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Advanced Manufacturing Processes in the Motor Vehicle Industry

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Final Report

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16. Abstract

Advanced manufacturing processes, which include a range of automation and management techniques, are aiding U.S. motor vehicle manufacturers to reduce vehicle costs. This report discusses these techniques in general and their specific applications in the motor vehicle industry. Examples of advanced manufacturing processes discussed here are robots, CAD/CAM, flexible manufacturing, group technology, just-in-time production, and statistical quality control. Examples are given of application of these techniques by the motor vehicle manufacturers, both in general and in specific types of plants.

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PREFACE

This report is the final product of a task to provide to the National Highway Traffic Safety Administration (NHTSA) an assessment of current and likely future penetration of advanced manufacturing processes in the motor vehicle industry, and their potential for cost reduction.

The author wishes to acknowledge Joseph Petrie and George Byron of TSC for aid in setting up the conceptual design for this study. The author also appreciates the support of Raytheon Service Corporation's Media Reference staff for providing essential information on advanced manufacturing processes in the motor vehicle industry, and especially Garry Prowe of Raytheon for special effort in developing Table 5-3.

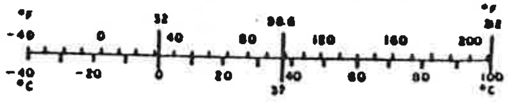
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. SUMMARY

Automation and management techniques are making an impact on the U.S. motor vehicle industry. The manufacturing costs of vehicles and many of their components are being reduced and will continue to be reduced within the next decade.

Robots are penetrating the automobile industry at a great rate. General Motors expects to use 14,000 robots by 1990. Total robot use within the North American automobile industry is expected to be 20,000 to 35,000 by 1990. The rate of introduction of robots in Japan shows no sign of slackening, with over 30,000 robots expected by 1985 in the Japanese automobile industry. At present, over four times as many robots are used in Japan as in North America to produce the same number of cars.

CAD/CAM is being incorporated rapidly by U.S. manufacturers, including the motor vehicle industry. General Motors has an advanced computer graphics system for use by Fisher Body and other company designers. Chrysler expects total computer-aided design of the passenger car by 1985, and its CAD system has already reduced engineering manpower requirements for new vehicles. Chrysler is also well on its way to integrating design and manufacturing operations in a single CAD/CAM data base. Chrysler, Ford and General Motors are all starting to link their data bases with those of vendors to allow more integrated design work.

Just-in-time production, practiced generally in the Japanese motor vehicle industry, is being introduced into the United States to some extent by nearly all manufacturers. The manufacturers thereby expect to reduce their inventory costs. General Motors has a goal of linking all its midwest plants into a just-in-time system; Ford and Chrysler are using it in some plants; and American Motors is planning it with many suppliers for the 1983 Renault Alliance product. Honda and Nissan are selecting suppliers for their new U.S. products with the requirement that they participate in a just-in-time system.

Each of the Big Three domestic manufacturers claims improved quality of product, with Ford claiming an almost 50 percent reduction in consumer complaints about defects since implementing its quality control program. Ford and GM's Pontiac division have taken the lead in statistical quality control. Ford's Employe Involvement Program, and GM's Quality of Work Life Program are claimed by the respective companies to have a positive influence on quality and productivity.

2. INTRODUCTION

For the purposes of this report, advanced manufacturing processes will be defined as automation or management techniques promising reduced manufacturing unit cost, that have been applied successfully to manufacturing, but are not used broadly or generally within the United States automobile industry. Therefore all of the approaches described here could in theory be used to reduce the manufacturing costs of U.S.-produced motor vehicles.

The general discussion of advanced manufacturing processes is divided into two parts: equipment, and systems that integrate different pieces of equipment. For example, computer-aided design and robots are equipment, while CAD/CAM is a system incorporating many types of equipment as well as integrating functional areas such as design and manufacturing engineering. Section 3 discusses equipment, and Section 4 discusses systems. Section 4 makes the important distinction between automation systems and management systems.

Section 5 presents a summary of advanced manufacturing processes that have been recently adopted by specific companies, divisions, and plants. The summary is organized by plant type, i.e., assembly, stamping, engine, etc.

An Appendix gives the definitions of terms commonly used in industrial automation, including all the concepts discussed in the report.

3. EQUIPMENT FOR ADVANCED MANUFACTURING PROCESSES

Advanced manufacturing processes are employing many types of new equipment. This section briefly discusses equipment that is being widely employed throughout industries similar to the motor vehicle industry, and that is an important ingredient for major potential increases in productivity. Developments in the following equipment areas are discussed in this section:

- Computer-aided design equipment and software
- NC and CNC machine tools
- Industrial robots
- Programmable controllers
- Optical inspection equipment.

Section 4 will discuss how this equipment is being used in factory automation systems.

3.1 COMPUTER-AIDED DESIGN EQUIPMENT AND SOFTWARE

Computer aided design (CAD) has several purposes. One is to speed up the design process, another is to improve accuracy. CAD relates to design as a word processor relates to report writing. Changes in a design are quickly implemented, producing a new design which is the starting point for further work. If a three dimensional part is being designed, two-dimensional views can be generated for any desired angle, eliminating the manual drafting step.

The information from the design can be used directly for computer-aided engineering (CAE). In this step, theoretical calculations are made of part weight and strength, and stresses can be simulated for specified uses of the part (e.g., a vehicle axle). Results of these simulations can be used to modify the design.

CAD is most fundamentally used as the front end to computer-aided manufacturing (CAM). In this process, normally called

CAD/CAM (to be described in more detail later), a single data base serves to support all product design, engineering, production planning, layout, tool design, and tool programming applicable to the part that is to be manufactured.

A CAD system consists of hardware and associated software. The hardware is a central computer and a set of time-shared terminals at which designers can visualize a piece being designed and alter it using interactive commands. Terminals may also be used for the engineering simulated tests that need to be performed. The software includes a universal and flexible data base that can represent the objects being designed in the detail necessary for design, engineering, and all functions further downstream toward manufacturing. In addition, interactive programs control the graphical display of the object being designed and, ideally, allow easy and rapidly executed user commands.

Until quite recently, most graphical displays and object representations within the data base were of the form called <u>wireframe</u>. The designer would draw lines and the computer would store information on edges and vertices of the object. For electronic printed circuit boards, this two-dimensional (2-D) wireframe representation is adequate. However, three-dimensional (3-D) wireframe representations of solid objects are ambiguous and cannot automatically be used to support machine tool programs. Hence, a field called <u>solid modeling</u> has developed, which has been defined as follows: "...solid modeling encompasses an emerging body of theory, techniques, and systems focused on informationally complete representations of solids--representations that permit, at least in principle, any well-defined geometrical property of any represented object to be calculated automatically."[1]*

Two approaches have been used in practice for solid modeling; <u>boundary representation</u> (B-rep) and <u>constructive solid geometry</u> (CSG). In boundary representation, the data base contains complete

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*Superscripts refer to references cited in the Reference Section.

information about the object's boundary; in constructive solid geometry, it represents an object as logical combinations of simple solids. Each method has advantages and disadvantages which are discussed in Reference 1. Briefly, while CSG is more concise than boundary representation and is guaranteed to represent a real physical solid, wireframe and surface drawings can be generated more rapidly and easily from the boundary representation. In both cases the user can input information in a variety of ways: as edges, surfaces, or solids.

Applications of computer-aided design are widespread throughout the manufacturing industry. The earliest major applications occurred in the mid-1960s in the design of aircraft, missiles, and naval vessels, primarily by McDonnell-Douglas and Lockheed-Georgia.[2] Over the past ten years, there has been a steady and systematic advance in the use of CAD in all aspects of aircraft design.

Computer-aided design, in principle could be applied to most manufactured parts in an automobile. At the present time in the North American automobile industry, one-third of automotive engineering is performed on CAD systems, and within five years it is anticipated that nearly all final designs will be produced by a CAD data base.[3] In Western Europe, use of CAD varies from one firm to another but on the average CAD use is less than in North America. In Japan, auto manufacturers are just starting to implement CAD and at present use of CAD is less than in Western Europe or North America.[4]

In 1981, the turnkey computer hardware market for CAD in the United States totaled $325 million, of which 25% to 30% was purchased by automotive customers.[5]

Information on selected solid modeling systems is presented in Table 3-1. The first five have CSG as a primary representation scheme; Shapes and Tips use logical combinations of general half-spaces to define solids, while GDP, PADL and SynthaVision

TABLE 3-1. SELECTED GEOMETRIC MODELING SYSTEMS

SYSTEM	COUNTRY	ORGANIZATION	PRIMARY REPRESENTATION SCHEME		STATUS
Shapes	USA	Draper Lab	CSG*	General Halfspaces	Research prototype for internal use
Tips	Japan	Hokkadio Univ.			Available from CAM-I, Inc.
GDP/GRIN	USA	IBM		Bounded Primitives	Research prototype for internal use
PADL-1,-2	USA	Univ. of Rochester			Available from Univ. of Rochester
SynthaVision	USA	Mathematical Applications Group, Inc. (MAGI)			Available from MAGI, Control Data, Applicon
GMSolid	USA	General Motors	Hybrid	CSG & B-Rep**	General Motors internal use
Anvil-4000	USA	Manufacturing and Consulting Services, Inc. (MCS)	Boundary Representation		Available from MCS, Honeywell
Build-2	UK	Cambridge Univ.			Research prototype
Design	USA	Manufacturing Data Systems, Inc. (MDSI)			In development
Euclid	France	Matra/Datavision			Available in Europe from Matra/Datavision
Geomod	USA	Structural Dynamics Research Corp. (SDRC)			In development
Glide	USA	Carnegie-Mellon Univ.			In development
ITS-10	Switzerland	CAD-Systems AG			Available from MARC Software International
Medusa	UK	CIS Ltd.			Available in USA from Prime Computer
Romulus	UK	Shape Data Ltd.			Available in USA from Evans & Sutherland
Solidesign	USA	Computervision			Available from Computervision
Unigraphics	USA	McDonnell-Douglas Automation Co. (McAuto)			Available from McAuto

*Constructive solid geometry.

**Boundary representation.

SOURCE: References 1 and 6.

build them from bounded primitive shapes. GMSolid is a versatile system, with both CSG and boundary representation. This allows the user to take advantage of whichever representation best fits the problem. This system is in use at General Motors after many years of development at GM's Research Laboratories.

The majority of solid modeling systems are oriented to boundary representation. Of these, particular mention should be made of Build, one of the earliest solid modeling research projects (it has been under development since the late 1960s at Cambridge University), which served as a prototype for Design and Romulus; and McAuto's Unigraphics, an outgrowth of its CADD project which has been developing since the mid-1960s and was the first turnkey CAD system available.

3.2 NC AND CNC MACHINE TOOLS

U.S. machine tool sales in 1980 totaled $4.7 billion.[7] A portion of this market was numerically controlled (NC) machine tools, defined as tools under automatic control of a device that makes use of numeric data introduced as its operation is in progress.

Numerically controlled machine tools were first developed through Air Force-sponsored research for use in the aerospace industry.[8] The first commercial NC machine was built in 1955.[9] Despite 25 years of use, today less than 4 percent of all machine tools in U.S. industry are numerically controlled, and NC accounts for only 10-12 percent of new machine tool producton.[9] The reason for this slow penetration is economic; although in theory an NC machine could be in use 95% of the time, in practice even 50% is impossible to achieve as long as loading/unloading, die changing and program changing has to be manual.[9] Today, robot loaders, automatic tool changers, automated parts handling and higher level computer controllers have changed this economic picture.

In the motor vehicle industry, however, NC tooling is so widespread that it should not be called an "advanced manufacturing process." Addressed here, under that concept, are certain extensions of NC which are still entering the motor vehicle industry in the U.S. and abroad.

Traditionally, the hardware to control an NC tool was a "hard-wired" box with switches and relays, which would be activated by a punched paper tape strip containing the programmed sequence of movements for the tool. The paper tape would be generated by a central computer where an NC programming specialist would work out the tool movements for the part as one element of the overall manufacturing process. This is called the NC "part program." With the advent of low-cost mini-computers and quite recently micro-computers, it has become economically feasible to replace the "hard wired" box with a dedicated digital computer associated with the machine tool. This concept is called computerized numerical control (CNC) and has initiated a machining revolution which still has a long way to go to realize its full potential. The following paragraphs summarize aspects of this concept.

The CNC computer not only has the capability to execute the NC part program; it can store it in memory, and the program can be rapidly altered. This makes it possible to test and debug the program more rapidly and adjust tool movements on the factory floor during a shakedown period. It is also possible to design a program as a set of subroutines to be executed without tape drive cycle time. Fewer mechanical parts in the execution of commands results in improved reliability and capability for increased complexity of commands, while maintaining a compact control unit. This latter characteristic has led to the "machining center" (Figure 3-1), a large size machine tool unit with many different heads that can be changed automatically. Hence a sequence of machining operations that formerly required a number of different machines can now be done on one machine.

Another feature now being incorporated in the machining center is rapid tool changing; the unit illustrated in Figure 3-1 is

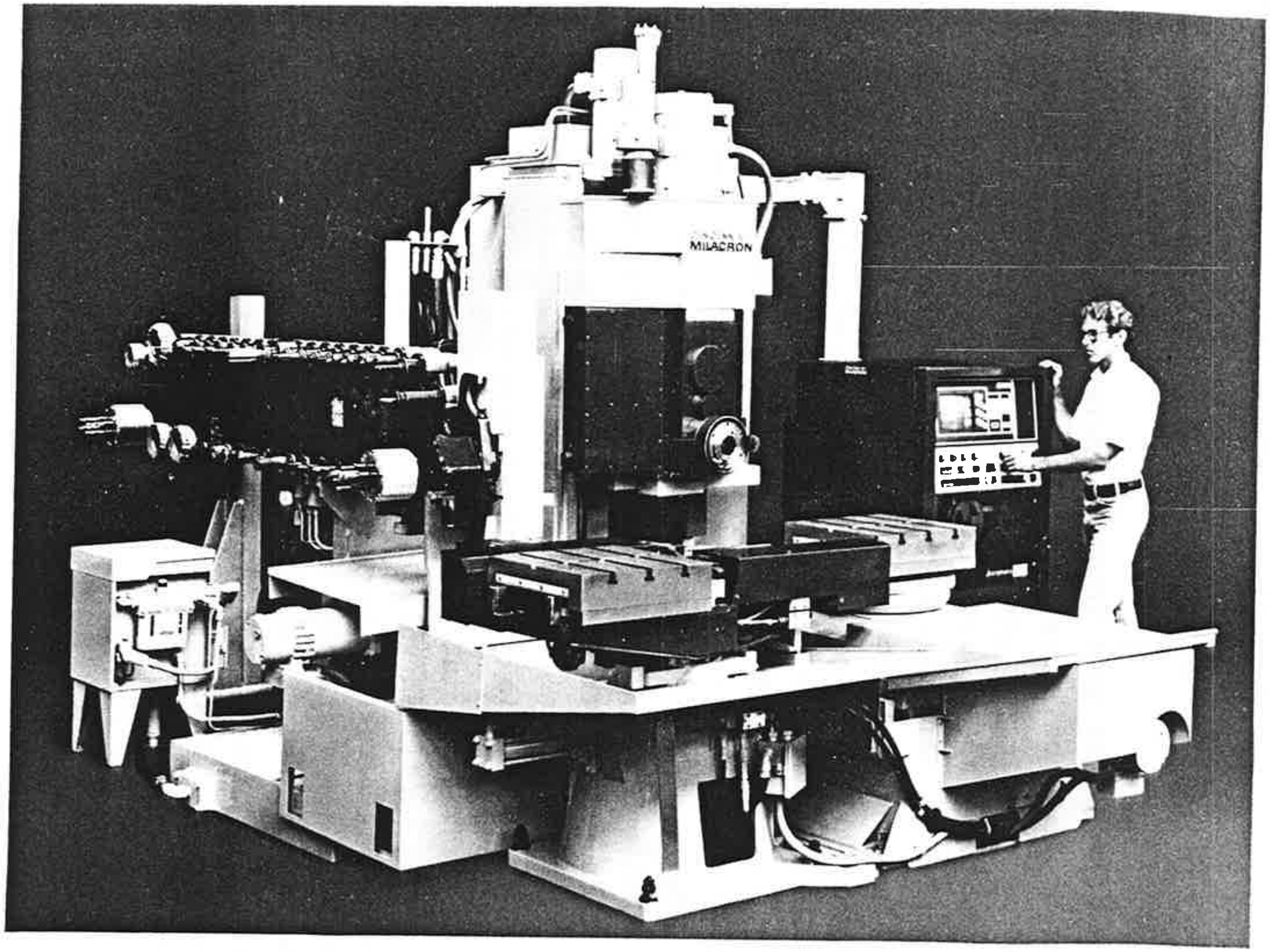


FIGURE 3-1. CINCINNATI MILACRON T-10 MACHINING CENTER

SOURCE: Cincinnati Milacron Co. Product Information.

advertised to change tools in 11 seconds. Some machining centers are now being designed to operate in an unmanned mode, with human intervention only for maintenance and repair, and to load parts on pallets if that task is not done by robot or prior to delivery. Examples of such unmanned systems are the Cincinnati-Milacron Variable Mission installation and the Kearney and Trecker Milwaukee-Matic.[10]

A development that promises increased cutting time relative to set-up time and is necessary for long periods of unmanned operation is adaptive control (AC). Under AC, cutting, boring or grinding tools are adjusted for tool wear so as to reamin within specification. Japanese machine tool builders have offered unmanned machine tools incorporating AC for six years;[11] the United States has trailed Japan in implementing AC. Two principal reasons for this are the much stronger Japanese push for unmanned shifts due to their labor shortage, and the extensive set-up costs required including costs of reliable sensors for measuring cutting rate. One example of recent availability of AC from a U.S. machine tool supplier is the Kearney and Trecker unmanned center mentioned above. In this center, the CNC computer monitors spindle speed and torque every 4 milliseconds, and then adjusts feed rates according to predetermined, optimal parameters stored in memory.[11]

As significant in the long run to machining productivity as the aspects mentioned above is the potential for integrating CNC machines into larger factory systems. Instead of the machines or machining centers standing alone, they can be controlled from a central computer with coordinated programs executed in real time instead of according to predetermined tapes or locally determined programs. This concept, called direct numerical control (DNC) will be discussed in the next section along with the related system concept of flexible manufacturing.

CNC can be applied in principle to all machining operations, and therefore to the manufacture of most automobile parts. Specific motor vehicle applications are discussed in Section 5.

3.3 INDUSTRIAL ROBOTS

The industrial robot has probably been the most visible element in the automation revolution that is going on in the manufacturing industry in the U.S. and around the world. This subsection provides a very brief overview of robotics. For more complete discussion, see Reference.[12]

An industrial robot is defined by the Robot Institute of America (RIA) as "...a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks." Although the control system of a robot may be similar to that of an NC machine tool, the robot must be a general purpose device. The first industrial robot was put into service in 1961 in a General Motors plant in Trenton, N.J. Until recently, the use of robots was light and the state-of-the-art did not advance rapidly. In the 1970s, however, the rate of innovation and quality improvement of robots accelerated, first in Japan and then throughout the industrial world, so that robotics growth rate is now at a very high level. Robot sales in 1980 and 1981 to U.S. industry were estimated at $90 million and $130 million, respectively.[13]

The RIA further classifies industrial robots by type as follows:[14]

TYPE A: Programmable, Servo-Controlled, Point-to-Point

TYPE B: Programmable, Servo-Controlled, Continuous-Path

TYPE C: Programmable, Non-Servo Robots for General Purpose

TYPE D: Programmable, Non-Servo Robots for Die Casting and Molding Machines.

Their Type E, non-programmable devices to do simple pick-and place operations, are not relevant to the needed sophistication of motor vehicle manufacture.

Servo-controlled robots (Types A and B) have feedback devices that provide position and, in some cases, velocity information back to the controller. Hence the robot's manipulator segments can be commanded to move and stop anywhere within their limits of travel. It is also possible to control speed, acceleration and deceleration, permitting controlled movement of heavy loads.

Type A robots control movement between discrete points in space, without controlling the path traversed by the arm between these points. These robots use hydraulic drives most commonly, although some have electric drives. They have a high load capacity and large working range.

Type B robots control movement along a complete path in space. Data is sampled on a time base rather than at discrete points in space; the memory capacity required to store this data is much higher than with the Type A robot. These robots use hydraulic or electric drives. They generally are of smaller size and lighter weight than Type A robots, and have lesser load capacities.

Type C and D robots are much simpler than Types A and B, since their motions are controlled only by activating limit switches. Thus, motion generally proceeds to the end of each axis; while it is feasible to provide intermediate stops, there is a practical limit to the number of such stops. Therefore, motion can occur among only a small number of positions in space. However, motion can be rapid and position repeatability is better than with Type A or B. Hydraulic or pneumatic drives are used.

The essential difference between Type C and Type D robots has been summarized as follows: The Type D robots are generally constructed to mount directly onto a die casting or plastic molding machine and provide only as many axes of motion as are necessary to perform a single function, namely, to extract a part from the machine and drop it into a container or onto a conveyor. In many cases, a Type C robot could perform the same function as a Type D but might have more capability than was required for the task and might not, therefore, be as cost effective or as efficient.[14]

Robot applications in motor vehicle-type manufacturing operations fall into five general areas: casting, forging, parts handling, welding and painting. In die casting, robot unloading of the cast piece is very common. Other foundry operations employing robots are pouring, core positioning, cleaning, and grinding flash. In forging, robots are used to handle and position the forged materials. All robot types are employed somewhere in these casting and forging operations.

Parts handling is a common use of robots; this function is performed in stamping, machining, and assembly operations. In stamping, robots are used to control transfer and orientation of parts between one step and the next. In machining, robots load and unload transfer lines and perform deburring operations. In assembly, Types A and C robots are used for orienting, loading and unloading subassemblies, for performing assembly operations, and for gauging dimensions at various steps in the assembly process.

Other applications are spot welding, which uses type A robots, and arc welding and spray painting, which require special-purpose, Type B robots. The automation of spray painting has eliminated a major health hazard from manufacturing plants.

Table 3-2 lists selected robots available in the United States. Type B robots, being the most sophisticated, are also the most expensive with a sample average price of $103,000, followed by Type A robots with a sample average price of $79,000. C and D robots, due to their simplicity, are quite inexpensive compared to Types A and B, having sample averages of $28,000 and $15,000 respectively.

Figures 3-2, 3-3 and 3-4 show current and anticipated robot use and production in different parts of the world. These figures indicate that Japan is well ahead of North America and is projected to remain ahead in total robot production and in automobile industry use for some time to come. Western Europe was, in 1980,

TABLE 3-2. SELECTED ROBOTS AVAILABLE IN THE UNITED STATES
(1 of 3)

TYPE	SUPPLIER	PRODUCT	PRICE RANGE ($000's)	AUTOMOTIVE APPLICATIONS
A	Armax	Armax	85-100	Spot welding, grinding
A	ASEA	IRb6	60-62	Arc welding, polishing, deburring, assembly, inspection
		IRb60	88-100	Spot welding, grinding, machine loading
A	Cincinnati-Milacron	T3	75	Spot welding, arc welding, machine loading, inspection
A	Cybotech	Type 80	150	Spot welding, arc welding, machine loading
A	General Electric	Allegro	75-175	Light assembly
A	General Numeric	M-0, M-1, M-3	40-70	Machine loading
A	Prab Robots	E, FA, FB	50-110	Spot welding, machine loading, press loading
A	Thermwood	Series Three	33-45	Machine loading, material handling
A	Unimation	1000	25-35	Die casting, machine loading
		2000	45-65	Machine loading, spot welding, material handling
		4000	65-85	Spot welding, machine loading, material handling
		PUMA	45-50	Light assembly
A	U.S. Robots	Maker	34-100	Light assembly, machine loading, inspection
	14 Products:	Range Average	25-175 79	

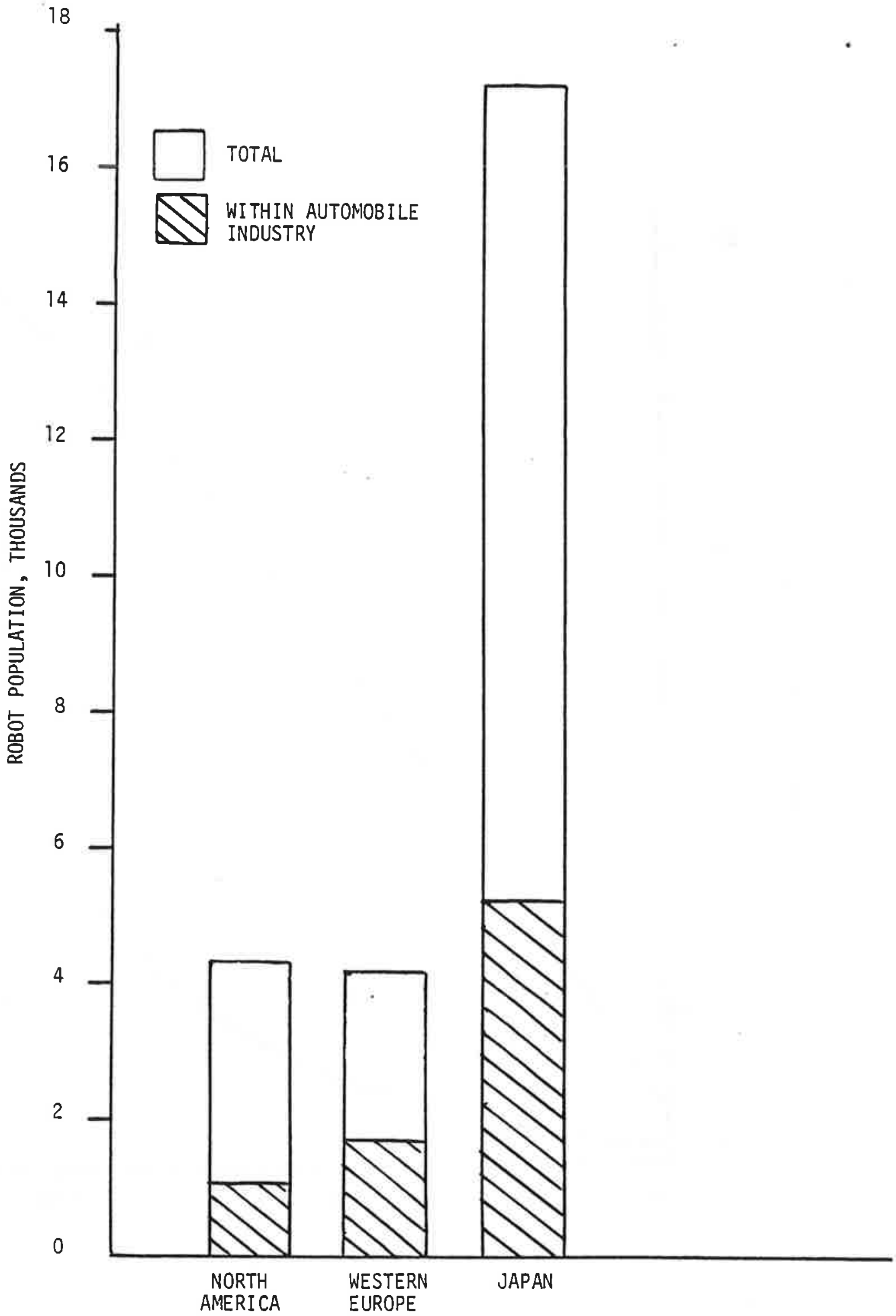
SOURCE: References 14 and 15.

TABLE 3-2. SELECTED ROBOTS AVAILABLE IN THE UNITED STATES (CONT.)
(2 of 3)

TYPE	SUPPLIER	PRODUCT	PRICE RANGE ($000's)	AUTOMOTIVE APPLICATIONS
B	Automatix	Robovision II	85-150	Arc welding
B	Binks	88-800	50-55	Spray painting
B	Cybotech	P-15	140	Spray painting
B	DeVilbiss	Trallfa	90-100	Spray painting
B	General Electric	AW-7	150	Arc welding
B	General Electric	S-6	100	Spray painting
B	Hitachi	Process Robot	NA	Machine loading, spray painting, plastic molding, welding
B	Nordson	Nordson	90-120	Spray painting
B	Shinmeiwa	PW200, PW752	80-130	Arc welding
B	Yaskawa	Motoman	60	Arc welding
	9 Products:	Range Average	50-150 103	
C	Armax	Armax	40-50	Die casting, material handling, machine loading
C	Copperweld Robotics	CR5, CR10, CR50	15-25	Material handling, light assembly, machine loading
C	Industrial Automates	Automate	15	Material handling
C	Manca/Leitz	Manta	15-45	Material handling, machine loading
C	Mobot	Mobot	10-75	Material handling, machine loading
C	Prab Robots	4200,5800	30-52	Die casting, plastic molding, machine loading, material handling

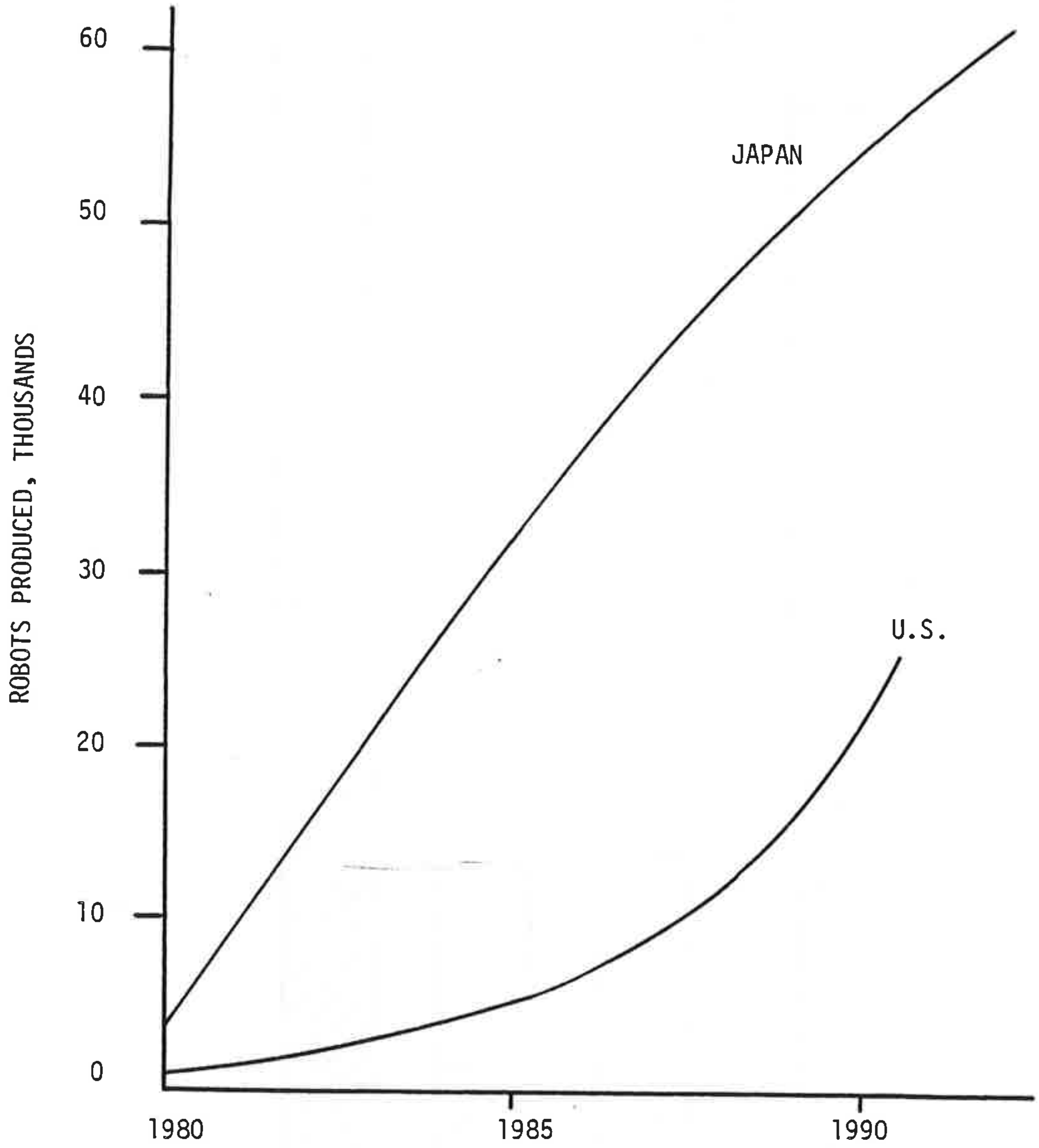
TABLE 3-2. SELECTED ROBOTS AVAILABLE IN THE UNITED STATES (CONT.)
(3 of 3)

TYPE	SUPPLIER	PRODUCT	PRICE RANGE ($000's)	AUTOMOTIVE APPLICATIONS
C	Seiko	Model 100, 200,400,700	5-11	Material handling, light assembly
	7 Products:	Range Average	5-75 28	
D	ISI	Modular	2-10	Press loading, machine loading
D	Sterling Detroit	Robotarm	22-28	Die casting, plastic molding
	2 Products:	Range Average	2-28 15	



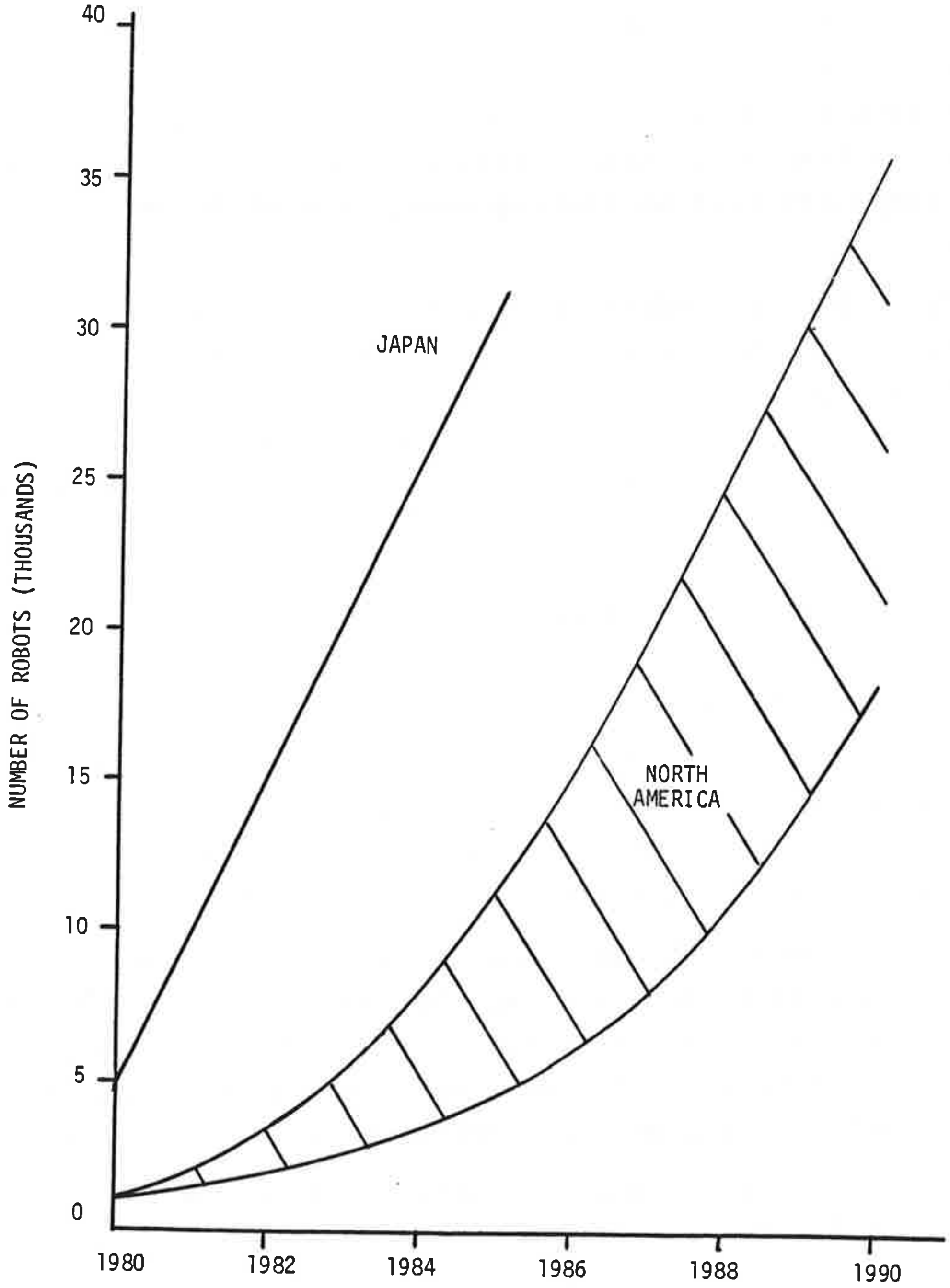
Source: Reference 14.

FIGURE 3-2. PROGRAMMABLE ROBOTS IN NORTH AMERICA, WESTERN EUROPE, AND JAPAN, 1980



Source: Paul Aron, Report #25, Daiwa Securities America Inc.

FIGURE 3-3. CURRENT AND PROJECTED ROBOT PRODUCTION, UNITED STATES AND JAPAN, ANNUAL UNITS



Source: Reference 14.

FIGURE 3-4. ROBOTS IN THE AUTOMOBILE INDUSTRY IN NORTH AMERICA AND JAPAN, CURRENT AND PROJECTED ahead of North America in auto industry robots and about even in total robots.

Table 3-3 illustrates the concentration of the U.S. robot industry, with Unimation and Cincinnati Milacron capturing 70% of the market between them in 1980. The top six companies had 97% of the market, and no other company had as much as 1%. This picture is likely to change rapidly with the recent entry of large companies such as Westinghouse, General Motors, IBM and Bendix.

The robot cost advantage occurs in the middle area of production volume that is generally called batch production. Figure 3-5 illustrates this in an idealized fashion. For sufficiently small volume, manual operation is cheapest because set-up costs are small. In the middle area, robots which are relatively inexpensive and have moderate set-up costs are superior to manual operation. For sufficiently high volume, dedicated transfer machinery, which is expensive and has high set-up costs, becomes the low-cost solution. In this example, the availability of the robot choice has pushed the break-even volume point for the dedicated transfer line from 0.8 million/year to 2.5 million/year.

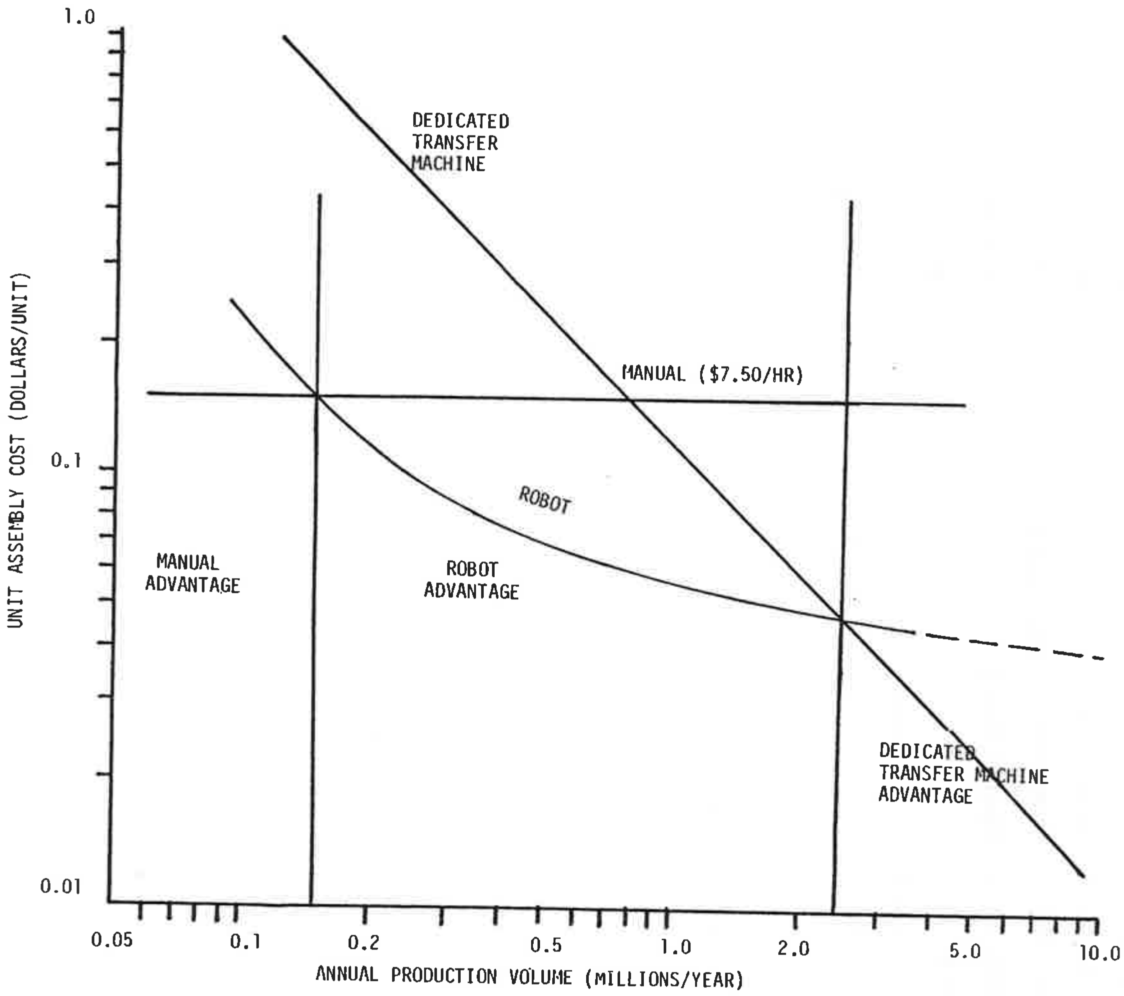
The following technical problem areas are being worked on in university, corporate and government laboratories, and results will enable more effective use of robots in the future.[17]

1. Accuracy - The absolute positioning accuracy of robots is rather poor, meaning that non-intelligent robots must be led through each task. Until this problem is solved and robots can be pre-programmed, assembly of small batches will be uneconomical because of long set-up time.
2. Dynamic performance - Improved speed and dexterity are needed for execution of complex motions to be practical. Improved gripper design and control systems would allow better small-motion dexterity. Until progress is made, assembly work by robots will be limited.

TABLE 3-3. CONCENTRATION OF THE U.S. ROBOT INDUSTRY

MANUFACTURER	1980 MARKET SHARE OF REVENUE
Unimation (Condec)	40%
Cincinnati Milacron	30
DeVilbiss (Champion Spark Plug)	9
ASEA (U.S. Operations)	7 1/2
PRAB	6
AutoPlace (Copperweld)	4 1/2
Others	3
	100%

Source: Reference 16.



Source: Lynch, "Economic-Technological Modeling and Design Criteria for Programmable Assembly Machines," Ph.D. Thesis at M.I.T., 1976.

FIGURE 3-5. COMPARISON OF ASSEMBLY COSTS AS A FUNCTION OF ANNUAL VOLUME

3. Sensors - Improved responses to touch and force are important for picking up and manipulating parts in any but a totally standarized environment. Optical pattern recognition (often called "vision") is the most popular research topic. Two-dimensional pattern recognition is being used in electronic assembly work, but for the motor vehicle industry 3-D shapes and relationships need to be perceived. The problems of sensory response and information processing are quite formidable and progress in optical patterns beyond the simplest level is likely to be slow.

4. Control systems - Improved control systems are needed to integrate the inputs from different sensors and to respond quickly. Also, control systems should work against more sophisticated internal models of the environment so that interpretation of what is perceived will be more accurate.

5. Software - Improved capability for automatic software, and software that can be used by non-systems specialists, are needed.

6. Interfaces - For robots to be used effectively in a system with other machines in the factory, standardized interfaces are needed to lessen the effort required in constructing software and control systems.

7. Mobility - Productivity of robots would be improved if they could move from one position to another, in order, for example, to load two machine tools alternately.

3.4 PROGRAMMABLE CONTROLLERS

A <u>Programmable controller</u> (PC) is a solid-state device designed to perform logic decision-making for controlling an operation or a process. Prior to PCs, large transfer lines were controlled by hard-wired relay panels. The first PC was delivered in 1970 to GM's Hydramatic Division to replace relay panels for a transfer line so that model changes could be accommodated.[18] Since that time, the market has grown in the U.S. to an estimated $200 to $300 million annually.[19]

Programmable controllers traditionally had the advantage that they were reliable and simple and that they were easy to program; specialized programming talent was not required. PCs have been widely employed in large process operations such as casting, forging, and plastic forming, as well as to control assembly lines and dedicated transfer lines.

At present, PCs are in a state of development and evolution, taking on more functions and competing to some extent with microcomputers. For example, PCs are being integrated into factory communication systems and perform test and sensing as well as control functions. This requires successful communication between higher level computer systems and PCs. PCs are moving into flexible machining operations to perform material handling functions. Specific automobile industry applications of these developments are discussed in Section 5.

3.5 OPTICAL INSPECTION EQUIPMENT

Optical equipment has started to be used in recent years for inspection in two general ways: 1) where the inspection is a measurement of the part being turned out or of the tool making the part, and 2) where a part is being oriented or checked for adequacy in some way. The optical approach has proven advantageous for speed, accuracy, and in reducing labor requirements.

In the case of measurement, the optical approach is being successfully used for gauging the parts or assemblies being manufactured, as well as machine tool fixtures. Great accuracy is possible by using laser distance measurement devices; however, ordinary light sources may provide sufficient accuracy for many applications and be considerably cheaper and more reliable.[20] Optical gauging has a great speed advantage over contact gauging, among them being that many checks can be made while a part is being machined or while assembly is taking place, without slowing down the process. Corrective action can be taken at frequent intervals, and defective product rates can be minimized.

Another optical application is measuring the quality of surface finish. Here, lasers are required to enable accurate interferometry.

The other function for optical inspection is sensing adequacy or orientation of a part. In this case, pattern recognition is applied to the optical image to check, for example, if an assembly is complete or to search for the holes in a stamping in order to insert cylinders. It is very natural to combine this kind of optical equipment with robots, as was previously discussed.

Optical inspection equipment is being applied to stamping, machining, and assembly manufacturing processes within the motor vehicle industry. Specific applications are discussed in Section 5.

4. SYSTEMS FOR ADVANCED MANUFACTURING PROCESSES

Equipment, both standard and advanced, combined with intelligent design and operation creates systems which can be used to implement advanced manufacturing processes. These systems can be broadly classified as automation systems and management approaches. These two concepts are not entirely exclusive but, in general, automation refers to mechanical and electronic control of processes to supplant human effort and decision, while management approaches refers to the intelligent use of information by human workers for efficient and high quality production.

The first two subsections that follow describe automation and management systems, respectively. The third subsection integrates these concepts and shows how they are being used by manufacturers in the evolution toward the automated factory.

4.1 AUTOMATION

Automation has been defined by a dictionary as "automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human organs of observation, effort, and decision." Automation systems tend to be interrelated and used in conjunction with each other in a plant. However, for the purposes of this report five major types of systems that can be applied in the motor vehicle industry are distinguished: DNC and flexible manufacturing, automated process control, CAD/CAM, group technology, and material and parts handling systems.

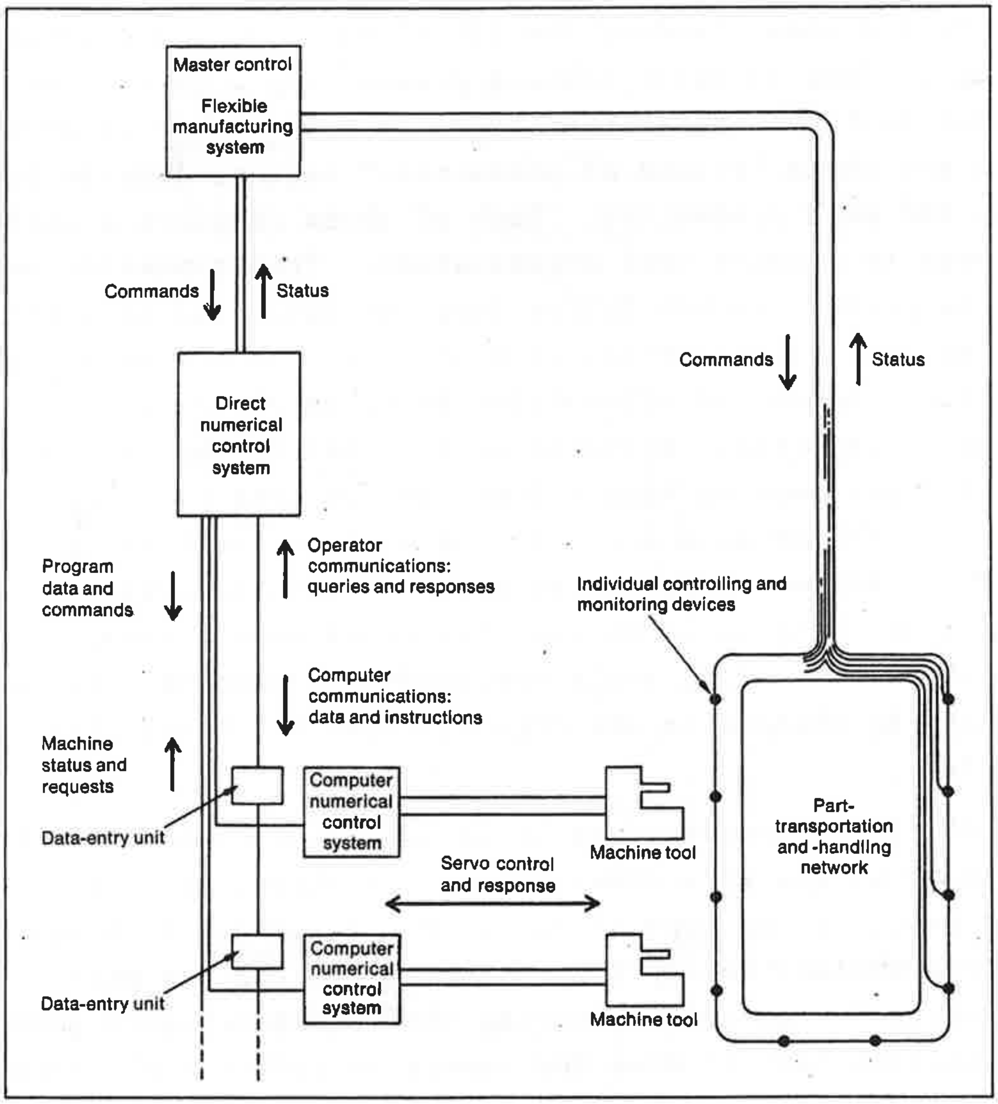
4.1.1 DNC and Flexible Manufacturing

Direct numerical control (DNC) is a concept where several NC machines are connected by a data transmission system to a central computer often called the DNC computer. The task of the DNC computer is to distribute part programs from a central memory at the proper time to the individual NC machine controllers. The DNC concept was developed as a way of bypassing the stage, common in the early use of NC equipment, where NC part programs would be generated to a specialized tape which would be physically transported and read into the machine controller. DNC, developed in the 1960s, actually predated the innovation of individual CNC computers controlling machine tools.[8]

Direct numerical control is a large step toward coordinated machining and handling of a workpiece. It makes possible a transfer line comprising individual machine tools or machining centers on which a piece, for example an engine block, is sent down the line and each machine initiates its job at the correct time without any human intervention. Changes in individual part programs can be made at the DNC computer and are instantly reflected in the machining process. If desired, robots can also be used as part of the transfer process instead of a mechanical assembly line feed, and tied into the same DNC computer. The status of each individual tool is monitored automatically and operator queries and commands can be made to the total system, instead of to each individual tool, through the DNC computer.

Another step beyond DNC is the flexible manufacturing or flexible machining system (FMS). Flexible manufacturing is like DNC with the added feature that the transfer system can move the workpiece from one machine to another in a programmed way, rather than a predetermined way that is characteristic of linear assembly lines.

As shown schematically in Figure 4-1, an FMS has three hierarchical levels of control. At the bottom level, each CNC system controls a single machine tool or machining complex and passes on information concerning machine tool status to higher levels. At the middle level, the DNC controller coordinates the actions of individual tools using its master program and machine and workpiece status reports. At the top level a master control computer



Source: Lerner, "Computer-Aided Manufacturing", <u>IEEE Spectrum</u>, November 1981.

FIGURE 4-1. SCHEMATIC OF A FLEXIBLE MANUFACTURING SYSTEM governs a part-transportation and handling network and coordinates the movement of workpieces with machining operations through the DNC system.

To aid understanding the significance of flexible manufacturing systems in motor vehicle production, a broad view of machine tool systems such as shown in Table 4-1 will be useful. There are three "volume of production" regions defined by piece, batch and mass production. Each of these requires a different approach to machine tool organization. Traditionally, motor vehicle production has fallen into the batch and mass production regions, with agricultural machinery, trucks and buses being in the batch region and automobiles being in the mass production region. Significant differences are that in mass production, emphasis has been on high volume and low cost-per-part; cutting tools are custom made for a dedicated transfer line; and flexibility to adjust to different designs is quite limited. In the batch mode emphasis is on flexibility at some increase in cost; some standard cutting tools are used in a machine tool complex that can be changed in its organization; and flexibility can be provided .

Flexible manufacturing is important to batch production and improves its efficiency and tool utilization. After completing a batch of one type of part, the changeover to a related part requires minimal set-up time since re-routing the part can substitute for physically moving the machines. Also when a certain machine tool is down for repair or cutter replacement, the system may be able to route pieces in a different order and bypass this machine temporarily. Alternatively, fabrication of a different scheduled part, whose fabrication does not require that machine, can be started.

Increasingly, flexible manufacturing is breaking down the barriers between batch and mass production for the automobile companies, since production runs of 200,000 per year are suitable for many automobile parts and are feasible for this technique. The need to produce for rapidly changing markets and the desire to

TABLE 4-1. COMPARISON OF MACHINE TOOL SYSTEMS FOR DIFFERENT TYPES OF PRODUCTION

	Piece Production	Batch Production	Mass Production
Annual volume per year*	1 to 10,000	5000 to 200,000	over 100,000
No. of part pieces per lot*	1 to 100	100 to 50,000	over 50,000
Primary motivation	Ability	Flexibility	Volume
Mfg. cost per part at full utilization	Highest	Lower	Lowest
Cutting tools	Standard	Some special	Custom
Automatic part handling	Seldom	Some cases	Always
Flexibility to change to a completely different part	Yes	Possible	Impossible
Flexibility to change to a similar but somewhat different part	Yes	Yes, if previously planned	Very limited
Ability to change materials	Yes	Limited	Extremely limited
Ability to implement gradually	Yes	Possible	Difficult
Machine tools best suited to the job	Tool Shop: several machine tools or NC machining centers	Job shop: NC machining centers, cell of machines	Transfer lines
Typical applications	Aircraft, tool & die shop, maintenance shop, repair shop, specialty machinery for industrial-process equipment (centrifuges, filters)	Agricultural machinery, off-road vehicles, mining machinery, trucks, furniture, truck diesel engines, associated sub-contract shops, aerospace propulsion	Automotive factory, automotive part supplier, metal fasteners, appliances

*Typical Case: Numbers vary with size, complexity and cost of parts.

Source: Paul S. Borzcik, Manufacturing Development Dept., TRW, Inc., Reproduced from Reference 21.

cut inventory, or match production more closely to demand, are leading the auto manufacturers toward smaller batch production runs than in the past, making FMS techniques more feasible.

Despite much publicity and availability of turnkey FMS from machine tool manufacturers, the number now existing in the world is estimated at only twenty-five to eighty.[22,23] However, this is certain to grow rapidly as corporate plans are implemented. One estimate has 50 percent of all NC/DNC tools in 1990 included in flexible systems.[22]

Table 4-2 gives basic information on selected FMSs in vehicle plants. Applications in the past have been concentrated in truck and tractor plants because of the medium volume scale of production in that type of industry. Planned applications in the motor vehicle industry will be covered in more detail in Section 5. At present, despite worldwide competition, Kearney and Trecker Corp., which pioneered FMS in the late 1960s, is considered to be the leading vendor of big systems;[24] and Caterpillar Tractor has the most separate FMS systems in operation in the world.[25]

4.1.2 Automated Process Control

Process control refers to the automation of continuous manufacturing operations. The oil refinery is an outstanding example of continuous manufacturing governed by a process control system. The motor vehicle industry has three manufacturing processes which are amenable to automated process control: casting, forging and plastic forming.

New methods of process control incorporating solid state electronics, microprocessors, and remote sensing allow control within narrower tolerances in green sand casting. Automated pouring, ladling and pressure filling systems are being used in sand mold casting, permanent mold casting, and die casting. Servo valves have been developed to control pressure of the molten metal in die casting, allowing control of both speed and fill rate of the molten metal. Today, on the average, it requires about 20 man-hours to produce a ton of iron castings, with a few foundries

TABLE 4-2. SELECTED FLEXIBLE MANUFACTURING SYSTEMS IN OPERATION IN VEHICLE PLANTS

User	Mission	Work Stations	Material Handling	Management & Control	Comments
Japan					
Yanmar Diesel (Amagaski Plant) Installed 1972 Vendors: Hitachi Seiki	Prismatic-Engine castings approx. 2 ft. cube-900 units per month.	5 Machine Tools	Palletized-Roller Conveyor-Loop with spurs	Limited-workpieces follow fixed sequence determined by operator at load time.	Direct labor reduction from 12 to 1 estimated.
Toyota-Tipros Installed 1973 Vendor: Toyota	Batches of 100 Prototype Engines-800 parts per month	9 machine tools (1 machining center) 4 machine tools do preliminary work	Palletized Roller conveyor with MT's on spurs.	Limited versatility Batch operation-each part visits each spur.	Fall of '77 consideration being given to converting to parallel transfer lines.
United States					
Caterpillar Installed 1974 Vendor: White-Sundstrand	Cast iron case and cover for tractor transmission. 6 parts. 1200 per year Approx. 3 foot cube.	5 Omnimills 2 G&L turret lathes 3 Omnimills 1 DEA inspection	Palletized parts, 2 carts move parts between machines and load area, which also serves as buffer.	Fixed sequence, due to tooling limitations, Production to monthly master plan.	Tooling constraints. Carts are weak link in system, replacement planned.
Allis Chalmers Installed 1971 Vendor: Kearney & Tracker	Produces cast iron tractor parts for direct assembly 23,600 per year. Approx. 3 ft. cube.	5 Machining Centers 1 Mill 4 Duplex multi spindle head indexers	Palletized work-pieces moved under computer control to work station on towed carts.	Work stations dynamically assigned by computer to balance load.	System incrementally installed. Work max changed drastically between design and use.
North American Rockwell Installed 1973 Vendor: Kearney & Trecker	Cast iron differential carriers for trucks in lots of 10 to 50. 33 parts. 1.5 foot cube .8 parts simultaneously. 24,000 per year	8 Machining Centers	Same as Allis Chalmers except a simple loop with spur rather than a network.	Same as Allis Chalmers	Original installation included inspection station. Greatly reduced set-up time and batch sizes, reducing WIP.
Cummins Engine Lakewood, NY	Produce cam-follower levers and housings from raw castings.	1 chain branch 2 special purpose mills 2 inspection stations 2 mills 1 drill 1 deburr 1 washer	4 Unimate robots internal storage conveyors	Continuous production	Product changes and high capital costs eliminated hand automation.
International Harvester Installed 1980 Vendor: White-Sundstrand	4 fast cube cast iron parts of 6 families with 4-5 variations of each	4 Horizontal Machining Centers 4 Tilt Head Machining Centers	Straight track with with 2 shuttle cars	See Caterpillar System	

TABLE 4-2. SELECTED FLEXIBLE MANUFACTURING SYSTEMS IN OPERATION IN VEHICLE PLANTS (CONT.)

User	Mission	Work Stations	Material Handling	Management & Control	Comments
<u>United States</u> (Cont.)					
Chevrolet Reported 1979 Vendors: Auto-Place robot and Opto Sense optics	Testing and visual inspection of valve covers of 2 types	Dial index with 6 dual fixture test station	Index table & robot	Continuous production	Included because of visual inspection. 1200 parts per hour with one man versus 300 with 4 men on 2 lines.
Chrysler Lima, OH Installed 1979 Vendor: Cincinnati Milacron	Produce turret and hull XMI tank parts, very large steel, up to 40 tons.	1 spec. adapt. horz. mach. ctr. 1 cluster head changer 1 special design 1 spec. adapt vert. mach. ctr.	Palletized, moved in each step on single line. Hydrostatic support for pallets.	All machines are NC and no hard tooling, minimum decision making required.	Expect substantial labor saving in material handling.
Chrysler Lima, OH Installed 1979 Vendor: Cincinnati Milacron	Produce a narrow family of torsion bar housings, approx. 3 foot cube	2 special design 1 horiz. Machine Center 1 Head Changer	Palletized parts on linear, powered roller conveyor.	See Chrysler above.	Expect substantial labor savings, as above.
Caterpillar Installed 1979 Vendor: Cincinnati Milacron	Very large tractor parts	1 Bridge Turret Machine Center 4 Horiz. Machine Center 2 Large indexing Turrets	Palletized parts on straight line conveyor with work performed off-line	Machines paired for simultaneous machining of 2 faces. Minimum management control problems.	Cost-benefit study predicted positive ROI.

Source: Reference 22.

achieving 12 man-hours per ton; future application of technology may allow five man-hours per ton.[26]

In hot forging, a new generation of automatic forging equipment is being procured. This employs a system of electro-hydraulic controls linked to a computer that simultaneously regulates radial and axial rolling faces. The control system measures ring diameter and height throughout production and automatically shifts axial and radial rollers to achieve the desired finished dimensions. Benefits anticipated from this integrated process include:

1. Reduced stock use of 15 percent.[27]
2. One operator doing the job formerly taking five people, plus material handling personnel.[28]

Improvement of control systems in plastic forming is having major benefits, including reduced cycle time, reduced reject rates and reduced setup time on injection molding machines. During plastic forming, electronic sensors and timers feed information on position, velocity, temperature, pressure and event times to the control unit, which sends commands to programmable controllers for process adjustments. A single control unit combines sequence and process control functions. Sequence controls govern the cyclical process of basic molding steps, while process controls govern combinations of mold pressure, hydraulic pressure, ram velocity, ram position, and temperature.

4.1.3 CAD/CAM

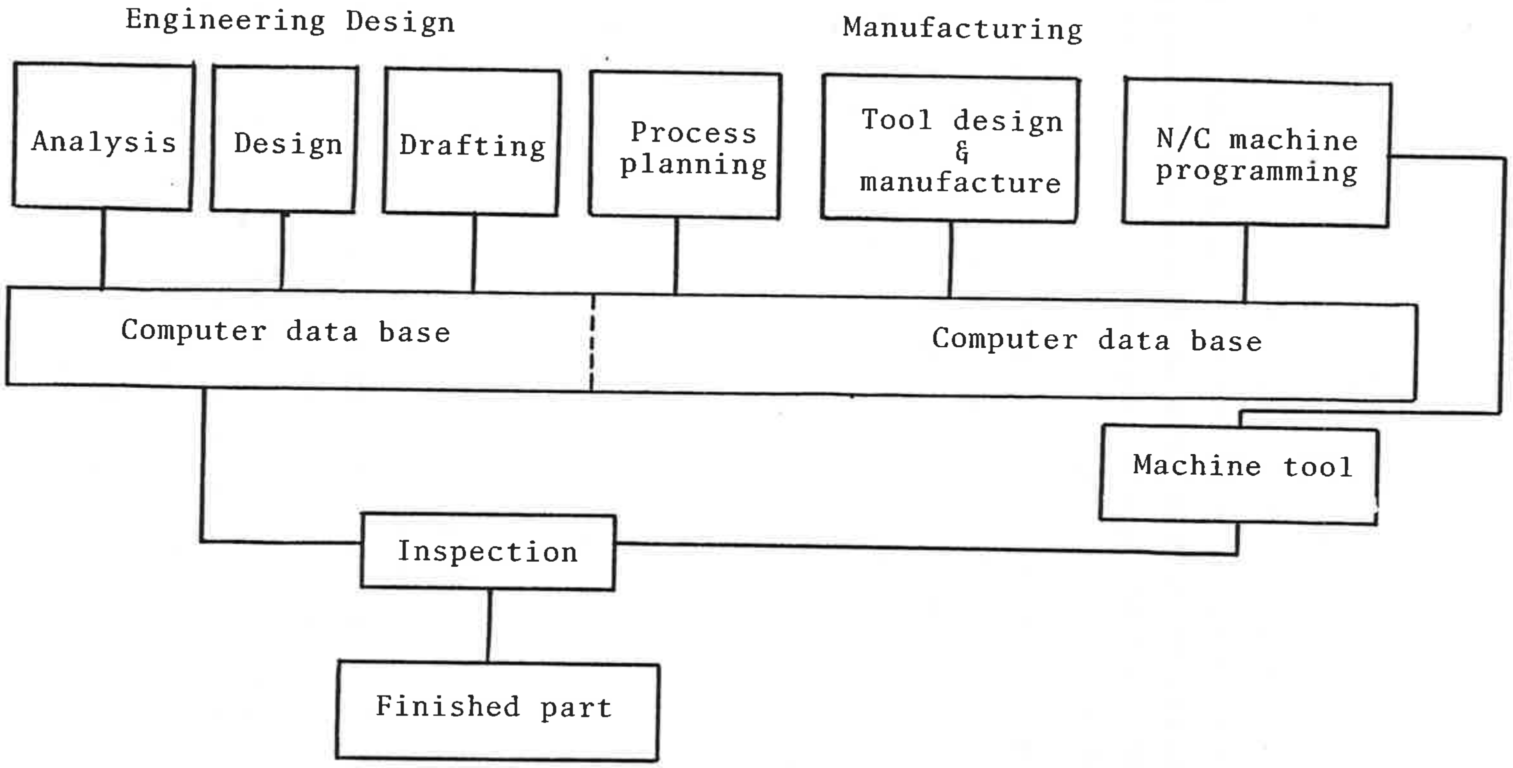
CAD/CAM stands for computer-aided design/computer-aided manufacturing. Computer-aided design has been discussed earlier. Computer-aided manufacturing has been defined broadly as "the effective utilization of computer technology in the management, control, and operations of the manufacturing facility through either direct or indirect computer interface with the physical and human resources of the company."[29]

CAM is sometimes used to indicate just about any computer operation in manufacturing. However, another term will be used here for this broader concept, namely computer-integrated manufacturing (CIM). The purpose of CAD/CAM can be stated more specifically as: to tie together the design, engineering, manufacturing production plan, and the actual manufacture of a part or family of parts.

Figure 4-2 illustrates what an ideal CAD/CAM system does to fulfill its purpose. Information on part design is stored in a computer database, and the designer works interactively with this data base in altering and refining the design. In addition, analytical programs can be called in by the engineering staff to test the theoretical design for material properties, stresses and performance capabilities. Views of the designed part can be automatically drafted from the data base.

Once a design has been created that is satisfactory from engineering and aesthetic points of view, the manufacturing engineers can view it using the same data base, not strictly from the drafted diagrams. Process planning or manufacturing production planning takes place, to determine the type of machines required and a plant layout. Tools and dies can be designed and manufactured automatically, or semi-automatically, especially when prior experience in manufacturing similar parts can be used. This prior experience is also stored in the data base. If it appears that the originally designed part is unfeasible or impractical to manufacture, this information can be fed back quickly to the design group and in principle the design and manufacturing engineers can work together (with rapid feedback) to create a more practical design.

At the same time as the tooling the third step of manufacturing planning is accomplished, the creation of N/C part programs. Actual production begins with the designated tools manufacturing the part under control of part programs; the parts can then be put through an inspection procedure which uses an automatic gauging technique to measure the finished part. These dimensions are compared to what they should be according to the part design in the computer data base, and the part is finished if these



Source: Reference 30.

FIGURE 4-2. FUNCTIONAL SCHEMATIC FOR COMPUTER-AIDED DESIGN/COMPUTER-AIDED MANUFACTURING dimensions are within tolerance. Random errors cause parts to be rejected, while systematic errors may be corrected by adjusting some aspect of the CAD/CAM process just described.

Table 4-3 summarizes the magnitude and growth of CAD/CAM. The world market for CAD/CAM suppliers, now $800 million, is projected to grow fourfold by 1985. U.S. market growth is projected at nearly the same rate, from a current $485 million. Mechanical technology applications of the type utilized in the motor vehicle industry are projected to expand their market share from a current 41 percent to 49 percent in 1985.

Market share by revenue of CAD/CAM suppliers (Table 4-4) shows less concentration than in the U.S. robot market discussed earlier (Table 3-3). The top five suppliers hold 83 percent of the market. U.S. firms are well ahead of foreign competitors in the world market. The recent entry of other computer firms such as Prime, Honeywell, Control Data, and Hewlett-Packard is not expected to capture much market share for any of them.[31]

Major U.S. users of CAD/CAM include Pratt & Whitney Aircraft,[30] General Electric[32] and General Motors.[33] Productivity improvements have been estimated as high as 20 to 1 or 30 to 1 (General Electric);[32] in the auto industry, an average 3 to 1 (General Motors)[33]. Since in general CAM has not progressed far compared with CAD, the potential for productivity improvement is very large; seventy-five percent of the cost savings have been estimated potentially on the CAM side of CAD/CAM.[34] In the auto industry, application of readily available CAD/CAM techniques could trim up to 25 percent of the $1500/car cost advantage that Japan holds over the U.S., according to one estimate,[35] which doesn't count added CAM techniques now under development.

The most important automotive use of CAD/CAM is in stamping and planning the assembly of body panels,[33] because of the frequent changes in car exterior design and the large amount of tooling required. However, CAD/CAM can be used in many other

TABLE 4-3. SIZE AND GROWTH OF THE CAD/CAM MARKET

Year	Revenues from U.S. Market ($ Millions)	Revenues from World Market ($ Millions)	Percent of World Market in Mechanical Applications
1976	53	71	33%
1981 (est.)	485	800	41%
1985 (proj.)	1,790	3,250	49%

Source: Reference 31.

Figures do not include internally developed CAD/CAM systems, which are significant in some companies, e.g. General Motors.

TABLE 4-4. ESTIMATED MARKET SHARE OF THE CAD/CAM MARKET BY SUPPLIER

Supplier	1981 Market Share of Revenue
Computervision	34%
IBM/Lockheed	16
Applicon (Schlumberger)	11
Intergraph	11
Calma (GE)	11
Auto-trol	6
Gerber	3
Others	8
	100%

Source: Reference 31.

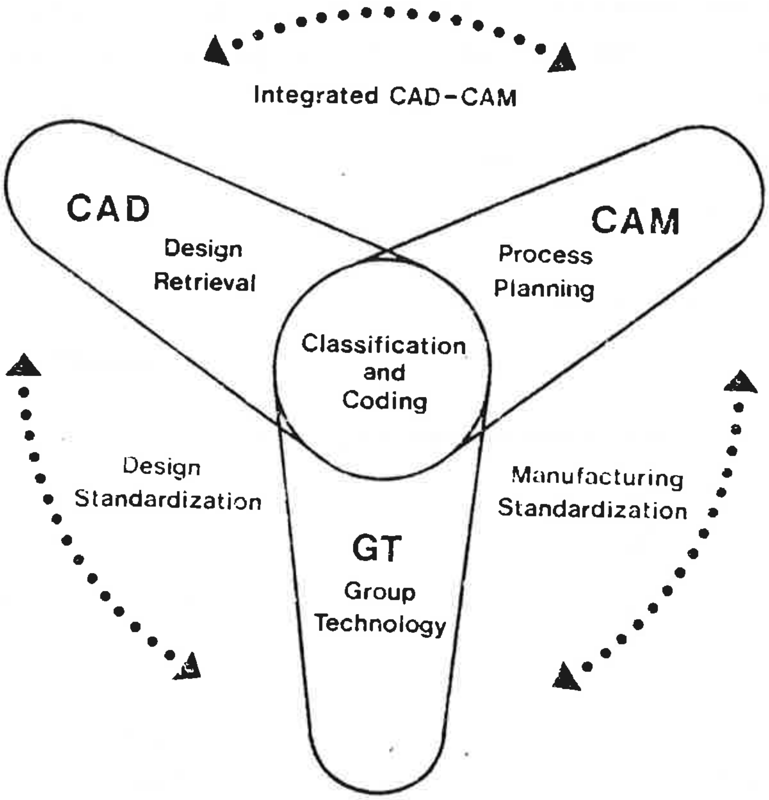
areas of motor vehicle manufacturing, in particular casting, forging, and the manufacture of many components. Specific motor vehicle applications are discussed in the following section.

4.1.4 Group Technology

The purpose of group technology is to better utilize past experience of design and manufacture of diverse parts against current requirements. Designs and manufacturing techniques are classified in some way so that new designs and manufacturing plans may follow standardized paths and increase productivity.

Group technology has been practiced in various forms for about 50 years.[36] Design engineers would keep a file of past designs and go to them when a new, similar part was required. Similarly, manufacturing engineers would keep a file of production plans and go to them when a new part which seemed similar had to be fabricated. The computer data base has transformed the practice of group technology and made it much more efficient.

It is possible and desirable to use group technology to enhance the productivity of CAD/CAM (Figure 4-3). Working from an appropriate data base, group technology can be used in conjunction with CAD for design standardization; the designer retrieves parts with similar design coding and can often use an existing design, or the new design can take advantage of features of earlier designs. Group technology can also be used in conjunction with CAM for process planning standardization; the manufacturing engineer retrieves parts with similar manufacturing-related attributes and can use previously specified machines and machine routings for the new part. Note that parts that are similar in their manufacturing attributes -- for example, coupling plates made of the same material with a round hole in the center -- may not have design similarity. From the point of view of the computer retrieval system, this does not matter since the code expresses any number of potential classifications independently.



Source: Reference 36.

FIGURE 4-3. GROUP TECHNOLOGY AS RELATED TO CAD AND CAM

After the routing of a part to a group of machine tools has been determined, the group technology classification can be combined with process planning information to show a detailed process plan which is satisfactory for that part. If none is available, process plans for similar parts will be retrieved and the engineer can save time in creating the new plan. Another capability of this system that has been exploited is the identification of NC part programs for similar parts and process plans, allowing shorter time for creation of the new part program.

Group technology, then, is an information technique that can enhance the productivity potential of CAD/CAM by using an extension of its data base. The success rate for group technology has been estimated at 50 percent,[36] with the following savings:[37]

- tool design effort -- 20 to 40 percent
- setup time -- 40 to 60 percent
- throughput time -- 40 to 60 percent
- process planning time -- 20 to 40 percent.

4.1.5 Material and Parts Handling Systems

It is wise to remember the benefit of the systems approach when assessing material and parts handling systems. The overall objective of any change in a factory procedure should be to increase productivity, decrease unit cost, improve quality and the like. A subobjective that may contribute toward this objective is improved handling. Possible subareas whose improvement may improve the handling process are the following:[38]

- Unused building cube
- Improper stock location
- Inefficient plant floor operations
- Poor inventory practices
- Poor use of handling equipment

In particular, less inventory means less handling, automatically improving handling. In fact, just-in-time production as pioneered by Toyota and widely used in Japan virtually eliminates inventory and therefore results in very little material handling. Furthermore, it may be equally true that improved handling lessens inventory required because what is needed is found and used more quickly and with less damage.

One means toward improving some of these problem subareas given above is an approach called automated materials and parts handling. This is an important approach currently under much discussion in the motor vehicle and other similar industries. One manufacturer (John Deere) has classified levels of mechanization in materials handling as follows:[39]

1. Simple mechanization -- replacing human labor with material handling equipment.
2. Replacing human guidance with electronic or mechanical guidance. Principal approaches are conveyors, often overhead to leave the shop floor clear; vehicles on towlines from an underfloor cable; and battery-powered guided vehicles which may have the capability of point-to-point operation along a grid.
3. Mechanical linkage between storage and delivery systems. This puts the vehicles or conveyor guidance systems of level two under the direction of an automated storage and retrieval system (AS/RS). For example, a needed part is automatically withdrawn from storage via a grid conveyor and loaded onto a vehicle which takes it where needed.
4. Linkage between automatically generated material handling data and the computer controlling the production process. At this highest level, integration between the material handling system and production conveyor or transfer line becomes possible. One way of doing this is by having automatically guided vehicles (AGVs) carrying, for

example, an automotive chassis, move to workstations for assembly operations.[40] This obviates a "production line" and provides the potential advantages of flexibility and improved quality since the time to work in one unit is not necessarily pressured by the sequence of operations.

Another possibility is the use of robots as integral parts of the vehicles to load and unload workpieces. Most of all, flexible manufacturing is well served by the material handling - production control linkage. An example is a system set up by SI Handling.[41] In this system, there is a medium high-rise storage bank for small parts. A new shipment of parts in a bin is automatically stored in a designated spot by an AGV using a forklift device. When a part is needed, it is retrieved from the right spot using the materials data bank memory by an AGV in the reverse manner to its storage, carried to the point needed, and unloaded. The system is completely responsive to production schedule changes.

Automobile applications of automated material handling are foremost in assembly, where many parts must be brought together. Potential applications exist in most other areas to a lesser extent.

4.2 MANAGEMENT APPROACHES

As compared with automation systems, management approaches are considered by many analysts of industrial production to be more important in their potential for increased productivity. One example: Harbour compares United States and Japanese hours to build a sub-compact car.[42] Total hours for assembly, stamping, 4-cylinder engine and manual transmission are 54.1 in the United States, 24.7 in Japan for a difference of 29.4 hours. In an explanation of advantage, nearly all the explainers relate in some way to management; however, the most direct management aspects are quality, inventory management, mass relief, and "other productivity" where Japanese gains relative to U.S. are primarily related to quality circles, the quality control program, and inventory management. In these four areas, the Japanese advantage is 22.0 hours, a majority of the total 29.4 hours.

The discussion of management techniques that follows is, of necessity, more general than the earlier discussion of automation. It is difficult to discuss management approaches and attitudes in specific or concrete terms. Management cannot be seen directly in the way a robot, or a factory layout, can.

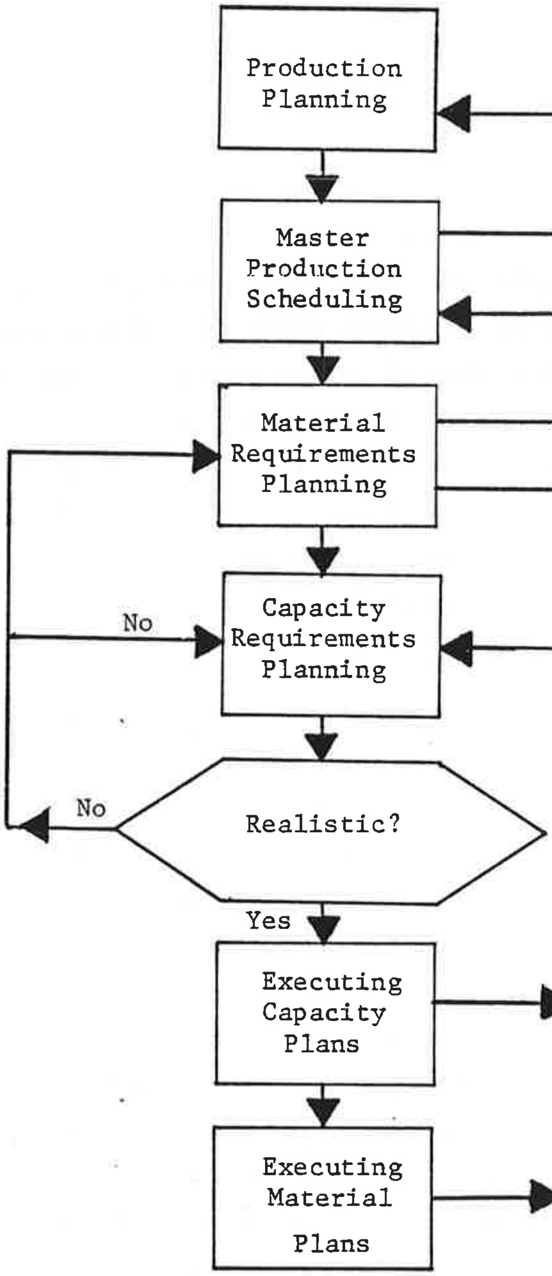
This section focuses on three management approaches that are new to most U.S. companies but are now being implemented: manufacturing resources planning (MRP), Kanban or just-in-time production, and statistical quality control. Other management approaches practiced in the Japanese automobile industry have been adequately discussed in a companion report by Kakatsakis.[43] These include the scheduling of shifts so that routine and preventive maintenance can be performed between shifts, and mass relief rather than the U.S. practice of individual or "tag" relief with substitutions. They also include a group of strictly worker-related practices: lifetime employment for the majority, worker technical training and re-training, broad rather than narrow definition of job function, major use of worker suggestions and recognition for suggestions, group rather than individual bonuses based on company performance, and Jikoda, or the worker obligation to shut down the production line to correct a perceived defect or quality problem. It is an open question, much discussed in the management literature,[44] to what extent these worker-related practices can be applied in the United States or instead uniquely American practices can evolve to increase work force effectiveness.

4.2.1 Manufacturing Resources Planning

To better understand manufacturing resources planning some historical perspective is useful. Manufacturers have always had systems of bill of materials (BOM), where the material requirements for each order, i.e., planned manufactured part, are laid out and the BOM's are aggregated to see what is needed, whether inventory can supply it, and when to order new inventory. In the 1960's, when computer systems were developed for this process it was called "time-phased requirements planning." It was considered to be a better technique for order accounting and purchasing inventory. Then additions to this system provided the capability to evaluate orders already released and to detect when the due date of an order was out of synchronization with the progress of work. The system could be used to reschedule open orders, thereby becoming a scheduling tool as well as controlling inventory. At this point the system began to be called material requirements planning.

At this point it was recognized that feedback from the production planning function would be useful to better relate production to orders. A system called closed-loop MRP (Figure 4-4) was developed, where production planning could drive a master production scheduling function, which input to material requirements planning and also lead to capacity requirements planning, so that labor, equipment and space would be adequate to carry out a production schedule. The computer system could be used to simulate the production process; if results were realistic, capacity and material plans would be executed. If not, new plans would be formulated. Extensive information feedback assures the realism and consistency of plans and data.

Further extensions of this computer-based information system are being called manufacturing resources planning (often abbreviated MRP-II, to distinguish it from material requirements planning, but here it will be abbreviated MRP). First, MRP can integrate the whole plant-based complex of information that has been described above with financial information. Instead of one



Source: Oliver Wight, *The Executive's Guide to Successful MRP-II*, Prentice-Hall, 1982

FIGURE 4-4. CLOSED-LOOP MRP

set of information used by manufacturing people and another set for financial people, often with different numbers representing the same entities because of differences in definition, there is only one system that both groups can use. The financial controllers therefore can aggregate any information to have an accurate current state and projection for each product line and for the company as a whole. MRP also becomes a powerful tool to plan well into the future, to coordinate a business plan with manufacturing details required to realize the plan, and to simulate many potential scenarios for optimal manpower and capacity planning.

It is evident that a substantial amount of time and effort is required to implement MRP. It has been claimed that 75 percent of all computerized material management systems fail to provide the accurate and timely information that should be provided to managers.[45] Many failures result from an attempt to move too fast with complex problems such as shop floor control and capacity planning. However, claimed benefits are substantial.

A survey of 326 U.S. companies that have implemented MRP[46] showed that before, the sales-inventory ratio averaged 3.5; after, the sales-inventory ratio reached 4.7, with future improvement projected at 5.6. Delivery promises met rose from an average 64 percent to 81 percent, with future improvement expected to 93 percent. Average leadtimes from order to delivery were reduced from 64 days to 57, with expected further decrease to 42 days. Average expected reduction in purchased costs is five percent after implementing MRP.[47] It is claimed that the American automobile industry spent over $100 million in 1979 on premium air freight, due to poor scheduling, a cost that could have been nearly eliminated using good scheduling procedures such as could be obtained with MRP.[47]

4.2.2 Just-In-Time Production

Just-in-time production provides a good contrast to the MRP system just discussed. Briefly, just-in-time production goes against the computer-based information system developed in material requirements planning. It does this by providing only those sub-assemblies and materials that are required at that time by the final assembly process. There results little or no inventory, and the detailed schedule of all processes leading up to final assembly is controlled automatically by these final assembly requirements. Hence a computer information base for this aspect of the company is not necessary.

To understand the full implications of the just-in-time production system, it is useful to examine it in the context of the Toyota production system where it originated. The philosophy of the Toyota production system has two basic tenets: reduction of cost through elimination of waste, and make full use of the worker's capabilities. A major means to elimination of waste, which includes inventory, surplus equipment and workers, and unproductive worker time, is just-in-time production or Kanban.

In the Kanban (meaning "card") system,[48] each work center is defined and has an inbound stock point and an outbound stockpoint. Two types of cards are used:

1. A <u>move card</u> which authorizes the taking of one standard container of a specific part from one work center to another.
2. A <u>production card</u> which authorizes a producing work center to produce another standard container of parts to replace one which was just taken.

Parts are kept only in standard containers, and only one card goes on each container. Containers full of parts come into the inbound stockpoints with move cards attached. When one of these containers is selected for use, the move card is detached and sent back to the supplying work center to authorize replenishment.

Each move card is used for just one part and circulates between a single pair of work centers (Figure 4-5).

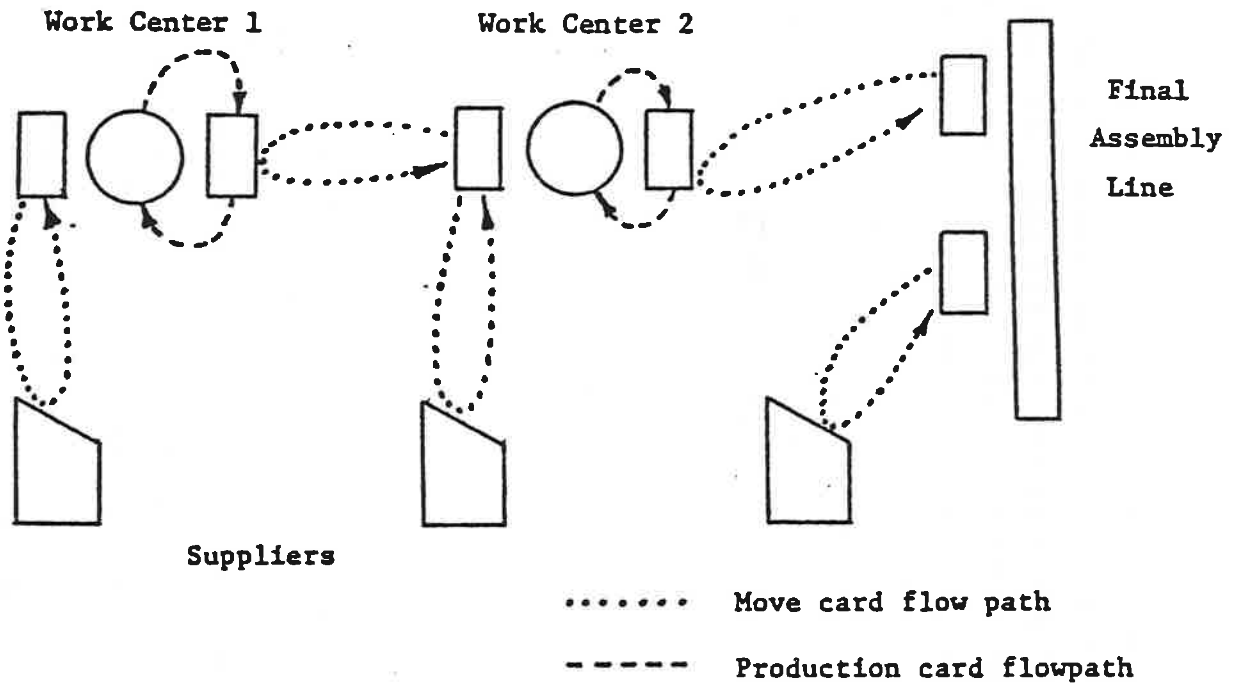
In each outbound stockpoint standard containers full of parts should have production tickets attached. When a container is picked to go forward, the production ticket is removed and the move ticket is attached. The detached production ticket stays at the same work center where it authorizes production of another standard container of parts to replace the one just taken. The production card is attached to a refilled container which is placed in the outbound stockpoint ready for pick up. The lot size equals the container size.

This system begins with the inbound stockpoints of the final assembly line. It allows the final assembly line to pull material from supplying work centers as needed, and some of those work centers may be outside suppliers. The work centers from which material is drawn then pass on the requirements for material to the work centers supplying them in a linkage all the way back to the outside suppliers.

The card system rules are the following:

1. A container full of parts should always have a card attached.
2. Using work centers always obtain parts from the supplying work centers.
3. Never take parts without using a move card.
4. Never produce parts without the authorization of an unattached production card.
5. Always use standard containers and always fill them with the correct number of parts.

If the rules are observed, the amount of work-in-process inventory of a specific part cannot exceed the level authorized by the total number of cards issued for that part. The cards control the work-in-process inventory level. The fewer the cards, the less inventory.



Source: Reference 48.

FIGURE 4-5. SCHEMATIC OF THE KANBAN SYSTEM

Three conditions need to be satisfied for the Kanban system to work.[49] First, the manufacturing process plan must be designed to allow efficient and smoothed production flow. In Toyota, it has been found beneficial to have men and machines arranged so that one man works several types of machines. Workers become multi-functional. This has the following advantages:

1. Machinery can be re-arranged and men re-assigned efficiently as product designs change.
2. Workers participate more in the total system of the factory and thereby feel better about their jobs.
3. Workers can engage in teamwork or help each other.

Second, manufacturing operations must be standardized. A cycle time is specified, which is the time required to produce a complete product (car) or part <u>in order to meet final demand</u>. Cycle time is determined from the following equations:

$$\text{Necessary output per day} = \frac{\text{necessary output per month}}{\text{operating days per month}} \quad (1)$$

$$\text{Cycle time} = \frac{\text{operating hours per day}}{\text{necessary output per day}} \quad (2)$$

Then just the right number of workers required for each process to produce one unit of output in a cycle time are assigned to that process.

An operations routing is also defined, giving the sequence of operations that a worker should follow in each process.

Third, production is smoothed at the final assembly stage. Without smoothing, variations would be magnified under the Kanban system at previous stages until they became disruptive. A lot of effort is made by Toyota to smooth production. This is enabled first by having fast tooling set-up times so that small lots may be produced economically. Monthly estimated sales forecasts are translated into daily necessary output of each product and cycle times by equations (1) and (2) above. Then a production plan is set up with the aid of computer programs which will intermix the different model options (e.g., different engines, transmissions, colors of Coronas) so as to achieve the cycle time per car. Workers follow this plan by electronically displayed instructions at key points. This only applies to the final assembly line; Kanban will adjust requirements at feeder plants. These plants are guided in capacity planning by average expected requirements.

Monthly estimated demand is changed frequently. If it increases, production will be stepped up incrementally day to day by lengthening hours (since there is a gap anyway between the two shifts, nominally 8 am - 5 pm and 9 pm - 6 am), and/or shortening cycle time. This "speedup" may be possible by re-assigning people, using a greater fraction of the work force in active production, and exploiting "slack" in processes which resulted from past productivity improvements. Conversely, if estimated demand decreases, production winds down smoothly. Workers who do not have the lifetime employment contract are laid off, both in Toyota and in supplier companies. Surplus workers with the lifetime employment contract, if they cannot shift to another plant, engage in other activities such as quality circles, set-up practice, maintenance and repair, manufacturing improved tools and instruments, repairing water leaks in plants, or manufacturing parts that formerly had been purchased.

The Toyota system strives to approach as a goal one-piece production and conveyance. That is, each process ideally would produce one piece, convey it to the next process, reach back for the materials for the next piece which appeared just then, etc. In practice, the smallest economical lots are specified.

Another corollary of the Toyota system is that demands are met with a minimum number of workers. However, machine capacity is high. Therefore increases in production are accommodated through reassignment of workers and hiring temporary workers while using the excess capacity of existing machinery.

A third corollary is that maintenance is practiced at a high level so that machine failures rarely disrupt the smooth flow of production. Also, if a worker has trouble with his supply material or meeting schedule, he flashes a warning light which will bring others to his aid to solve the problem. If production must be stopped due to machine failure or quality problem (Jikoda, signalled by a red light) attention is focussed on the problem by the whole group for quick resolution.

The other basic tenet of the Toyota philosophy is the full utilization of workers' capabilities. This is accomplished first through elimination of waste movement by workers, i.e., workers must make only products that have value. The waste of making too much is taken care of by just-in-time production. The waste of idleness is prevented through multiple machine assignments, increasing worker responsibility so lines do not need to be supervised, and other activities as discussed previously. The waste of unsuitable operations for men, i.e., injurious to health, requiring hard labor or involving monotony is alleviated by automation. The waste of defective production is prevented by Jikoda, including vigilance of individual workers.

Second, safety in design of operations is considered an obligation of management; again, Jikoda and elimination of worker idle times contribute to safety. In 1974 Toyota's injury frequency rate was 1/2 that of U.S. auto workers.[50]

Third, the system allows self-display of workers ability. Jikoda is one realization of this. Although the priority order of parts is given by management, each shop under the control of its foreman decides on the local production organization. Minimum inventory and minimum workers results in a lean organization where trouble becomes highly visible, and all workers, not only managers and foremen, are encouraged to spot and correct trouble.

Just-in-time production is not just a mechanical production technique, but where practiced most successfully is intertwined with a particular management philosophy and factory social system. The innovation of just-in-time production in the United States may require some profound changes in the management and social environment of the factory in order to realize potential gains in productivity.

4.2.3 Statistical Quality Control

W. Edwards Deming has defined statistical control of quality as "application of statistical principles and techniques in all stages of production, design, maintenance, and service, directed toward the economic satisfaction of demand."[51] As defined the scope of statistical quality control is narrower than quality control in general. The latter applies non-quantitative behavior and managerial approaches, as well as quantitative approaches, to the problem of supplying goods that are satisfactory to the users. On the other hand statistical quality control is more than the development of statistical measurements by quality engineering specialists; it is a management approach that incorporates but goes beyond some well-chosen statistical information. It resembles just-in-time production in that the correct use of a certain technical discipline is likely to require far-reaching changes in the corporation.

Statistical quality control (SQC) originated with Dr. Walter Shewhart of Bell Laboratories, who wrote a book on the subject in 1931. During World War II a number of SQC experts including Dr. W. Edwards Deming worked with the War Department to encourage military contractors to use SQC to improve productivity. This effort was partly successful but after the close of the war most of this activity died due, in Deming's opinion, to a lack of commitment of top management.

In 1950, Deming was invited by the Japanese Union of Scientists and Engineers (JUSE) to give a series of lectures on SQC. During this period he spoke to the Industry Club, a group of 45 top managers. Successful implementation of SQC in some companies was achieved, SQC ideas and commitments spread throughout Japan, and productivity and quality started to improve.

In Deming's view, the convergence of four factors provided the impetus for the initial success of SQC in Japan: the widespread knowledge of statistical theory, the commitment of JUSE, teaching of engineers, and conferences with top management.[51] Continued success was made possible by a massive training program in statistics in Japanese companies down to the level of foreman. An additional force was added to this program in 1960 with the formalization of quality circles by Dr. K. Ishikawa.

The commitment of company management is essential for successful implementation of SQC, according to Deming, who has formulated the following fourteen-point plan.[52] Management must:

1. Innovate. Plan products with an eye to the long-range needs of the company.
2. Learn the new philosophy. No company can compete in the world market until its management discards old notions about acceptable levels of mistakes, defects, and inadequate training and supervision.
3. Eliminate dependence on mass inspection for quality. Use statistical controls for incoming and outgoing goods.
4. Reduce the number of suppliers.
5. Recognize that there are two sources of quality problems: faulty systems (85%) and the production worker (15%). Strive to constantly improve the system.
6. Improve job training.
7. Provide a higher level of supervision.
8. Drive out fear by encouraging open two-way communications.
9. Break down barriers between departments so everyone can work together to solve mutual problems.

10. Get rid of numerical goals and slogans.

11. Examine closely the impact of work standards. Do they help anyone do a better job or are they actually impediments to productivity?

12. Teach statistical techniques. The rudiments can be learned in five-day crash courses.

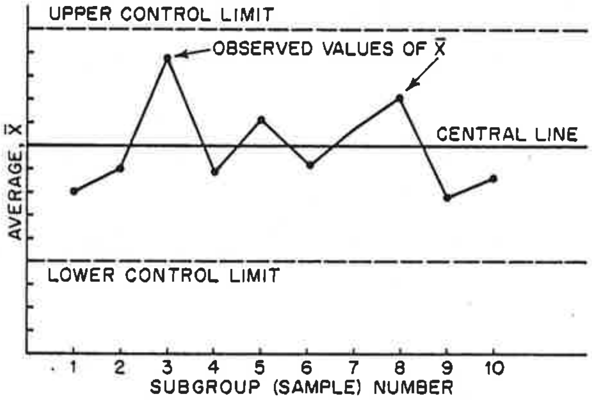
13. Institute a vigorous training program in new skills.

14. Make maximum use of the statistical knowledge and talent in the company.

The following is an outline of the statistical quality control method when applied to manufacturing production. A more technical discussion is presented in Reference 53.

Starting from management Point 5 above, courses of quality problems can be divided into <u>common causes</u> and <u>special causes</u>. Common causes are faults of the system; these make up about 85 percent of the problems. They remain until management changes the system. Special causes are specific to a worker or machine; these make up 15 percent of the problems. If special causes are identified when they occur, they can be eliminated by specific worker or machine adjustment action.

To determine sources of variation and their causes, the use of control charts is necessary. Data are obtained on one or more variables critical to quality (e.g., the dimension of a part). Figure 4-6 gives the simplest example of a control chart, plotting sample averages of a variable. If the upper and lower variables are at ±3S variation where S is the sample standard deviation, then over 99 percent of the sample averages <u>generated by a stationary statistical process</u> will fall within these limits. If this is not the case, that is if outlier points occur even after collecting a substantial amount of data for the averages, then it is fairly certain that the outliers are associated with special causes. By correlating the occurrence of outliers with particular machines, set-ups, workers, etc., these special causes can be



Source: Reference 53.

FIGURE 4-6. GENERALIZED CONTROL CHART FOR AVERAGES determined. Management point 8 is important: in the absence of fear and an atmosphere of blame, workers and foremen can cooperate with engineering staff and perform an honest search for these special causes. In Japan, the foremen are keeping the charts.

Once special causes are eliminated, the remaining variation is due to common causes which stem from the system. Eliminating some of these causes is a hard job which requires intelligent thought at all levels of the company, and is best done by groups working together. If the effort is successful, the range defined by the control limits in Figure 4-6 will narrow, but random variations can never be entirely eliminated.

Quality improvements due to elimination of special and common causes of variation will generally result in manufacturing cost reduction for two reasons. First, less or no end-of-the-line inspection has to be done to maintain quality of outgoing products. Second, only non-defective products can be measured as output but all products including defective ones contribute to total manufacturing cost.

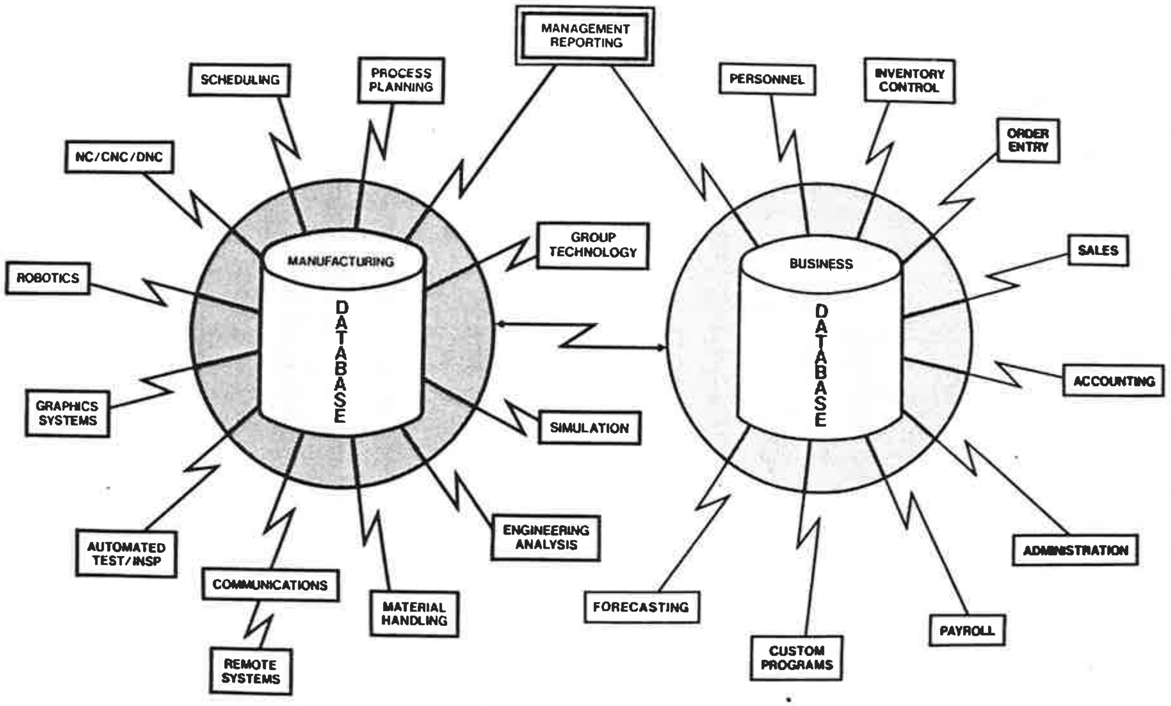
It is not worthwhile to make costly changes in the system to reduce variation that do not have corresponding quality and/or productivity benefits. To determine this, superpose acceptability limits on Figure 4-6 (e.g., acceptable dimension tolerances). The probability of units failing to be acceptable can be calculated from the statistics. If this probability is sufficiently low for the needs of the customer (the customer should know this number), penalty costs are small, and the productivity improvement to be gained from reducing the defect rate is sufficiently small, then further system changes should not be made. Problems with other products should be addressed instead.

Very recently in the United States there has been a renewed management commitment to SQC. The Nashua Company has used this management approach and has been happy with the results. The Ford Motor Company North American operations and GM's Pontiac Division have employed Deming to help them implement this method in their plants.

4.3 TOWARD THE AUTOMATED FACTORY

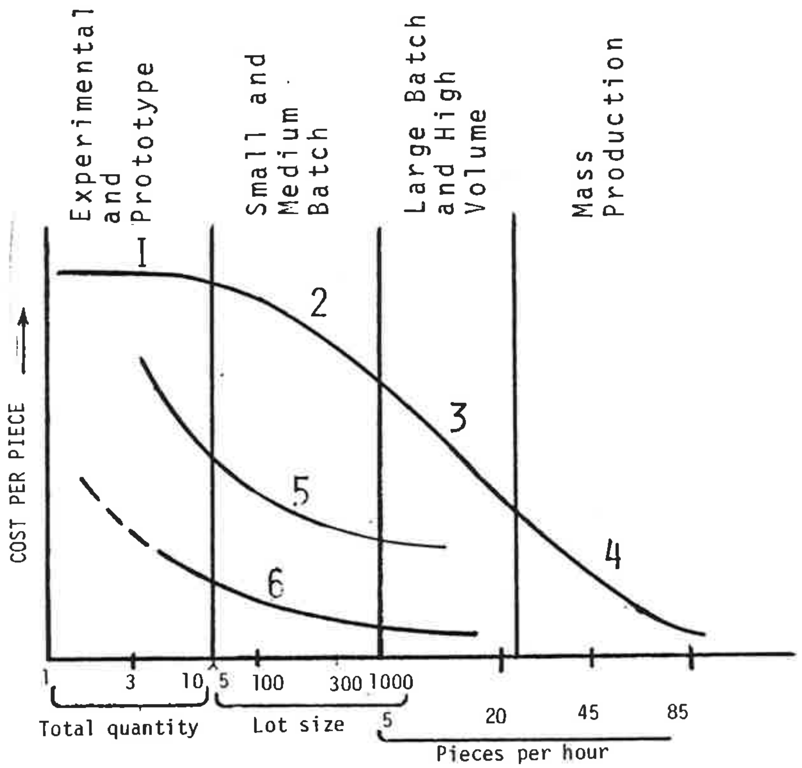
The combination of all the approaches discussed in Section 4.1 above is often called computer-integrated manufacturing (CIM). It should be emphasized that good management approaches as discussed in Section 4.2 are necessary for CIM to be strongly effective in improving productivity. Figure 4-7 gives an overview of CIM. The CAD/CAM data base is extended to support all manufacturing functions. In addition, a business data base which is related to the manufacturing data base, as described in Section 4.2.1 on manufacturing resources planning, supports all the demand planning functions. The demand planning imposes requirements on manufacturing output, which in turn is a guide to manufacturing planning. Within manufacturing planning, CAD/CAM leads automatically from design to tooling, and links with flexible manufacturing and group technology in production planning.

Figure 4-8 shows the potential cost reduction due to computer integrated manufacturing. For small, medium, and large batch volumes, CIM cost could be substantially lower than the costs of competing approaches. Only in the highest volume of mass production can automatic transfer lines not be improved upon, and this assumes continued production of the same designed part over a long period of time. This condition is satisfied less and less often in the changing automobile industry of today.



Source: Productivity International, Inc., Dallas, Texas.

FIGURE 4-7. ARCHITECTURE FOR COMPUTER INTEGRATED MANUFACTURING



Key: 1 - Tool Room Machinery
2 - General Purpose Machine Tools
3 - Special Purpose Machines
4 - Automatic Transfer Lines
5 - NC and CNC Machine Tools
6 - Computer Integrated Manufacturing Systems.

Source: Barash, "Computer Integrated Manufacturing Systems," Proceedings of ASME Winter Annual Meeting, 1980.

FIGURE 4-8. DEPENDENCE OF MACHINING COSTS UPON MODE OF PRODUCTION AND EQUIPMENT

5. USE AND IMPACTS OF ADVANCED MANUFACTURING PROCESSES IN MOTOR VEHICLE PRODUCTION

Automation is rapidly being implemented in the motor vehicle industry. Table 5-1 summarizes the comparative levels of automation (as of 1980) in the three major automobile producing regions: Japan, North America and Western Europe. The big difference between Japan and North America is the greater automation of Japanese stamping plants, which have quick die change (QDC) presses as standard equipment. North American presses generally require manual die changes, taking much longer, but QDC is being introduced. The state-of-the-art in machining is similar in the two areas, but some North American engine lines have not been modernized and are less efficient than new lines. Assembly plants are similar in automation but North American plants are more labor intensive. Western Europe is similar to Japan except in the case of assembly where it resembles North America.

There are other measures of comparative automation. Figure 5-1 shows that, in Japan, almost 90 percent of body welding is done using automated techniques, while in North America the figure is just over 50 percent. Western Europe is in between. Table 5-2 shows the number of robots used to produce 10 million vehicles annually in 1980. Japan is way ahead in robot use with 7,390 robots for this level of production, compared with 1,670 in Western Europe and 1,480 in North America. Japan is well ahead of the other regions in robot use for each of the functional areas of assembly, stamping, engine and transmission, and components and other. Western Europe exceeds North America in assembly robot intensiveness but lags in the other functional areas.

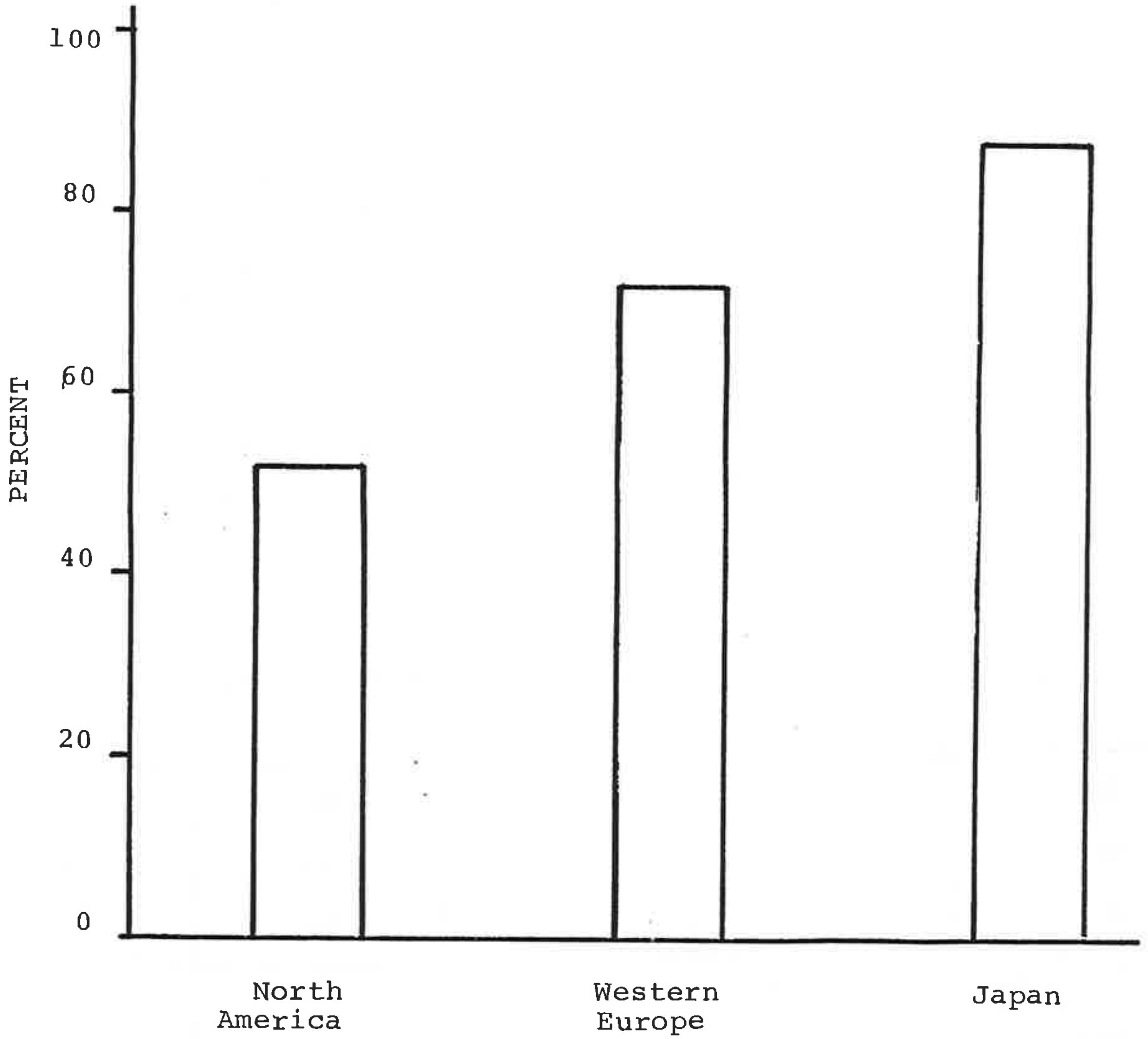
Figure 5-2 shows the tremendous increase in robot use in the North American automobile industry that is anticipated during this decade along with the expected shift of use. In 1980, the major use of robots was in welding; by 1990, the major use is expected to be in assembly, followed by fabrication and machining, with welding third.

TABLE 5-1. COMPARISON OF AUTOMATION LEVEL IN THE AUTOMOBILE INDUSTRY: JAPAN, NORTH AMERICA, AND WESTERN EUROPE

COMPARISON OF AUTOMATION LEVEL IN THE AUTOMOBILE INDUSTRY: JAPAN, NORTH AMERICA, AND WESTERN EUROPE

SUBJECT	JAPAN	NORTH AMERICA	WESTERN EUROPE
STAMPING	QUICK DIE CHANGE PRESSES USED ALONG WITH HIGH DEGREE OF AUTOMATION BETWEEN PRESSES. DIE CHANGES TAKING 5-10 MINUTES PERMIT SHORT CYCLES, REDUCING NEED FOR IN-PROCESS INVENTORIES. LOW MANPOWER NEEDED.	PRESSES REQUIRE MANUAL DIE CHANGES TAKING 6 TO 8 HOURS. SOME LINES ARE AUTOMATED TO SAME DEGREE AS JAPANESE BUT MOST ARE NOT. LONGER CYCLES, HIGHER INVENTORIES AND GREATER MANPOWER REQUIREMENTS THAN JAPANESE.	SIMILAR TO JAPANESE OPERATIONS.
MACHINING	TRANSFER LINES UTILIZED FOR MACHINING MAJOR COMPONENTS. CASTING OPERATION TIED INTO MACHINING OPERATION.	SIMILAR TO JAPANESE BUT SOME OLDER ENGINE LINES NOT EFFICIENT AS NEW LINES.	SIMILAR TO JAPANESE OPERATIONS.
ASSEMBLY	WITH THE EXCEPTION OF A FEW VERY HIGHLY AUTOMATED BODYSHOPS, JAPANESE ASSEMBLY PLANTS ARE SIMILAR TO NEWLY TOOLED SMALL CAR PLANTS IN NORTH AMERICA.	SIMILAR TO JAPANESE BUT MORE LABOR INTENSIVE.	SIMILAR TO JAPANESE BUT MORE LABOR INTENSIVE.

SOURCE: ARTHUR D. LITTLE INC., BASELINE DATA OF QUALITY CONTROL SYSTEMS, DECEMBER 1980.



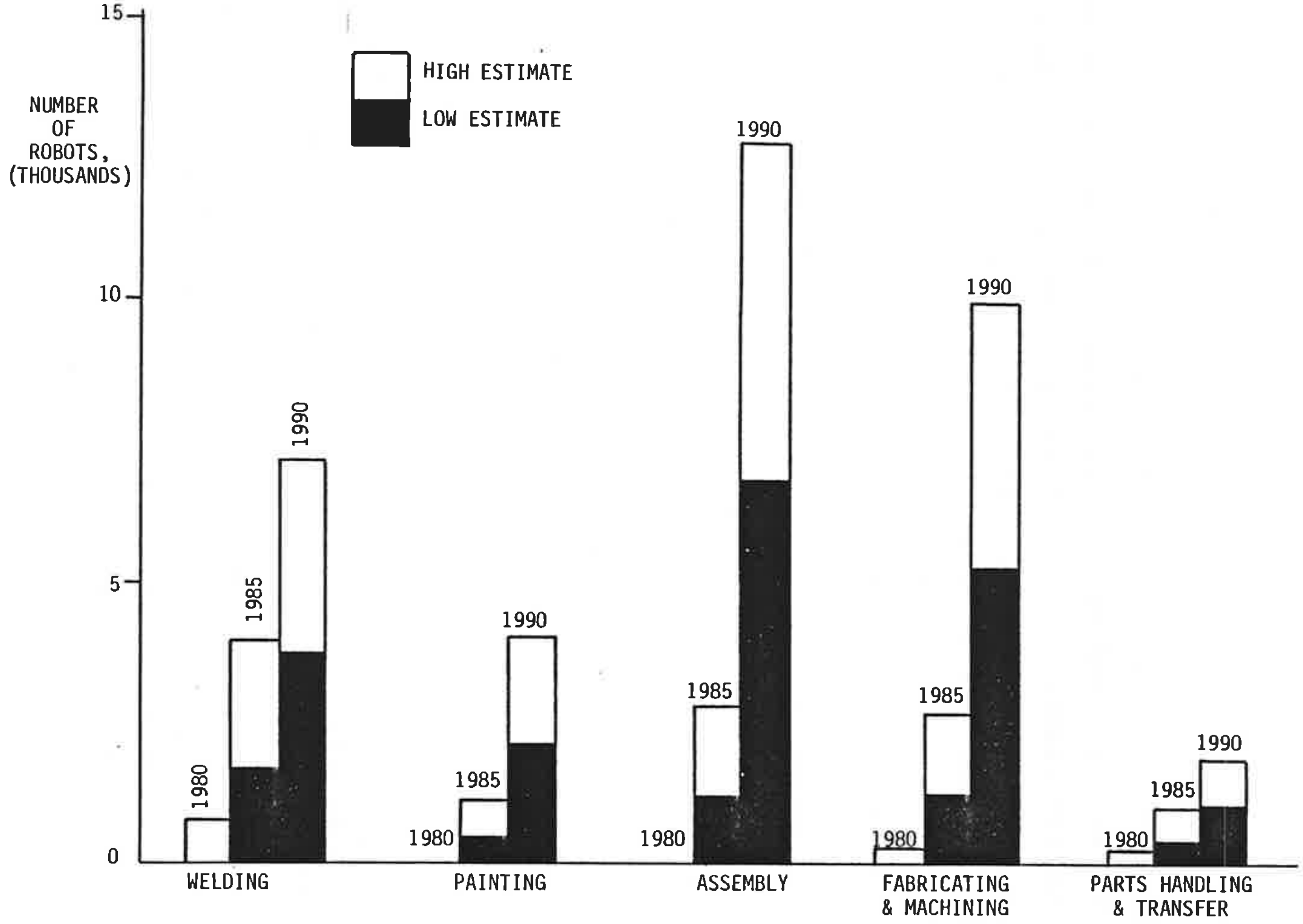
SOURCE: Tanner and Adolfson, <u>Robotics use in Motor Vehicle Manufacture</u>, 1982

FIGURE 5-1. PERCENT OF BODY WELDING DONE WITH AUTOMATION IN THE AUTOMOBILE INDUSTRY IN NORTH AMERICA, WESTERN EUROPE AND JAPAN, YEAR-END 1980

TABLE 5-2. NUMBER OF ROBOTS USED TO PRODUCE 10 MILLION VEHICLES ANNUALLY, 1980

SECTOR	TOTAL ROBOTS	ASSEMBLY	STAMPING	ENGINES & TRANSMISSIONS	COMPONENTS & OTHER
NORTH AMERICA	1480	1150	60	110	160
WESTERN EUROPE	1670	1490	20	90	70
JAPAN	7390	3590	940	1970	890

SOURCE: Tanner and Adolfson, Robotics Use in Motor Vehicle Manufacture, 1982



SOURCE: Tanner and Adolfson, Robotics Use in Motor Vehicle Manufacture, 1982

FIGURE 5-2. ROBOT USE IN THE NORTH AMERICAN AUTOMOBILE INDUSTRY BY FUNCTION, CURRENT AND PROJECTED

The following are highlights of advanced manufacturing processes that have recently been introduced or are now being introduced into the motor vehicle industry. Highlights of management approaches are discussed first, followed by automation highlights.

Just-in-time production is being tried in many U.S. plants. General Motors' Michigan assembly plants determine need for engines, axles, and transmissions on the following day and arrange for delivery of the right number of these components before the next day's production starts. A more limited, experimental program is being tried at GM's Linden, N.J. and Tarrytown, N.Y. assembly plants. Saginaw Steering Gear plans to reduce in-process inventories by 25 percent using a just-in-time system. Buick intends to inaugurate the system on a mid-1980's car line to be built in Flint, Michigan; 80 percent of the parts would come from within a 60-mile radius of the plant with daily shipments.

A Ford truck plant in Louisville, Ky. is being supplied with drive shafts by Dana Corp. under a just-in-time arrangement. Also Ford's Wayne, Michigan assembly plant is supplied from the Utica trim plant twice a day, and its Saline plastics plant supplies instrument panels to Wixom, Michigan assembly daily on a just-in-time basis. However, the system did not work when the Wayne plant was linked with Dearborn engine, due to option complexity. Ford plans to further implement the system through computer information links involving 11 assembly plants, 13 manufacturing plants, and eight outside suppliers producing 700 different parts.

Chrysler has an experimental just-in-time program feeding its Belvidere, Ill. assembly plant from Trenton, Michigan engine and Kokomo, Ind. transmission plants on a daily basis. American Motors is planning to have up to 40 suppliers providing equipment on a just-in-time basis to its 1983-model Alliance assembly in Kenosha, Wisc. It will stick with a determined assembly schedule for three weeks into the future, with each day's production set for the next week and variations from planned production being limited during the following two weeks. Nissan and Honda are selecting suppliers based on their capability to participate in a just-in-time process for their planned light truck and car production in Smyrna, Tenn. and Maryville, Ohio respectively.

The use of two shifts with extensive maintenance work in between, a procedure long used in most Japanese auto plants, is now being adopted by U.S. manufacturers in their machining operations. (Assembly plants have always been on two shifts). The added maintenance allows increased uptime of machining lines, thereby increasing production per hour. The use of two nine-hour shifts instead of three eight-hour shifts with the increased production rate results in almost the same average daily production. Examples are the following:[54]

1. At Chevrolet's Flint Motor plant, productivity on the block line increased nearly 50 percent after the change to two shifts and the plant saves $1.5 million annually.
2. At Buick's engine plant, productivity gains after the change to two shifts has freed one block line which can be retooled for a new engine.
3. GM's Saginaw Steering expects uptime improvements of 10 to 20 percent after the change to two shifts on transfer lines that make housings for hydraulic steering pumps and steering gears.
4. At Ford, all machining operations have been reduced by 10 to 30 hours per week after the change to two shifts, with only 5 percent loss in production capacity and substantial cost saving.

The Ford Motor Company and the Pontiac division of General Motors have applied statistical quality control (SQC) to the greatest extent among U.S. auto manufacturers. Both have employed Dr. W. Edwards Deming as a consultant to get them started. Ford's program is credited with reducing consumer-perceived defects in new cars by 48 percent in two years, compared with 24 percent for Chrysler and 12 percent for GM.[55] In Pontiac's 2.5-liter engine plant, the rejection rate of engines in final test fell from 2.1

per thousand before implementation of SQC to 0.6 per thousand after implementation. Also, the cost of repairing faulty engines is down and in-plant inventories of spare parts needed for repair have decreased from $3.8 million to $0.8 million.[55]

GM's Quality of Work-Life Program, begun in 1973, and Ford's Employe Involvement Program, begun in 1980, deserve mention as helping to provide a climate of cooperation between management and labor which is necessary for realization of most productivity improvements.

In automation areas, Chrysler leads in application of CAD/CAM. Its CAD system with 500 computer graphics terminals has reduced engineering manpower requirements for design and will allow a total computer-aided design of the passenger car by 1985. Chrysler is hooking up the tool and die operations of its stamping and assembly divisions to the CAD/CAM data base, which will expedite NC programs for the machine tools. Chrysler has also linked its data base with three vendors, making the vendors' design tasks easier.

General Motors, as discussed earlier, has a substantial in-house capability for computer-aided design, but is just starting to have on-line connections with vendors. Ford is also starting to have the same kind of connection with its vendors.

A number of U.S. plants have implemented various aspects of automated assembly. GM's Chevrolet Motor Division is installing a non-synchronous, flexible assembly system for 1.8-liter and 2-liter gasoline engines at the Flint, Mich. plant, which will be one of the most automated installations of its kind. It will reduce manual assembly requirements by up to 50 percent.[56] American Motors has purchased a number of robots from Cybotech and Unimation for assembly of the 1983 Renault Alliance cars in Kenosha, Wisc. Framing and respot welding operations will be performed automatically. GM is installing a flexible assembly operation at the Oklahoma City plant, enabling them to assemble the front-wheel-drive Citation and the new front-wheel-drive intermediate on the same line at varying mix between the two. Chrysler's renovated

St. Louis assembly plant welds using the Robogate system; the floor panel (including the engine compartment panel) and the two sides of the body are locked into place and automatically welded. This creates identical body dimensions in the vehicles. Subassembly welding is done with multiwelders, and painting is almost totally automated. The Renault plant in Douai, France employs 125 robots and can switch easily among three different models (R-5, R-9 and R-14) or ten different variations of the R-9.

General Motors plans to use 14,000 robots by 1990 and has recently entered into a partnership with Fujitsu Fanuc to produce robots for its own use and also to market them. Renault has entered a joint venture with Ransburg Corp., creating a U.S. subsidiary called Cybotech, which will design and produce robots for Renault and American Motors plants as well as for sale to others.

Table 5-3 presents a representative list of advanced manufacturing processes being applied in the motor vehicle industry. The list is organized by plant type, and within each plant type by manufacturer and division or plant. A summary is presented of the process or innovation; the year implemented and costs and benefits are presented when available. Benefits are in the form of increased production rates, decreased time per operation, reduced labor requirements, improved quality, increased uptime, etc. Advanced manufacturing processes have been documented for the following plant types: car assembly, light truck assembly, stamping, electronic component, plastic, glass, forge, auto and light truck engine, medium and heavy truck engine, transmission, transaxle, axle, brake, engine components, and steering.

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Car Assembly	GM	Buick Division	Plans to have suppliers use a Just-in-Time system.	1982	-
	GM	Orion Michigan	Extensive use of robots planned	1983	-
	GM	Oklahoma City, OK	Flexible assembly system	1982	Allows different models to be assembled on the same line
	GM	Doraville, GA	Numerical control robot painting system	-	-
	GM	Norwood, Ohio & Leeds, MO	Robot operated body inspection systems	-	$20,000/probe - 100% quality inspection
	GM	Willow Run, Michigan	Robot to perform metal preparation for car bodies	1981	-
	GM	Bowling Green, Ky.	Use of solvent-based enamel paint to paint metal and urethane body components on the same line	1981	Produces a more glamorous finish and requires less heat for curing
	GM	Indianapolis, Indiana	32 station, 160 foot-long, crimping welding and hemming line to assemble doors	1981	25-30% faster than conventional door welding systems

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Car Assembly (Continued)	GM	Leeds, Mo.	24 robots for automatic respot welding and body gaging	1981	Assurance of proper fit at 20-30 different points
	GM	Lordstown, Ohio	Experimenting with Kan-Ban; stamping plant located adjacent to assembly plant; using rapid die change technology	-	-
	GM	Wilmington, Delaware	14 robot stations for body welding	-	-
	GM	Linden, N.J and Tarrytown, N.Y.	Testing the Kan-Ban system	-	-
	GM	Pontiac Division	Initiated the use of statistical quality control in a number of key operations	-	-
	GM	Zaragosa Spain	Body shop with 104 robots, 98% automated	1982	-
	Ford	Kansas City, Kansas	33 Unimate robots used to spot and respot welds	1981	$2m
	Ford	Wayne, Michigan	Receives only those engines needed for assembly on a daily basis from the Dearborn Engine plant	-	-

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Car Assembly (Continued)	Ford	Wixom, Michigan	An advanced robot gaging system uses contact-type linear displacement transducers to check the bodies of cars	1980	-
	Ford	Assembly	Robots check the dimensions of body shells	1981	Can check 5-6 per hr. instead of 1-2 per 8hrs. with same level of support
	Chrysler	All plants	Increasing the use of statistical quality control methods	1982	-
	Chrysler	All plants	Use of mass relief rather than traditional tag relief	1981	Fewer workers needed, less production but greater efficiency and quality
	Chrysler	St. Louis Missouri	Automated welding, painting, transfer, storage; electronic testing	1981	$75m
			Use of CAD/CAM to design assembly line	1981	-
			Use of programmable controllers	1981	-
	Chrysler	Detroit & Newark, N.J.	Robot welders and an automatic body framing system	1980	Output increased from 60 to 75/hr.
	Chrysler	Belvidere, Illinois	Robots perform 80% of body spot welding	1978	Production boosted 17%

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Car Assembly (Continued)	AMC	Kenosha, Wisconsin	28 robots for use in assembling the Renault Alliance	1983	-
	Nissan	Japan	Considering extensive use of robots in all painting lines	-	-
	Renault	Douai, France	Robots perform 40% of all assembly operations	1981	-
	Honda	Marysville, Ohio	Use of automatic paint spraying and programmable robots	1982	-
	Volvo	Gothenburg, Sweden	Fully automatic 10-station body welding line using 27 robots	1978	47% of welding is automatic - uptime of 85% on welding line
	Fiat	Italy	Using over 200 robots for body welding	1977	-
	Toyota	Tahara	Flexible assembly lines, high level of pressing and welding automation, automatic storage and transfer, Just-in-Time production	1982	-
Light Truck Assembly	AMC	Toledo, Ohio	26 robots work on 3 automated welding lines	1981	$5m
			Computer vision scans body mounting points to determine the number and type of shims needed to assure a correct body fit	1980	-

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Light Truck Assembly (Continued)	Nissan	Tennessee	Robots used for painting; will use Japanese management methods; automated transfer and storage lines	1983	-
	IHC	Chicago	Uses a manufacturing control language that combines off-line robot programming with total manufacturing cell control	1982	-
			Uses 60 robots for welding, material handling, and painting	-	-
	GM	Truck and Coach Division	Uses 22 robots and 12 flexible automated welding machines	1981	87% of all welds performed automatically
	GM	Morraine Ohio	Limited Kan-Ban system for truck seats-supplier must move to within 2 miles of the assembly plant	1982	-
			Quality of work life program	1981	Absenteeism and grievances decreased
Stamping	GM	Flint metal stamping plant	Combination 6-station dial and 11-station in-line subassembly and welding transfer machine joins pieces of subassemblies	1982	600 parts joined/hour
	GM	J-cars	"net-hole" process of stamping body panels	1981	Assures proper fit of

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Stamping (Continued)	Ford	Walton Hills stamping plant	Established an environment of participative management known as "employee involvement"	1981	Saved the plant from being closed due to low productivity
	Ford	Stamping	Use of quick die change	1981	Time required to change dies reduced from 6-12 hrs. to 5-10 minutes
	Honda	Sayama, Japan	Robots handle stampings through presses	-	7-press line operates with four workers instead of 28
Electronic Components	GM	Delco Electronics Kokomo, Indiana	Computer vision system inspects circuit chips used in electronic ignition systems	1977	-
Plastic	GM	Oshawa, Canada	12 machine operation for mass-production of reinforced RIM	1982	-
	GM	Buick Plastic Plant	Electronic factory control system that oversees the entire plant operation	-	Consistent cycle time
	GM	Saline, Michigan	Delivers instrument panels on a daily basis	-	-
Glass	Ford	Dearborn Glass Plant	"Employe involvement" program	1981	Doubled productivity for special projects

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Forge	GM	Chevrolet Detroit Forge	Automated forge operations	1978	Substantial cost reductions
	Alfa-Romeo	Italy	Robots load and unload forging presses	-	Reduces labor by 50%; increases production by 5% to 20%
Auto and Light Truck Engine	GM	Flint, Michigan	A programmable controller system controls all machine movements	1981	-
	GM	Morraine, Ohio	Robots handling loading and unloading; fully automated test stands; uses a work team approach; daily shipment of parts	-	Increasing output from 600 to 810/day
	GM	St. Catherines Canada	Automatic gauging, classifying and marking system for camshaft, crankshaft and distributor bases	1981	Permits instant calibration
	GM	Pontiac Engine	New Just-in-Time program; statistical quality control methods; quality of work life programs	1982	Inventories at plant reduced 50%
	GM	Chevrolet Motor	Electro-optical laser inspection equipment	1982	More accurate and consistent inspection

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Auto and Light Truck Engines (Continued)	GM	Flint Engine Plant	12 robots used for machine loading and engine assembly	1981	$1.8m
	GM	Tonawanda, N.Y.	Uses programmable robots for machine loading and unloading	1981	-
	GM	Cadillac Engine Livonia, Michigan	Wide range of automatic operations, (CAM) computerized machine monitoring and maintenance, automated parts storage, an engine hot test system, new worker-management relations program	1981	Low absence rate
	GM	Flint Engine Plant	Cameras inspect cylinder heads for valve keys	1980	-
	GM	Delta Township Michigan	Engine blocks are bore-gauged automatically and classified into as many as 9 different sizes for selective piston fits	-	-
	GM	Saltillo, Mexico, St. Catharines, Ontario Dayton, OH	3 engine block broaching machines	1979	$5.5m

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Auto and Light Truck Engines (Continued)	Ford	Dearborn Engine Plant	Programmable 27-station weld-assembly system to put 5 different sizes and styles of gas tanks together for at least 8 different vehicles	1982	450 tanks/hr.
	Ford	Windsor, Ontario	Laser etches code symbols on engine components and enters codes into permanent records	1981	Provides information on all engines produced at the plant
	Ford	Dearborn, Michigan; Cleveland Ohio	Computer system to streamline receiving and warehousing	1980	$1.5M/yr. savings
	Ford	Chihuahua, Mexico	Potential for manual or robot application everywhere	1983	-
	Ford	Windsor, Ontario	Programmable controllers, highly automated assembly machines, high speed transfer lines, computer controlled test equipment	-	-
	Chrysler	Trenton, Michigan	Ships engines to the Belvidere assembly plant on a daily basis	1981	-
	Iveco	Sofim, Italy	Robots, automatic machining and testing equipment	1978	-

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Auto and Light Truck Engines (Continued)	Saab-Scania	Sodertalje Sweden	Robots to be used for transfer and assembly operators	1983	-
	Renault	Cleon, France	Shape recognition robot used for transferring components	1982	$150,000 payback in three years
Medium and Heavy Truck Engines	GM	Detroit Diesel Allison	Robotized washing system	1982	-
	Cummins	Lakewood N.Y.	Robotized machine loading	-	-
Trans-missions	GM	Windsor Ontario	25 robots lift transmission cases from a store and fit them into machine tools for cutting	-	-
	Ford	Livonia and Sterling Hgts. Michigan	Statistical process control programs	1982	-
	Ford	Sharonville, Ohio	2 robots load and unload parts	1981	-
	Ford	Bordeaux, France	Robot used to speed up gearbox production	1981	-
	Ford	Batavia, Ohio	Laser inspection system	-	-

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Transaxle	GM	Saginaw Steering Gear Division	Computer numerical control machines for two spindle vertical turning	1980	-
	Ford	Dearborn, Michigan	Automated laser welding station to produce planetary gear carriers	1983	-
	Ford	Batavia, Ohio	Ford's most computer-integrated facility-robots, numerical controls, 125 tool compensation systems		-
Axles	Eaton Corp.	Glascow, Kentucky	2 robots used for production of medium and heavy duty truck axles	1982	-
	Hayes-Dana	Axle Division Barrie, Ontario	18 computer controlled robots used in arc welding 6 different families of axle housings	1979	-
	Ford	West Germany	Automatic welding operation to produce rear axles	-	-
Brakes	GM	Chevrolet Saginaw, Michigan	Disk brake rotor gaging machine that inspects 400 rotors/hr. checking 13 factors	1981	$300,000
	GM	Chevrolet	Increased use of ceramic cutting tools to produce disc brake rotors and diamond tool machining	-	-

TABLE 5-3. ADVANCED MANUFACTURING PROCESSES IN THE MOTOR VEHICLE INDUSTRY (CONTINUED)

PLANT TYPE	MANUFACTURER	DIVISION OR PLANT	PROCESS OR INNOVATION	YEAR IMPLEMENTED	COSTS AND BENEFITS
Engine Components	GM	Diesel Equipment	6 laser inspection systems to check valve lifter blanks for porosity	1980	$400,000
	GM	Buick Division	Transfer machining with diamond tooling, direct current slide drives, automatic gaging and automatic tool wear compensation for the production of aluminum pistons	1983	900 pistons/hr. production rate
	GM	Detroit Diesel. Allison Division	3 pallet transfer machines to produce rocker arms	1979	250 parts/hr.
Steering	GM	Saginaw Michigan	Beginning to use a Kan-Ban system	1981	Goal to reduce floats and in-process inventory by 25% by model year 1982

APPENDIX A

GLOSSARY OF COMMON TERMS USED IN DISCUSSION OF INDUSTRIAL AUTOMATION

Adaptable—Capable of making self-directed corrections. In a robot, this is often accomplished with visual, force or tactile sensors.

Adaptive Control—A control method in which control parameters are continuously and automatically adjusted in response to measured process variables to achieve better performance.

Analog Control—Control involving analog signal processing devices (electronic, hydraulic, pneumatic, etc.).

*Analog-to-Digital Converter (A/D) - A device that changes physical motion or electrical voltage into digital signals consisting of ones and zeros.

Automation - Automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human organs of observation, effort, and decision.

*Batch Manufacturing, Batch Production - Non-continuous processing of unlike parts.

*Central Processing Unit (CPU) - A unit of a computer that includes circuits controlling the interpretation and execution of instructions.

*Chip - (1) Integrated circuit. (2) An integrated circuit mounted on a base to enable connection to a larger circuit.

*Computer-Aided Design (CAD) - A design or drafting system whereby an operator interacts with a computer system to carry out a function. The computer serves as a calculation, storage, record keeping and formatting device, but does not make decisions.

*Computer-Aided Manufacturing (CAM) - The effective utilization of computer technology in the management, control, and operations of the manufacturing facility through either direct or indirect computer interface with the physical and human resources of the company.

Computer-Aided Manufacturing International (CAM-I) - A nonprofit R&D organization to advance CAD/CAM technology, supported by industrial companies, educational institutions and government agencies in North America, Europe and Japan, and located in Arlington, Texas.

*Computer Graphics - A person-oriented system which uses the capabilities of a computer to create, transform and display pictorial and symbolic data.

Computer-Integrated Manufacturing (CIM) - a system incorporating CAD/CAM and managerial elements to lead, to the greatest extent possible, toward a fully automated factory.

*Computer Numerical Control (CNC) - The use of a dedicated computer within a numerical control unit with the capability of local data input.

Continuous Path Control - A control scheme whereby the inputs or commands specify every point along a desired path of motion.

*Data Base Management Systems (DBMS) - System software which controls and supervises the updating, editing, and executing of items from files in a multi-user environment.

*Data Bus - A common highway which allows coded data in a parallel or series mode to be transmitted between processors or subsystem components.

Digital Control - Control involving digital logic devices which may or may not be complete digital computers.

Direct Numerical Control (DNC) - A system connecting a set of numerically controlled machines to a common memory for on-demand distribution of data to the machines.

Fixture - Device used to hold a part such that its reference axes are in a defined orientation with respect to the reference axes of a tool; may or may not be an integral part of a pallet.

Flexible Manufacturing System, Flexible Machining System (FMS) - A system containing programmable machine tools and transfer devices to take parts from one tool to another, all under central computer control.

Gauging - The process of measuring a dimension or group of dimensions according to some standard.

Gauging, In-Process - Gauging performed on partially finished parts while they are still in the manufacturing process.

*Group Technology (GT) - (1) The means of coding parts on the basis of similarities of the parts. (2) The grouping of parts into production families based on similarities in their production so that the parts in a particular "family" could then be processed together. (3) The grouping of diverse machines together to produce a particular family of parts.

Industrial Robot - A reprogrammable multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

*Integrated Circuit (IC) - An electronic circuit that is packaged as a single small unit, ranging in size from about 0.3 inches square to about 2 inches square. The circuits vary in complexity and function from simple logic gates to microprocessors, amplifiers, and special devices such as A/D and D/A converters. If the integrated circuit is constructed on a single semi-conductor substrate, it is called monolithic.

Integrated Computer-Aided Manufacturing (ICAM) Project - An Air Force project with a goal to organize every step of aircraft manufacturing around computer automation. Part of the Manufacturing Technology Program, Air Force Material Laboratories, Wright-Patterson Air Force Base, Ohio.

Intelligent Robot - A robot which can be programmed to make performance choices contingent on sensory inputs.

*Large-Scale Integration (LSI) - Refers to monolithic integrated circuits of high density. Such circuits typically have on a single chip the equivalent of hundreds to thousands of simple logic circuits.

Machining Center - A module which is capable of performing a variety of metal removal operations on a part including drilling, milling, boring, etc., usually under automatic control.

Manufacturing Resources Planning (MRP, MRP-II) - Planning and monitoring all of the resources of a manufacturing company: manufacturing, marketing, finance and engineering. MRP-II incorporates the capability of Material Requirements Planning and uses the output from the latter to generate financial information. Simulations can be performed to anticipate the effects of uncertain demand for the company's products on the manufacturing schedule and on financial performance.

Material Handling System (MHS) - System or systems used to move and store parts, as well as materials used in processing the parts (e.g., tools, coolant, wastes).

Material Requirements Planning (MRP) - Originally, a technique used to take finished product requirements, bills of materials and inventory records to generate the material requirements for the finished product. Has been further developed to generate a master production schedule, capacity requirements, plant scheduling and vendor scheduling. Includes the capability to simulate the manufacturing process to check the feasibility of a master production schedule to meet the finished product requirements desired by marketing.

*Microcomputer - A computer that is constructed using a microprocessor as a basic element of the CPU.

*Microprocessor - A basic element of a CPU that is a single integrated circuit.

*Medium-Scale Integration (MSI) - Refers to monolithic integrated circuits having typical complexities of 10 to 100 simple logic circuits.

Numerical Control (NC) - Automatic control of a process performed by a device that makes use of numeric data usually introduced as the operation is in progress.

Pallet - Device which serves as a standardized conveyance for the part in a flexible machining system; may or may not be an integral part of a cart.

Part Family - Generic family of parts based either on form (e.g., parts of rotation, prismatic parts) or manufacturing technology (e.g., stamped parts, milled parts).

Part Program - A set of instructions in the control language and format necessary for a machine to perform the operations required to produce a given part.

*Pattern Recognition - Theory or method to automatically recognize patterns of data read or input mechanically. The identification of shapes, forms, or configurations by automatic means.

Pick-and-Place Robot - A simple robot, often with only two or three degrees of freedom, which transfers items from place to place by means of point-to-point moves. Little or no trajectory control is available. Often referred to as a "bank-bank" robot.

Point-to-Point Control - A control scheme whereby the inputs or commands specify only a limited number of points along a desired path of motion. The control system determines the intervening path segments.

*Process Control - Pertaining to systems whose purpose is to provide automation of continuous operations.

Production Plan - Information required to produce a desired system output; information includes part numbers, quantities, tools, machines, schedules, etc.

Programmable Controller (PC) - A solid-state device designed to perform logic decision-making for control applications.

*Random-Access Memory (RAM) - An IC containing a functionally complete portion of a read-write memory, any of whose storage cells can be addressed. The chip or package usually contains the decoding logic and may also contain the sense amplifiers.

*Read-Only Memory (ROM) - A storage device generally used for control programs, whose content is not alterable by normal operating procedures.

Sensor - A transducer whose input is a physical phenomenon and whose output is a quantitative measure of the physical phenomenon.

Servo-Controlled Robot - A robot driven by servomechanisms, i.e., motors whose driving signal is a function of the difference between commanded position and/or rate and measured actual position and/or rate. Such a robot is capable of stopping at or moving through a practically unlimited number of points in executing a programmed trajectory.

Statistical Quality Control - The application of statistical principles and techniques in all stages of production, design, maintenance and service, directed toward the economic satisfaction of demand.

Transfer Line - Group of work stations closely connected together by an automated material handling system and designed for high-volume production of single part number or very similar part numbers.

Very Large-Scale Integration (VLSI) - Refers to integrated circuits containing 100,000 or more components on a single chip.

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