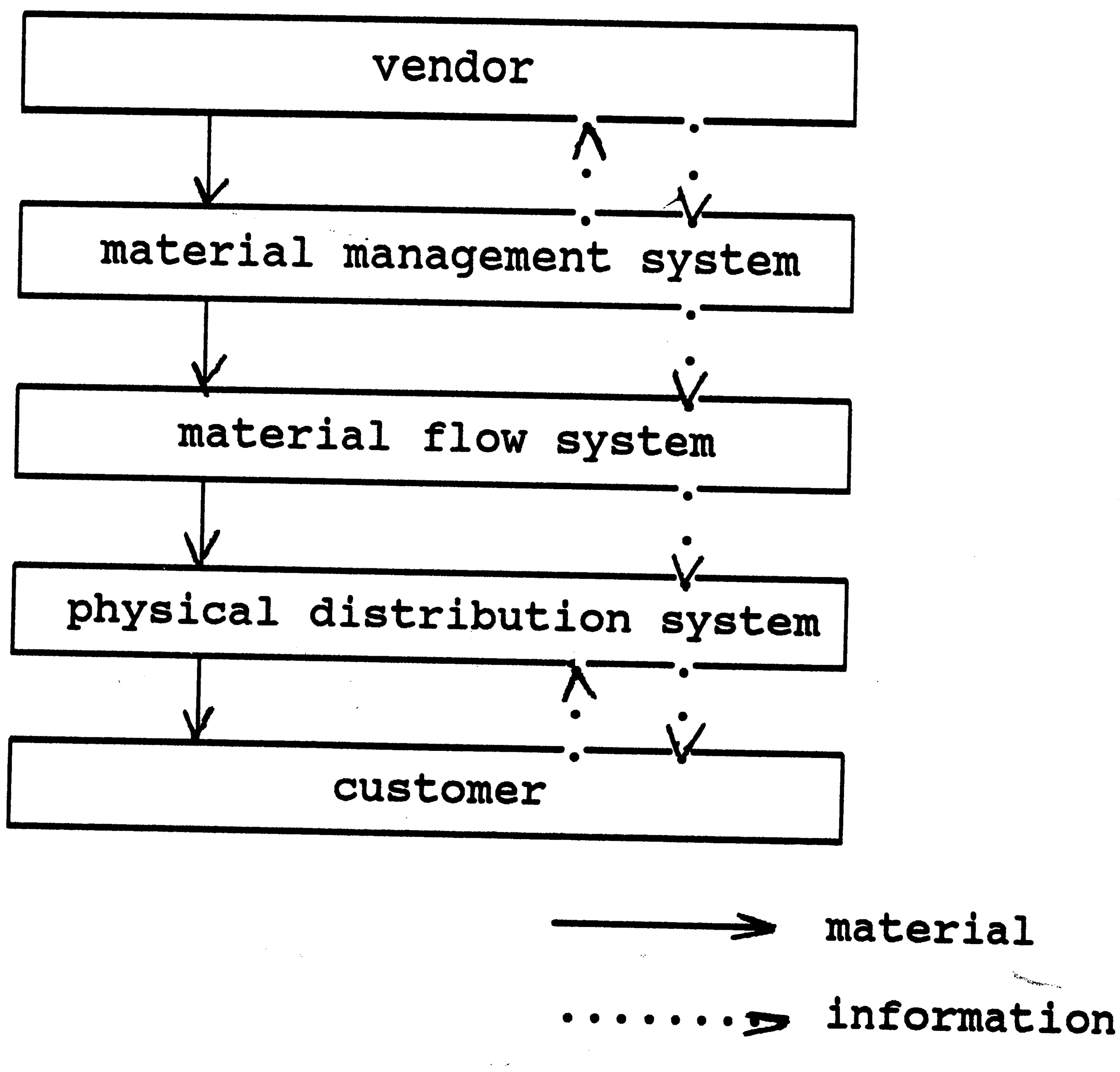
Within the material flow system, a large volume of material is located in the manufacturing departments either being processed or waiting to be processed. This is referred to as Work-in-Process (WIP) material. The time spent waiting in most facilities is generally longer than the actual process time. In fact, for a typical batch type metalworking facility, materials are moving or waiting 95%



MATERIAL FLOW WITHIN FACILITY

FIGURE NINE

of the time that they are on the shop floor. In addition, much of the 5% of the time it is on the machine is spent loading, gauging, and positioning the parts. Facilities of this type are not uncommon. One estimate reported that 40% of the total manufacturing employment is involved with batch metalworking [30]. Thus, the occurrence of large amounts of idle material is a common problem among manufacturers and needs to be addressed by those wishing to improve efficiencies.



OVERALL MATERIAL LOGISTICS SYSTEM

FIGURE TEN

Controlling and ultimately reducing the amount of WIP can reduce confusion, free additional space, and lower inventory carrying costs. To accomplish this one needs knowledge of workstation capabilities and availability, the amount of backlog for each operation, the exact location of components, and the priority of work orders.

Once this material status information is obtained, it can be utilized by other functions to manage the enterprise. Production control will be able to initiate release of material from storage. Inventory control will be able to initiate material replenishment. Financial control is possible through monitoring production costs and the transfer of WIP between departments. The degree of accuracy and timeliness of the material status information directly affects the operation of these other departments. Ideally, the desired information should be generated on demand in real time.

At each stage of material flow, there is the potential for inventory problems due to error of carelessness. Willoughby [31] has analyzed some of these potential problems in a flow model similar to that of Thompkins and White. The incentive for his analysis of material flow inefficiencies is his estimate that 30-70% of total product cost is directly related to material handling.

Much attention is paid to the receiving and material storage function. Inefficiencies and errors here have a "ripple effect" on subsequent steps in the material flow system. Congestion is a problem when material is backed up at the dock waiting to be validated for quantity and content. Hasty processing to alleviate this congestion could result in an increase in the number of errors. Because of these errors, there must be larger safety stocks and the associated carrying costs. Confusion is a problem if poor record keeping does not accurately reflect inventory levels. Also, time will be wasted if location information is incorrect.

When material is released to production, shop floor control is required. Typically, a work document accompanies each order as it travels to the various manufacturing areas. Naturally it must remain intact and legible throughout the process as this information will need to be extracted at some point. Also, as WIP is stored temporarily, the exact location and quantity will need to be known, adding to the information load.

Material eventually makes its way to final assembly and packaging. Information to confirm the move and quantity should be processed as well. A final label is attached to the part or container and it is diverted to the proper storage location. Again exact quantity and location must be recorded. Finally, when a shipment is made, a reconciliation is required between what is being shipped and the recorded receipts at the distribution center. From the preceding scenario, it should be evident that in addition to considerable material movement, there is considerable data to be entered, processed, and stored.

In most manufacturing facilities, the monitoring of the procedures mentioned above is a major effort. Indirect labor spends much time resolving shortages, finding missing parts, and managing engineering changes.

Balcezek [3] describes an electronics assembly plant in which bar code labels are placed on each assembly. The code can reveal where the part has been, where it should be, and where it should go next. A chronological history of the component is automatically recorded as it passes through each workstation. The control system in this facility embodies such CIM elements as shop floor control, factory data collection, WIP tracking, process flow control, networking of automation, interfacing with MRP and financial systems, and resource management and reporting. These elements are integrated into a single control system utilizing bar code data entry. The inherent inaccuracies in the paper trail behind the material flow are eliminated by a properly implemented data entry and data processing system.

IX. THE PATH TOWARD CIM

A. MATERIAL CONTROL

From the previous section it should be apparent that monitoring the flow of materials can be a cumbersome task. There can be considerable confusion in maintaining the data, resulting in error prone and outdated information. A large overhead of indirect labor is generally employed to track materials and sort out the errors. The use of computers to assist in these tasks is very common and becoming a necessity for all but the smallest manufacturers.

The most common computational method for assisting in material control is Materials Requirements Planning (MRP). Software for MRP converts a master schedule of end products into a detailed schedule for the raw materials and components which make up the end products. The exact quantity and delivery schedule of all materials is calculated. Consideration must be given to the ordering leadtimes of both purchased and fabricated items. Also of importance are the common use items, which are used in more than one end product. The technique for determining materials requirements is not complex in theory. What makes it difficult is the sheer magnitude of data.

There are three inputs to MRP computational software: the master production schedule, the bill of materials file, and the inventory records file. The master schedule is the listing of the quantity of each product to be produced and when it is to be produced. This schedule is based on customer orders and forecasts of demand. The bill of materials file contains product structure information by listing the components that make up each product. The inventory record file shows the current inventory level for all materials. The scheduled deliveries and planned order releases must also be accounted for to keep a running tab on materials needs.

From these three input files, the requirements of each material are calculated considering leadtimes and common use items. Output from the software includes such items as order release notices, reports of planned order release notices, rescheduling notices, cancellation notices, reports on inventory status, and inventory forecasts.

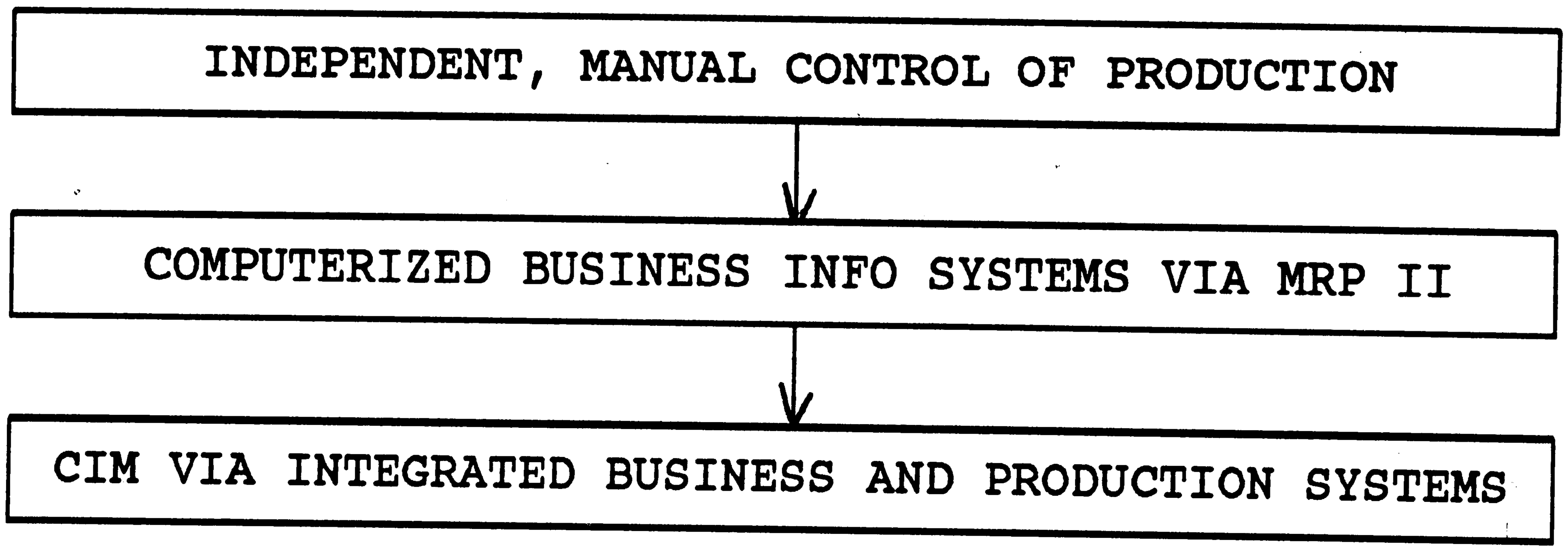
A similar but more involved computational technique is provided by Manufacturing Resource Planning, known as MRP II. This is a comprehensive management planning and control system. The software progresses from long range strategic planning to intermediate decision making to detailed scheduling of work centers and vendor deliveries. Typically, the output of production planning and control is converted to financial terms such as inventories in dollars, labor budget, shipping budget, and standard output in dollars. MRP II is a formal business planning process in which every function can share a common system with the same data.

Material and resource control are an important aspect of Computer Integrated Manufacturing (CIM). Hans (REF) has emphasized this aspect in justifying CIM strategies. Her approach to implementing CIM calls for starting with a strong business information system upon which to build an integrated manufacturing system. The strong business information system in her view is MRP II. It is a proven, mature tool with predictable cost benefits and a good return on investment.

Hans claims MRP II to be the ideal base upon which to build CIM due to its accurate information on current operations such as production costs and inventory levels. The first step toward CIM is to integrate accounting, order entry, inventory management, costing, and shop floor control into a centralized database of accurate, easily accessed information. This results in the ability to create realistic production plans to control the shop floor.

In essence, there is a much better understanding of what is working well in the factory and what isn't. With the business system in place, the next step is to integrate the automated systems. Links need to be constructed between computer aided design and manufacturing systems, automatic data collection devices, production control systems, and automated equipment. The progression from traditional manufacturing to CIM is illustrated in very basic form in

Figure eleven.



SIMPLE PROGRESSION TOWARD CIM

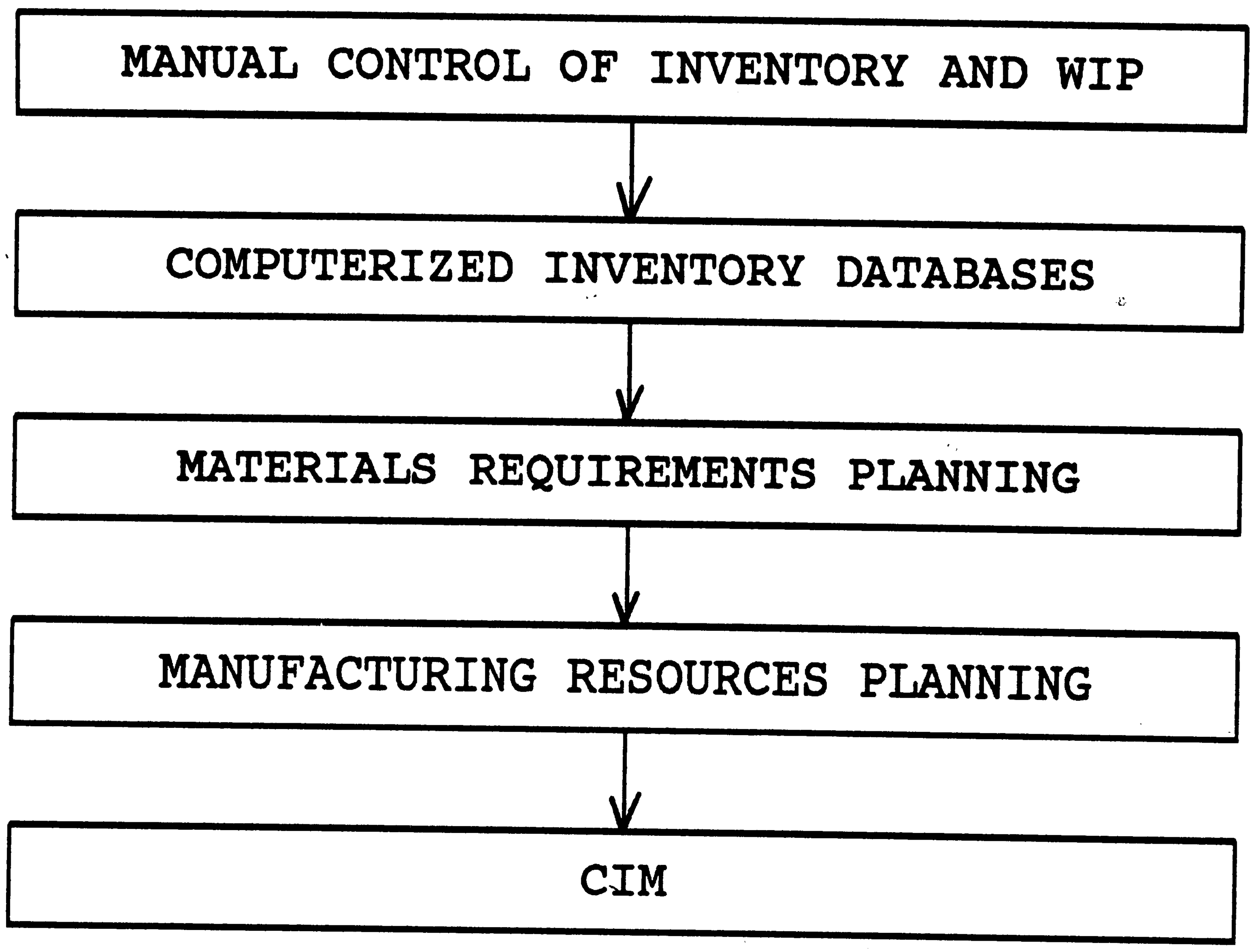
FIGURE ELEVEN

The connection between MRP and CIM can be explored further by reviewing the information processing activities in Groover's pipe model. Included in the design process is the development of bills of materials. The planning process includes the master schedule. The control function includes inventory control of which the inventory record file is a part. These three items, bills of materials, master schedules, and inventory records, are the three inputs to MRP software.

The significance of the MRP inputs to the pipe model are that each is from a different function. The breadth of the CAD/CAM activities are represented in the MRP structure. Furthermore, the separate functions use the common framework of MRP as a step towards integration of their activities. This can be carried one step further by upgrading from MRP to MRP II. Certain business functions would then be included within the scope of control mechanisms as a prelude to full integration of all systems.

Appreciable preparation is required to implement MRP. Included in this preparation is development of accurate bill of materials files and reasonable demand forecasts for developing master schedules. Perhaps more effort is required for organizing inventory files so that they reflect accurate and timely information. The previous section discussed the extensive path that material follows and the documentation required to track it. As mentioned, manual systems to track this flow are labor intensive and error prone. Converting these systems to a computer based system can result in more effective files which can be accessed more readily.

The path toward CIM described by Hans thus has more than a jump from MRP II to CIM. Many organizations start with manual control of production, inventory, and WIP. This must be compiled into computerized databases in order to implement Materials Requirements Planning. In turn, this is expanded into Manufacturing Resources Planning as a prelude to CIM. The path that this planning and control progression follows is represented in Figure twelve.



PLANNING AND CONTROL PROGRESSION

FIGURE TWELVE

B. INTEGRATING THE PROCESSES

The path toward CIM emphasizes the information processing activities to control production systems. This includes inventory control, WIP control, scheduling, materials planning, and other support activities. In addition to these functions, there must be consideration given to the physical fabrication of the products as well. This is the central activity in the pipe model and the center of activity in the real world as well.

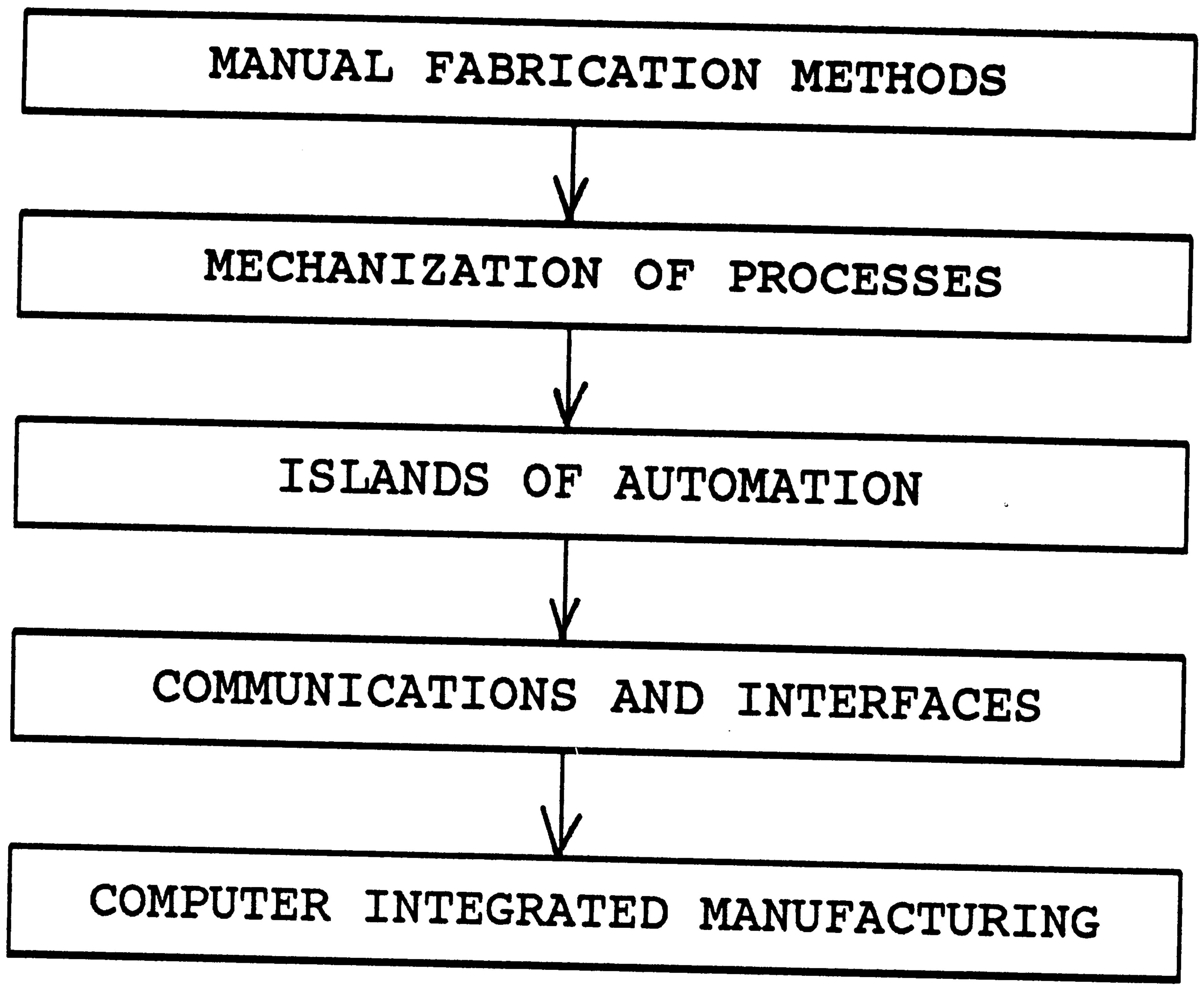
Although there have been great advances in automation, there are still areas where manual processes are used. These include small facilities which cannot afford to automate, certain processes at larger facilities which do not meet payback criteria, and highly skilled activities requiring craftsmanship or artistry. It is safe to say that there will always be manual methods, yet these must be constantly reviewed to determine the feasibility and value of automation.

The majority of the factories in the industrialized world have a great deal of mechanization and automation. Some of the equipment is very simple such as a conveyor belt for moving material. Other systems could be quite complex, such as vision and robotic systems for sorting and aligning components. There is a progression in production lines from manual methods to these varying levels of automation and complexity. The devices in this progression could include the following.

automated assembly machines
automated machine tools
automated material handling systems
automatic identification
automatic inspection machines
automatic guided vehicles (AGV)
automatic storage and retrieval systems (AS/RS)
expert systems
flexible manufacturing systems (FMS)
group technology (GT) cells
industrial robots
numerically controlled (NC) machines
sensors and adaptive control devices

As a manufacturing facility grows, it will add processes and equipment, and in turn automate many of them. At some point, there may be only one or two automated processes. In the long run, all of the processes could be automated. As a result, there could be the islands of automation which were discussed earlier. These are the individual pieces of equipment which are automated, but operate independently of one another.

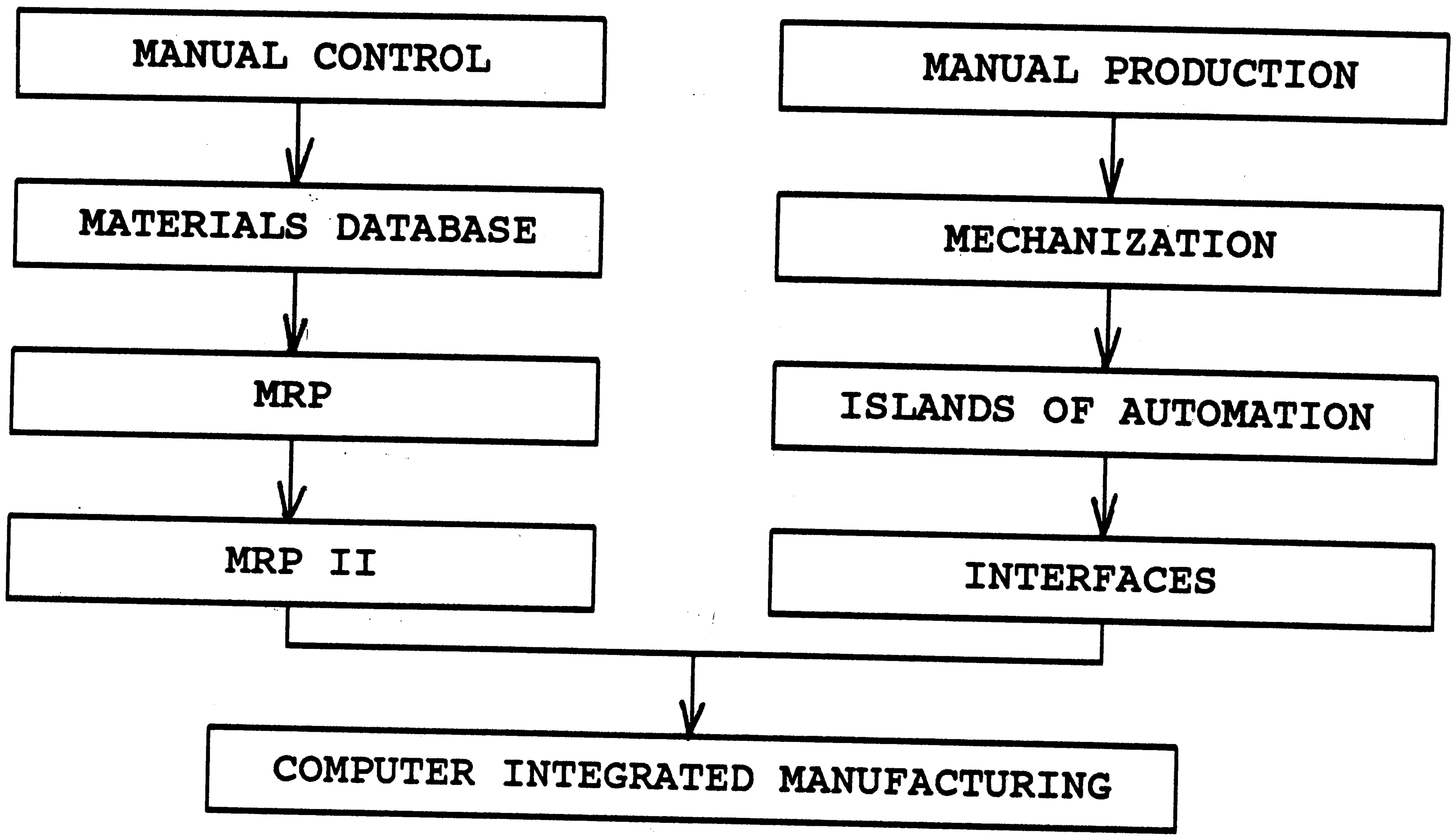
The next step toward CIM would involve implementing a communications network to serve as an interface between various pieces of equipment. For example, a palletizing robot could indicate to an automatic guided vehicle that a pallet is to be removed. There is a subtle upgrade in converting from interfaced machines to integrated machines. Integration involves a seamless, unified approach to communications with a higher degree of interaction. This is the final stage of CIM. The path from manual systems to mechanized systems to islands of automation to CIM via integrated communications is summarized in Figure thirteen.



PRODUCTION SYSTEMS CIM PROGRESSION

FIGURE THIRTEEN

The equipment progression of Figure thirteen can be combined with the planning and control progression of Figure twelve. In fact, if they are not combined, the goal of computer integrated manufacturing cannot be achieved. Both paths must be pursued and integrated. This combined progression is illustrated in Figure fourteen.



COMBINED CIM PROGRESSION

FIGURE FOURTEEN

X. THE ROLE OF BAR CODE

Achieving the final goal of Computer Integrated Manufacturing is not a simple task. It is a complex undertaking and requires expertise in many areas. There are many tools to help in the process and bar code is one such tool which has advantages in certain applications.

If the benefits of bar code can be summed up in two words they would be speed and accuracy. Bar code data entry is nearly instantaneous. In a properly designed system, the data will be available in real time. As soon as a transaction is complete, that information is entered and is immediately available for those requiring the information. It is, in all likelihood, correct information as well. Error rates in systems using high print quality tend to be one error in several million symbols scanned.

Bar code identification can provide exact information at the right time. Inventory control is one important area where timely, accurate information is vital. Bar code symbols can be attached to the parts themselves or to a work order or to a container. As material passes from one location to another, a scanning sequence identifies the exact material and location.

Bar code thus enters the planning and control progression of CIM at the early stage of computerized inventory databases. It is bar code that provides the integrity and confidence in the databases so that they can be properly used for materials planning. Without an accurate database, inventory levels must be estimated and large safety stocks must be maintained. Shortages and gluts can easily occur. Bar code controlled inventory systems on the other hand, have been shown to control inventory at accuracies above 99%. Precise, real time usage of materials can then be monitored to support planning.

In many cases organizations have implemented MRP without the support of bar code. This is certainly an acceptable situation as there have been many successes. Bar code should still be considered here for the same speed and accuracy advantages mentioned above. An MRP system can be improved by the quality of the data which it uses. The implementation of CIM then becomes more effective due to the more reliable data.

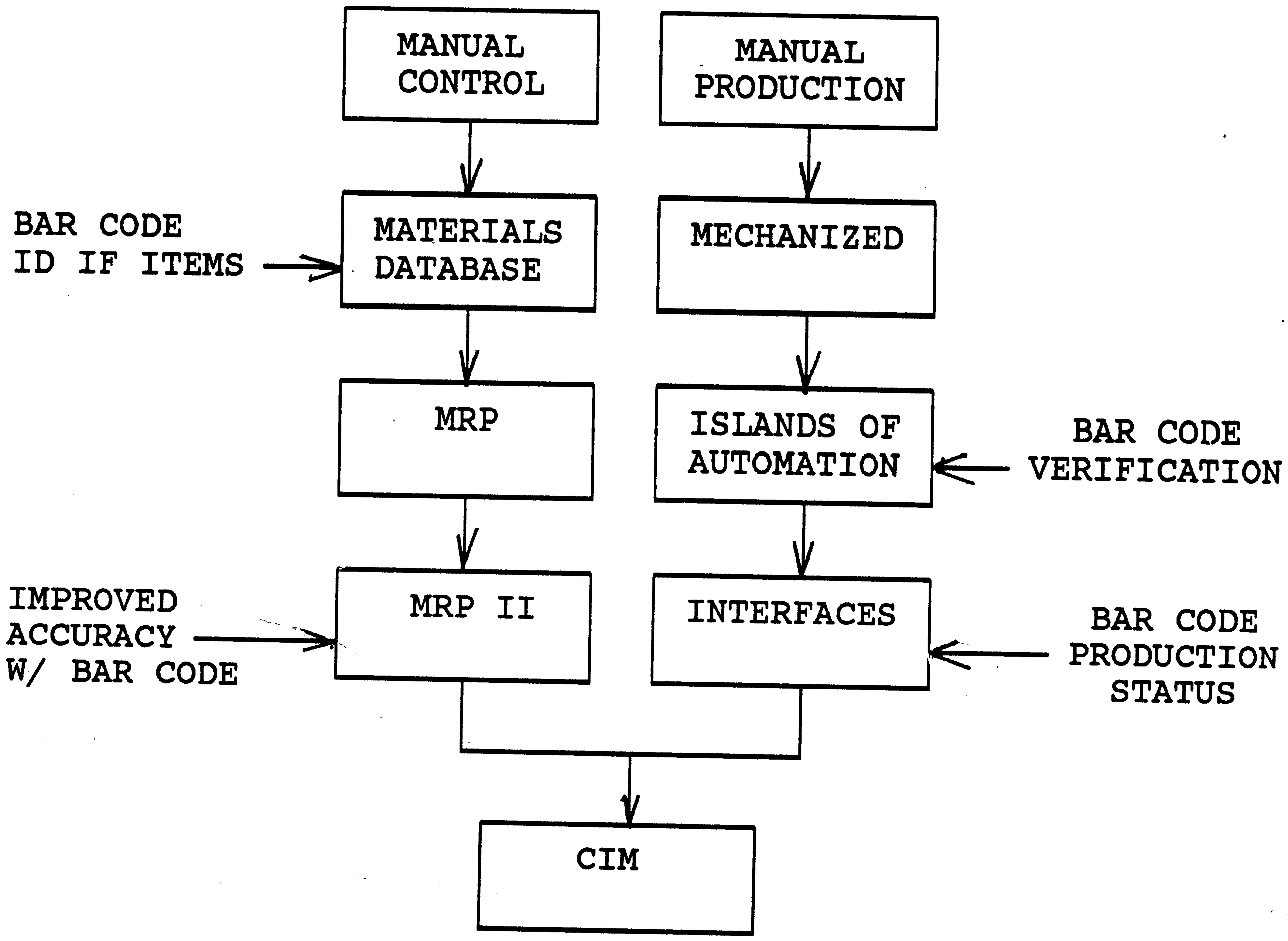
Bar code data entry also has its place on the processing side particularly in the area of interfaces between equipment. Bar code input can be used to monitor production status. Scanning sequences can indicate commencement and completion of tasks as well as interruptions due to malfunctions or changeovers. This can be useful for product traceability, or the ability to associate a finished product with a particular machine, operator, or time.

Another application on the equipment side would be automatic tool verification. As a tool is automatically delivered to a robot for example, a scanner can read the bar code label on the tool to verify that it is the correct tool for the task ahead. A similar process is utilized in verifying that the correct labels has been applied to a package. The verification applications can be applied to various islands of automation such as an AS/RS which uses a bar code scanner to confirm storage location.

The production status applications and the verification applications are both useful tools on the road to CIM. Their places in the progression are shown in Figure fifteen which is an extension of Figure fourteen. Also shown is the inventory and WIP applications either as an initial project or to improve the accuracy of an MRP system.

There have been some recent activities in the bar code industry to demonstrate that bar code is an excellent tool to support MRP. Intermec Corporation is one of the largest suppliers of bar code equipment. A January 1988 Manufacturing Engineering article reported an Intermec marketing agreement with Data 3 Systems, Inc. [20]. The objective is to improve the database integrity of Data 3's MRPS, which is an MRP II system run on the IBM Systems 38 and 36.

The companies claim that the formal methods of material, production, capacity, and business planning within MRP have had a difficult transition from manual methods due to problems with database integrity. In this system, the relational database uses bar code data collection equipment in a real time system. It is claimed to be the first product offering a standardized, economical, and seamless way to integrate bar code into a manufacturing database.



THE ROLE OF BAR CODE

FIGURE FIFTEEN

A similar announcement was made in April 1988 concerning Intermec and MSI Advanced Manufacturing Incorporated [16]. As part of a cooperative marketing agreement, Intermec will supply "Shopscan", its PC-based automatic shop floor data collection system. It will be used with MSA's Advanced Manufacturing Applications (AMAPS), an MRP II software system. Real time data input to AMAPS will be used for applications in WIP, labor distribution, issues and receipts, and dock to stock tracking.

Those are just two examples of bar code data entry used in conjunction with MRP II. These joint ventures are a reminder of the trend towards systems integraters as opposed to concentrating one product type. This is especially true when integrating a CIM system rather than just an inventory control or MRP system.

Even before those two joint venture announcements, there were successful marriages of MRP II and automatic identification. Magnetic stripe ID cards as opposed to bar codes are in use at TRW's Valve Division [15]. Sixty IBM 3640 terminals have been installed on the shop floor to automatically update records of the inventories and processes in the facility. The system serves 1500 hourly and 500 salaried employees at four manufacturing facilities.

The communication system tracks time and attendance, records shop floor data, monitors tool crib activity, and tracks WIP inventory. Strict control of labor hours and inventory levels is maintained. The MRP II project leader views the ID cards as an extremely important link in the MRP II system.

XI. LOOKING AHEAD

American competitiveness in manufacturing has come under fire in recent years. Critics have pointed to high quality, low cost products from foreign competition, particularly from the Pacific Rim. It is also an issue in the 1988 Presidential campaign. Returning the competitive edge to American manufacturers has definitely become a popular topic among politicians, educators, and those in business and industry.

The nature of manufacturing is changing in light of this threat. There is an increasing emphasis on product quality and reliability. Products are having shorter life cycles as innovations and new product introductions are becoming a strategic initiative. Many of these new products are customized such that a lot size of one is becoming less of a rarity. Manufacturers must be flexible enough to meet these ever changing customer needs. Meanwhile reduced inventories are demanded as Just-in-Time (JIT) principles grow in popularity.

One response to the changing environment has been attempting to implement Computer Integrated Manufacturing. This means different things to different people and perhaps it needs to be adapted to each situation where it is intended to be used. It would certainly include aspects of quality, innovation, and flexibility as well as the control and information needed to obtain these characteristics. It may be that implementing CIM is like shooting a moving target. As the manufacturing environment changes, manufacturers must have current information to be responsive.

Bar code technology is an important tool for keeping track of current manufacturing status, problems, and trends. Information is the key to adaptable manufacturing and achieving the goals of JIT and CIM. Bar code is the source for this information. The extreme accuracy assures that it is the correct information. Real time electronic transmission assures that it is up to date information. With a reliable information base, better decisions can be made in the pursuit of manufacturing strategies.

The impressive growth rate of bar coding has been presented. Along with that is the increasing acceptance of the technology among user groups. The high visibility in groceries and retail has aided in increasing the confidence level in other areas. Managers are hearing of success stories and considering their own projects. Users are accustomed to the technology and are willing to exploit it. While another technology may eventually surpass bar code as an data entry tool, bar code will certainly remain a leading tool for modern manufacturing systems.

CONCLUSION

Accurate information on materials, parts, and processes is essential for all manufacturers, particularly those manufacturers attempting to implement CIM. In order to achieve a fully integrated manufacturing system, one must have accurate, current information on the status of all aspects of the system. This includes planning and control aspects of manufacturing and can be achieved by implementation of bar code data entry with MRP and MRP II. MRP II databases have become accurate, reliable and timely due to the use of bar code data entry.

The automated equipment aspect of CIM needs bar code as well for such tasks as facilitating a communications interface between islands of automation. Furthermore, production status can be monitored, product traceability can be developed, and process verification can be undertaken. The speed and accuracy of bar code make it an essential component of the information based manufacturing environment of today.

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[32] "The Winning Edge- Managing for Success with Bar Code" seminar notes from Intermec Corporation, 1986

VITA

Mark Robert Stockwell was born 11 March 1961 in Worcester, MA to Walton and Shirley Stockwell. He attended Wachusett Regional High School in Holden, MA, graduating in 1979. His bachelor of Science degree is in Mechanical Engineering from Worcester Polytechnic Institute. In 1984, he graduated with distinction. Project work in his major field involved axisymmetric stress analysis using the Finite Element Method. Additional project work involved developing a tutorial to teach children to program the Apple computer.

Following graduation, Mark worked as a packaging engineer for Astra Pharmaceuticals Products, Inc. in Westborough, MA. Primary responsibility was in specifying materials and components for pharmaceutical packaging. The position also provided his first exposure to bar coding as the company began implementation of the Health Industry Bar Code. Mark was in charge of developing the implementation plan and selecting printing and quality control equipment. He left that position in January 1987 to pursue his Master of Science in Manufacturing Systems Engineering at Lehigh University, Bethlehem, MA.