A LOGICAL MODEL OF INTEGRATED MANUFACTURING

A Thesis
Presented to the Faculty of Graduate Studies
The University of Manitoba
in Partial Fulfilment
of the Requirements for the Degree of
Master of Science
in
Mechanical Engineering
(Industrial Engineering Program)

by

Jeffrey S. Russell

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ABSTRACT

This work constitutes the thesis component of a Master of Science degree in Mechanical/Industrial Engineering on the topic of the development of an integration model for advanced manufacturing in Canada and was carried out during the period of April, 1987 to April, 1988.

Data collected and proposals put forward refer to the machinery and metalworking industries across Canada. Closely related manufacturing sectors include the automotive, aerospace, farm equipment, machine shops, metal fabricators, and tool and die makers, among others. The range of industries under study represents approximately 50% of users of automation in Ontario today. This represents 70% of all such industries in Canada according to the Ontario Ministry of Industry, Trade and Technology (24).

The scope of this thesis covers the following objectives:

1. to develop a model of the sequential steps that have been followed by manufacturers in the Canadian manufacturing sector during their introduction of advanced manufacturing systems (AMS);
2. to outline the future steps being proposed by that same group of manufacturers;
3. to analyze and discuss the utilization of manufacturing systems applications to date in Canada;
4. to develop a logical model of such integration in line with the needs of small Canadian manufacturers based on present day literature and available manufacturing technologies, drawing on available industrial experiences;
5. to document current factory floor utilization of microcomputer applications within the Canadian manufacturing population under study;
6. to develop a model of factory floor microcomputer adaptation paralleling the logical integration model;

7. to discuss the transfer of technology relating to various levels of the manufacturing organization;
8. to assess further areas of research into the continuing evolution, and more effective introduction of tomorrow's advanced manufacturing systems into Canadian industries.

Results of the Canada-wide survey of machinery and metalworking (MW&M) industries indicated that large manufacturers are clearly the more experienced users of automation. A direct correlation between the size of each firm (small, medium and large based on the numbers of employees), and the number of introductions into advanced manufacturing was found, revealing the following results:

% of Survey Respondents	Size of Firm		Number of Introductions
38%	Small Manufacturer	(1-75 employees)	1-4
27%	Medium Manufacturer	(76-400 employees)	5-8
35%	Large Manufacturer	(401-+ employees)	8-+

From the figures shown above, the small manufacturing group made up the largest percentage of survey respondents, 38% of 75, while introducing the lowest number of advanced manufacturing technologies. It is, however, encouraging to see a high activity of technological application by small manufacturers in Canada today. The future of Canadian manufacturing needs a strong presence of new technologies among all sizes of firms to remain competitive. The larger plants of today are scaling down production operations concentrating more on the assembly of the final end-product, which is placing the onus on smaller plants who are receiving an increase in subcontract work. Smaller manufacturers will need to increase part quality and the flexibility of their production facilities in order to stay abreast of a new manufacturing era.

Other important results of the survey included:

- A decreasing rate of computer-assisted information handling applications from large to small-sized respondents;
- Early introduction of NC/CNC machinery by all sizes of manufacturers;
- Lack of fundamental gorup technology concept and bar code technology

within the sample population;

- Reduction in the gap between automated information and part handling applications in the smaller manufacturers category;
- Lack of integration between automated information and part handling tasks;
- Domination of robotics and material handling applications by the large manufacturers of the survey respondents.

A logical approach to integrated manufacturing proposed in this thesis follows a building block sequential approach to new introductions of technology. Each introduction builds upon the previous one providing the educational skills, and cost savings necessary to implement the next attribute of advanced manufacturing. A logical approach to achieving systems integration spreads out the costs of new technologies, assisting the small manufacturer to adopt new methods of operating cost-effectively. A step by step sequence of new technological introductions allows for system requirements to arise logically instead of being forced upon the organization. Each system requirement can be controlled and monitored over a period of time, documenting the impact on personnel, productivity, quality, and market competitiveness.

The sequence of applications taken by all the survey's respondents did not suggest a clear reason for the order of each new introduction. By definition of each technology outlined in the survey, the sequential order of application by Canada's MW&M industry manufacturers did not follow a logical approach.

The Logical Model to Integrated Manufacturing proposed in this thesis places the emphasis on automated information handling (e.g. computer-aided design, computer-aided process planning, etc.) first before that of factory automation, or automated part handling. This approach assists in establishing a framework of structured databases at the management level, first which factory automation can eventually utilize to produce more efficiently. The step-by-step approach to systems integration assists communication between both computer-aided applications and the people that work around new workcentres. Proper communication links between new computer databases, and throughout organizational departments will have an important role in tomorrow's manufacturing successes.

ACKNOWLEDGEMENTS

First and foremost, all Canadian metalworking and machining manufacturers that responded to the survey must be thanked, for without them this thesis could not have been developed with original Canadian industry data. It was very encouraging to see that businesses of various manufacturing dimensions returned completed surveys that enabled definitive relationships to be derived. The data generated allowed us to develop our logical model of integrated manufacturing as discussed in the thesis.

The nine manufacturers that gave their time and energies for in-depth interviews must also be gratefully thanked for enabling in-house tours and investigations that generated additional new and exciting data.

Thanks to Professor Ostap Hawaleshka, Head of the University of Manitoba Industrial Engineering Program, who provided continual encouragement and knowledgeable input. The support staff of the department is also to be thanked for practical hands-on ideas, as should the computer staff for helping define the evolution of the microcomputer.

This thesis could not have been completed in the time taken without the unqualified support from my parents, June and Gordon Russell, now residing in Denver, Colorado who have always been available for me, and to Miss Gina daRoza who is a continual source of stability and happiness in my life. To these people, I thank you for putting up with me over the past year and for being there when I needed you the most.

My days as both an undergraduate and graduate student in the University of Manitoba's Industrial Engineering Department have been a great experience. From the excellent and friendly staff of professors to the state-of-the-art laboratories in advanced manufacturing systems made available to myself and fellow students, thoughts of the

school will always remain with me, and ideas and experiences gained from the past six years will be called upon during the years to come in the professional climate of engineering management.

I hope readers will find this thesis interesting. It is my hope that I may contribute to encouraging manufacturers across Canada in following a logical route of integration to available manufacturing technologies and concepts. Use the computer as a helpful and easy tool to manage information, but don't forget the people in your business who must communicate openly with information to and from workcentres. Don't expect a turn-key system from each new project, but perform the proper groundwork that will ensure long-term success of your investment and in the employees of your company.

Jeffrey S. Russell
B.Sc. (IE)
September 1988

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CHAPTER 1: INTRODUCTION

1.1 Integrated Manufacturing

In an effort to produce a low cost, high quality product within competitive markets on a regional or international level, manufacturers must fully comprehend the variety of applications associated with today's computer-assisted manufacturing operations.

The technology leading to higher productivity, greater product quality and customer service, lower manufacturing costs, and increased flexibility is available, but our postulate is that it is not only the technology itself, but the management of system implementation that will ultimately spell success. It is becoming more and more recognized as new manufacturing related technologies and concepts evolve, that great importance must now be put on the appropriate sequence of technology implementations. This aspect of advanced manufacturing is what this thesis sets out to accomplish.

Effective integration involves laying the foundation of computer-based technology so that each new technological step provides the tools necessary to accomplish the next step. Education, physical and/or conceptual relationships, allocated capital, coupled with human and technical expertise define the necessary managerial and financial attitudes that affect the successful transfer of technology into the workplace.

A well designed building block approach to factory system integration will have significant effects on education for, and application of new technologies and concepts. Ideally, technology transfer begins by correctly informing, and gaining support from the corporate decision level, followed by engineering staffs, and by factory floor supervisors and operators. Importance must be given to educating people in all areas of the organization so that everyone understands what is taking place, and is working towards common goals without fears of the unknown.

It is our belief that all types of manufacturers may progress into advanced manufacturing technologies if they follow an "integrated manufacturing" approach. This is different from the introduction of so-called flexible manufacturing systems (FMS) that have been heralded in recent times as the solution to North American manufacturing competitiveness (39). FMS applications may be suitable for larger producers, but not for the typical smaller manufacturers. Although sequential steps towards factory automation may eventually evolve into FMS-type applications, their organized integration aids effective introduction of technologies by spreading out up-front capital costs over a period of time, while reducing the learning curve effect of new technologies.

Canada's rate of adoption of advanced manufacturing systems (AMS) has been slow. The process of system integration represents the key to unlocking the application of available manufacturing technologies. It is hoped that this thesis may contribute to a better understanding of systems integration. As the maturity of computer-aided information handling surpasses that of factory-floor part handling, Canada's manufacturers are faced with new challenges in choosing proper steps to follow into uncharted technological waters. Exhibit 1 defines the various special technologies that make up the Advanced Manufacturing System (AMS).

1.2 The Computer Age

The main component of modern AMS is the digital computer. From the days of the large mainframe computer used in the early 1960's by manufacturers to process corporate-level data, evolved a fast, and cost effective means of acquiring, transmitting and manipulating data right on the factory floor. With increasing performance capabilities, coupled with decreasing costs, the microcomputer responds to the demand for application to the manufacturing workplace where real-time data is a must to ensure that quick action be taken on matters ranging from machine breakdown, work-in-process bottlenecks, to engineering change orders and part deviations.

EXHIBIT 1

Glossary of Related Technologies

Advanced Manufacturing System (AMS)

A generic title which covers a variety of technologies and applications which have experienced an advance in their state-of-the-art. The study has covered a wide variety of both information and part handling technologies and corresponding computer applications. The heralded FMS (Flexible Manufacturing System) was not included because of its inappropriateness to a large proportion of Canadian MW&M manufacturers due to an FMSs degree of advanced system integration.

Computer-Aided Design (CAD)

Encompassing computer hardware, software programs and peripherals applied to design and drafting activities. Other applications performed on a CAD include facilities planning and graphical simulation of plant layouts.

Computer-Aided Process Planning (CAPP)

A computer database of shop floor operations generated from engineering drawings and factory operational capabilities (i.e. machinery, manpower, tooling). Process planning encompasses operational methods, time standards, routings, and all tooling/fixturing required to complete a process. Establishing a computer database of process plans increases the information flow betweeen the shop floor, production control, and engineering so that design/process changes, job scheduling and manpower levelling can be easily accessible to all when needed. A CAPP database also generates a structured format for printout of shop floor work orders ensuring factory operator interpretation on shop floor organization.

Materials Requirement Planning (MRP)

MRP is a production control concept that integrates master production scheduling, inventory control and bills of materials into one operational system. Computerizing the MRP function helps generate quicker production transactions, while effectively managing the dynamics of the data incoming and outgoing.

EXHIBIT 1 (Cont'd)

Group Technology (GT)

Group Technology takes process planning one step further, linking the parameters of an operation with the shop floor workcentre. The concept uses similarities in operations, manpower, machinery, time standards, tooling, storage locations and raw materials to formulate part families of similar operational attributes. Extending group technology to the shop floor combines cells of machinery dedicated to processing certain part families. The conceptual phase of GT occurs at the process planning stage while execution of GT takes place with the formation of factory floor workcentres and material flow routings.

Bar Code Technology

A data acquisition tool enabling real-time monitoring of work-in-process, inventory and tooling. Parts and tools are marked with bar code identification made up of characters representative of Group Technology part families. By integrating with a bar code reader (pen-like wand, laser gun), part and tools can be easily identified by a pass over the bar code tab (or by aiming the gun at the bar code), downloading the information directly into a local computer for access by information management systems.

Computer-Aided Manufacturing

Integrating with computer-aided-design (CAD) on the factory floor using computer part/tool programs to communicate with NC machinery and robots for production processing.

NC Machinery

Numerically controlled machinery (mills, lathes, drills, edm's, laser cutters, etc.) automatically processes materials/parts via machine tool part programming through data links between the machine's processor and CAD/CAM computer workstations. Human input is still needed at NC stations to monitor incoming part quality, toolwear, coolant flow, programming problems, tool loading/unloading and part loading/unloading.

EXHIBIT 1 (Cont'd)

Automated Guided Vehicle (AGV)

A computer controlled vehicle used for the transport of work-in-process (WIP) through the factory environment. The platform that makes up the top side of an AGV is utilized for carrying part pallets, tooling and materials to critical workcentres needed for processing. AGV's represent a flexible and concise method of transporting WIP throughout the factory.

Robots

Reprogrammable linkage of pneumatically, hydraulically or electrically driven multifunctional manipulators used to handle, load/unload, monitor, assemble and process parts and tools with a high level of consistency.

Automated Storage/Retrieval System (AS/RS)

A generally large warehousing system containing a computer-controlled stacker crane used to input and retrieve stored parts, tools/fixturing and materials located in pre-defined storage bins all joined together.

Flexible

A commonly applied term used to describe manufacturing equipment and entire systems, i.e. Flexible Manufacturing Cell.

Manufacturing flexibility allows efficient runs of small part lot sizes over a period of time as product life cycles decrease with changing markets. Building flexibility in to a manufacturing business allows quicker changeover times and lower costs associated with changes in markets.

Computer-Integrated Manufacturing

An all-encompassing term used to describe the total integration of computer-assistance and communications from the top levels of a business down to the shop floor.

Larger mainframe computers do still play an important role in the manufacturing infrastructure, but mainly as database managers, for corporate information (37). The smaller producer entering the computer age can now easily start with a powerful microcomputer and graduate to mini and mainframe computers if increases in data manipulation, storage and processing activity warrant it. Enormous increases in a micrcomputer's dataprocessing and memory storage capabilities allow the smaller manufacturer to cost-effectively initialize efficient data management. The role of microcomputers must run in parallel with the introductions of automated hardware and support software at the shop floor level if full advantage of the new technology is to be taken. Their introduction on the factory floor allows for real-time operational data to be accessed locally and sent upwards into larger data management systems in the office.

All aspects of manufacturing possess a common thread: the necessity to acquire, manipulate, transmit, and store information or data, pertinent to the operating environment. The role of computers is essential to each and every Canadian manufacturer, be it a microcomputer able to handle a small firm's financial and sales needs, or a structured network of computers linking the factory to the top level of the corporation.

1.3 Modularity and Appropriateness: A Key Issue

Two important considerations of the application of advanced manufacturing systems are: modularity and appropriateness. By modularity we mean that new technologies be introduced in a step-wise manner that leaves open the option of easy addition of capacity and performance at a later time so as to reduce process interruptions and re-learning, and to allow for a cost-effective increase in the productivity of existing systems.

The microcomputer represents an excellent tool for achieving system modularity. As the introduction of applications demanding the attention of the microcomputer's real-time processing and communications abilities are recognized on the factory floor, additional micros can easily be added to the support mechanism for a variety of information and part handling tasks.

By appropriateness we commonly describe how suitable a technology is to a manufacturer's operations. To illustrate this point, a small manufacturer operating on a contract basis with continually changing products, seeks a solution to shop floor production problems. The group technology concept to factory integration which is based on the formation of similar groupings of part configurations and processes coupled with the physical grouping of workcells on the shop floor is considered. Because of physical constraints imposed by the firm's ever-changing product runs, group technology would not,by definition, be an appropriate solution for this manufacturing environment. The high up-front costs of an Automated Storage/Retrieval System, or plant-wide Automated Guided Vehicle System would put in question their suitability to producers operating with low volumes of stored and transported materials, and manufactured parts.

1.4 Literature Review

When attempting to formulate a survey representative of an area of interest to be studied, it is beneficial to have results of previous surveys and studies available to draw upon for comparisons.

To date, surveys and studies published with respect to Canada's utilization of Advanced Manufacturing Technologies (AMT's) have centered mainly on our country's lack of their application compared to other industrialized countries (Japan, USA, West Germany, Sweden, United Kingdom). Problems restricting the implementaiton of AMTechnologies are commented on, but no clear resolutions have been proposed (27). Most publications reviewed, both provincial and federal government sponsored, as well as foreign organizations seem to agree that the greatest stumbling block between available technologies and their successful application lies not in the technologies themselves, but in the process of their system integration.

Like most new system technologies, development and eventual introduction of an Advanced Manufacturing System is an evolutionary process, and the sequence of steps taken towards the desired goal of integrated manufacturing demands attention so that the evolution does not stop. It is time that studies carried out by governments and research centres focus on how to correct Canada's seeming lack of AMS prowess, and spend less time on the number of successes of AMS applications abroad. Admittedly, the strategies taken by foreign countries such as Japan and Sweden in attaining highly competitive manufacturing levels can serve as teaching blocks for our own manufacturers, but at the same time publicizing Canada's lack of technology motivation reduces the morale and character of our manufacturing organizations. Emphasizing successes abroad by the large users of AMS applications tends to leave the smaller-sized manufacturer discouraged and resigned to fighting fires on the shop floor instead of planning out long term survival through integration of computer-aided manufacturing. The problem is not in how much it costs to start investing in new technologies, but in what it will eventually cost by not stepping into the uncharted waters of CAD/CAM, NC, Robotics, and Group Technology (6). That first step will play a large role in the eventual system integration. Developing a logical model of integrated manufacturing may help guide the small producer through the transfer of applicable technology into his office and factory.

1.4.1 The Role of Government in Technology

Highlighting the efforts of foreign governments' efforts to ease the transfer of technology into the private sector provides Canada with formative ideas regarding a national strategy for adopting AMS technologies. Articles have indicated that due to the relatively small size of Canada's manufacturing sector, as compared to Japan, U.S.A. and Sweden, for example, Canada should direct attentions to the application of available technologies, and not so much to research and development of new technologies (27). The University of Manitoba Industrial Engineering Program in particular has shown industry the methods of AMS application and integration on the shop floor through flexible manufacturing cells combining facets of CNC machinery, robotics, vision systems, material handling, storage retrieval, and CAD/CAM into a scaled-down manufacturing cell. It is important that universities play a key role in tomorrow's adoption of new technologies by the manufacturing sector. Positive signs are seen all across the country in the development of dedicated centres of advanced technology, networks of research, and learning forums sharing innovative ideas between the academic setting and private industry.

To date, no real strategic plan has been adopted by the Canadian Government concerning future competitive manufacturing via computer-assisted applications. Recent initiatives indicate $1.3 billion being injected into the development of new centres of knowledge across Canada for the purpose of developing new technologies. Such programs must be maintained and upgraded as market conditions demand and should not be allowed to fall into neglect as federal governments and political objectives change.

The governments of the major countries involved in R&D and application of new manufacturing techniques have developed different routes of assistance (24). The majority of measures and programs have been directed towards furnishing support funding for specific technology developments and applications. Japan is the only country that has used tax incentives to promote utilization of a specific technology (Robotics) (27).

Sweden, with a manufacturing base similar in size to that of Canada, has structured industry to allow amalgamation of companies to create larger firms capable of adopting AMS attributes quicker. Consolidation of capital and expertise has helped in very successfully transferring new technologies into Swedish industry.

Strategies adopted to-date include:

- funding of scientific and technical personnel to work with small and medium sized companies (West Germany).
- funding of FMS demonstration systems in small and medium sized companies who are expected to share experiences (West Germany).
- favourable financing terms for leasing of robots (Japan).

- promotion of joint country research (Europe).
- funding of information networks to stimulate contact between industry and universities (West Germany).

It is up to Canadian governments and universities to work hand in hand with local industry and stimulate innovative thinking and aiding application of suitable technologies. New centres of expertise established by academic institutions, governments, and industry must pursue system integration in a building block fashion showing the manufacturer how each step of automation will promote higher productivity, quality and the innovation of intellectual assets amongst their personnel.

Governments are in the position of reducing the cost of information transfer and improving the timeliness of integration. Many of the available studies focusing on the transfer of technology into Canada's manufacturing sector firmly state that:

- lack of management awareness
- lack of employee training
- lack of up-front capital

all represent key roadblocks to the introduction of new technologies. "The biggest barriers to automation are identified as inadequate management awareness, insufficient operator training and financial constraints" (6). Interviews conducted with very small and large MW&M sector managers as preliminary research to this thesis revealed no real problem with inadequate managment awareness regarding new technologies. Some managers felt that some applications did not apply to their individual operations. For example: a large aerospace manufacturer operating primarily on a contract basis with continual changing product families felt group technology could not provide a fundamental link between their management information handling systems and shop floor part handling. In another situation, a medium sized farm implement producer was considering an automated storage/retrieval system, but could not justify the high costs of a full-blown system. Not all aspects of new manufacturing technologies are for everyone because of one reason or another, but greater understanding of each application and its relationship with other technologies will ensure that knowledgeable decisions are made along the road to integration.

1.4.2 Industry Publications

Review of journals, conference proceedings and industry publications on a world-wide scale has provided an insight into the developments taking place today in related AM Technologies. To gain a better understanding of the theories and practicality behind each application, a necessary research of up-to-date literature was required. As computer-related technologies advance at a quick pace, current documentation is needed for a greater insight to the concept of integrated manufacturing. Utilizing the computer itself to tap potential topical material from around the world allowed us to gather much relevant information. Success stories of industry adopting a variety of new technologies at the management and factory levels helped provide practical examples for this thesis.

Industry profiles of large, capital intensive, automated systems, in the past, have been limited to only the very large manufacturers (Ford, General Motors, Chrysler, IBM, Westinghouse, etc.). Such systems were predominantly global to the factory and office including flexible manufacturing systems, automated assembly lines and large CAD/CAM mainframe-based workcentres (36). With the declining costs and increasing performance of the microcomputer, new doors are being opened for the smaller manufacturer in areas of management-information systems, CAD/CAM, CAPP, GT and local factory data centres. Research efforts must now concentrate on how suitable technologies can be successfully adopted by the large sector of Canada's small manufacturers struggling under new global economies dominated by overseas markets.

Canadian manufacturers must first begin to consider themselves worthy of new technology, and possessing the participative skills required to phase in new technologies. It is time that managers step away from the daily fire-fighting and begin the planning process towards a logical framework to integrated manufacturing. Without concentrated efforts by industries, governments, universities and industry consultants to resolve the problem of system integration, many Canadian manufacturers will go on dousing the flames of a problematic production environment, without regard to needed long term information and part processing mastery, thus eventually leading to their demise.

1.5 Practical Experience

Industry experience in the Canadian MW&M manufacturing sector yields first hand data regarding available technology's role in the workplace. Each organization has its individual ways of managing people and new technology. Witnessing the operation of an AMS application process from a technical and humanistic standpoint generates ideas regarding how one should plan for a given technology, and how it should be executed and maintained to make certain of successful technology transfer. Decision-making at the top ranks of organizations inevitably dictates if, or how automation is going to play a role in attaining corporate objectives. People and technology must interact together. Many emotional barriers are created when changes (new technologies) are encountered, and the study of how firms manage this change is a prerequisite to the development of practical models for the introduction of new technologies (8).

1.6 Database Formation

In order for us to establish a model of Canada's utilization of AMS applications, and the sequence of steps that were taken in their introduction, two distinct and original resource bases were established and used to create our unique database. In addition, a review of available topical studies and literature was made. These two databases were based on:

(1) mailing of 1000 surveys to companies in those manufacturing industries known to have introduced one or more of the following technologies: NC machinery, robotics, CAD/CAM installations, and coordinate measuring machines. The 1987 MacLean Hunter Machinery and Metalworking Census of Canada's utilization of the above mentioned AMS technologies

was also used (40). This provided a rich listing of Canadian manufacturers who have already taken steps into AMS technologies.

(2) Personal interviews, and plant tours. These consisted of 9 interviews and plant tours with manufacturers operating in a variety of manufacturing industries. The nine manufacturers represented industries in aerospace, farm implement and tractor, emergency vehicles, industrial fans and pumps, and air-flow products sectors. The size of firms (ranging from 25 to 2000 employees), combined with the variety of manufacturing industries evaluated, helped us to gain an inside look into the strategies being followed in the introduction of AMS technologies by a broad base of Canadian manufacturers.

The following two chapters outline these two unique sources of information.

CHAPTER 2: DEVELOPMENT OF THE SURVEY

Since surveys are traditionally dismissed with a "who has time for it" attitude by the targeted respondents, the University of Manitoba Industrial Engineering Advanced Manufacturing Systems survey was developed in a very simplistic fashion so as to ensure ease of completion, but was kept innovative in concept in order to raise interest. Exhibit 2 displays the three pages making up the survey and the covering letter used to outline the purpose of the survey and attempts to instill a feeling of importance in each recipient regarding their role in tomorrow's competitive manufacturing. Emphasis was put on ensuring that specific questions were not asked concerning the success rate of various technology applications nor their impact on profits so as not to bias the number of respondents.

2.1 Section I of the Summary: Hardware Steps Taken Towards Integrated Manufacturing

The first section of the survey: Hardware Steps Taken Towards Integrated Manufacturing, was designed to determine the time frame and sequential order of AMS applications throughout the organization suitable to the machinery and metalworking industries. The 1000 manufacturers contacted were known to have made at least one formal introduction of automation at the manufacturing level. This ensured that all potential respondents fell within the area of our interest.

The section dealing with present and future technology applications as indicated in Exhibit 2, develops a step-by-step model of available technology introductions already taken by Canadian manufacturers to date, while also indicating long term strategies being considered by experienced as well as inexperienced users of automation. In a climate of changing markets, higher demands of quality by the consumer, and rising material costs, a manufacturer must attempt to lay down in advance the groundwork for a highly flexible, low cost operation maintaining built-in product quality. Smart investments of applicable automation introduced step-by-step starting from management and extending through to the factory will have a large impact

EXHIBIT # 2

THE UNIVERSITY OF MANITOBA

DEPARTMENT OF MECHANICAL ENGINEERING
and INDUSTRIAL ENGINEERING PROGRAM

Winnipeg, Manitoba
Canada R3T 2N2

(204) 474-9803
TLX: 07-587721

Dear Sir/Madam,

We would appreciate if you or your delegate could assist us with the collection of information regarding the status of advanced manufacturing systems in your company.

My present thesis studies in Manufacturing Engineering, within the Masters Program at the University of Manitoba, is centered around the establishment of the precise sequential steps of automation to ensure a successful and fully integrated manufacturing system.
Knowledgeable decisions must be made at each stage of the automation process in order to recognize the full potential of the fully integrated factory concept. The report will also consider the role of the microcomputer in tomorrow's factory floor operations.
The ability of Canadian manufacturers like yourself, to effectively introduce applicable automation into your production environment will ultimately play a large role in Canada's competitiveness amongst world producers.
We would greatly appreciate your support in filling out the accompanying questionnaire indicating the applications and stages of automation in your present facilities. The specific information obtained in this survey will be kept confidential, and will be restricted to use by the University of Manitoba Industrial Engineering Program to appear in my M.Sc. Thesis in a non-company-specific manner.
I look forward to hearing from you, and gaining valuable information that will help increase the awareness of automation's role in the Canadian manufacturing scene.
We would appreciate a reply by June 30, 1987 and thank you in advance for your cooperation.

Sincerely,

Jeff Russell B.Sc.(IE)

Ostap Hawaleshka
Associate Head, Department of Mechanical and Industrial Engineering

Encl. A brief description of the University of Manitoba's Industrial Engineering Program Objectives;

The Industrial Engineering Program at the University of Manitoba is unique to Canada. A strong emphasis is put upon production and manufacturing control. Our main interests lie in the area of advanced manufacturing technology, and aiding in the introduction of these technologies in the workplace.

1987
UNIVERSITY OF MANITOBA
INDUSTRIAL ENGINEERING PROGRAM
ADVANCED MANUFACTURING SYSTEMS
SURVEY

The following questionnaire is broken up into four sections;
1) Hardware Applications taken towards Integrated Manufacturing
2) Role of Microcomputer at the Factory Floor Level
3) Technology Transfer
4) Effects of Technology Implementation

PART I. STEPS TAKEN TOWARDS INTEGRATED MANUFACTURING

PRESENT OPERATIONS			FUTURE PLANS		
ORDER OF INTRODUCTION	YEAR INTRODUCED		PROPOSED ORDER OF IMPLEMENTATION	TIMEFRAME 1-2Yrs.	3-6Yrs.
		Computer System/Financial Database/Management Information System			
		Departmental Microcomputers			
		Computer-Aided Design System			
		Computer-Aided Engineering			
		1) Process Planning			
		2) Materials Requirement Planning			
		3) Other ______			
		CNC/NC Machinery Operations;			
		1) Mills			
		2) Drills			
		3) Lathes			
		4) Other ______			
		Automated Storage/Retrieval System			
		Robotics Applications			
		1) Material Handling			
		2) Quality Control			
		3) Assembly			
		4) Fabrication			
		5) Painting			
		6) Other ______			
		Workcell Configurations based on;			
		1) Cell Technology			
		2) Group Technology			
		3) Part Families			
		Bar Coding 1) In-Process Control			
		2) Warehousing/Inventory Control			
		Communications Network			
		1) Factory Level			
		2) Office Level			
		Automated Central Materials Handling System 1) AGV			
		2) Conveyor System			
		3) Rail System			
		4) Other ______			
		Automated Quality Control Applications			
		1) Coordinate Measuring Machine			
		2) Vision Systems			

______	______	3) Tactile Sensors	______	______	______
______	______	4) Other ______	______	______	______
		Sensor Applications/Specify ______			
______	______	Automated Tool Changing Capabilities	______	______	______
______	______	______	______	______	______

PART II. ROLE OF MICROCOMPUTER AT THE FACTORY FLOOR LEVEL

PRESENT OPERATIONS			FUTURE PLANS		
ORDER OF INTRODUCTION	YEAR INTRODUCED		PROPOSED ORDER OF IMPLEMENTATION	TIMEFRAME 1-2Yrs.	3-6Yrs.
______	______	Part Programming CNC	______	______	______
______	______	Cell Controller/Machines, Robots etc.	______	______	______
______	______	On-Time Scheduling, Part Routing	______	______	______
______	______	On-Time Data Acquisition	______	______	______
______	______	Word Processing	______	______	______
______	______	Storage Area/ Central Materials Handling	______	______	______
______	______	Tool Crib Control	______	______	______
______	______	Quality Control	______	______	______
______	______	Factory Communications Network/ Horizontal Flow of Information	______	______	______
______	______	Order Processing/Tracking	______	______	______
______	______	Inventory Control	______	______	______
______	______	Bills of Materials	______	______	______

PART III. TECHNOLOGY TRANSFER

SYSTEM DESIGN AND EMPLOYEE TRAINING

How Long did it take to be fully operational	______________		(Timeframe)
Formal Courses in use of technology	Yes ______	No ______	Other ______
In-House Training by courses	Yes ______	No ______	Other ______
On-The-Job Training	Yes ______	No ______	Other ______
Retraining of former workers	Yes ______	No ______	Other ______
Hiring of new workers	Yes ______	No ______	Other ______
Use of consultants in design of system	Yes ______	No ______	Other ______
Use of consultants in implementation	Yes ______	No ______	Other ______
Use of consultants in training	Yes ______	No ______	Other ______
Use of government programs for training	Yes ______	No ______	Other ______

Did you find the consultants useful? Comment ______________________________

____

HOW TECHNOLOGY WAS OBTAINED

% of Company Funds/ Specify ______________________________

% of Government Program Assistance/ Specify ______________________________

INVOLVEMENT OF INTERNAL STAFF

Who initiated the introduction of the technology?

Top Management	Yes ______	No ______
Engineering	Yes ______	No ______
Operators	Yes ______	No ______

Do Workers participate in continuous operations?
Yes ________ No ________

METHODS OF COST JUSTIFICATION

Rate of Return ________
Payback Period ________
Organizational Strategic Justification ________
Others ________

MAJOR ROADBLOCKS IN SYSTEM IMPLEMENTATION

Financial (Specify) ________

Lack of Employee Training ________

Lack of In-House Expertise ________

Lack of Management Awareness ________

Other(s) ________

PART IV. RESULTS OF TECHNOLOGY IMPLEMENTATION:

EFFECTS OF NEW SYSTEMS ON COMPANY

Marketshare Improved Yes ________ No ________ N/A ________
Productivity Improvement/ Specify ________
Customer Service/ Specify ________
Reduced Manufacturing Costs/ Specify ________
Increased Quality/ Specify ________
Others/ Specify ________

NET EFFECT ON EMPLOYMENT

Management Levels	Increased	________
	Decreased	________
	Steady	________
Engineering	Increased	________
	Decreased	________
	Steady	________
Operators	Increased	________
	Decreased	________
	Steady	________

ACCEPTANCE BY STAFF:

Top Management/ Comment ________
Engineering/ Comment ________
Operators/ Comment ________
Union/ Comment ________

GENERAL COMMENTS:

on these objectives.

The "Future Plans of Automation" section of the survey provides an opportunity for identifying potential trends in AMS applications. Gauging the time frame of big and small Canadian manufacturers' adaptations of available technology as compared to the maturity of the adopted technology, provides the reason for including both year and order of introduction.

2.2 Section II of the Survey: Role of Microcomputer at the Factory Floor Level

The importance of accurate and responsive data acquisition and communication in the integrated manufacturing models of today and tomorrow will depend largely on the introduction of microcomputers at the factory floor level. The major technological advances of the microcomputer's processing, memory storage, and multi-tasking/user capabilities have provided a strong impetus for a new era of manufacturing automation. The microcomputer is important because it provides the manufacturer with a tool on the shop floor to gather and transmit critical data important to the entire organization.

Developing a model of the sequential steps taken in the use of microcomputers on the shop floor will help us measure relationships between integration of real-time shop floor data with that of automated part and information tasks throughout the organization, while measuring the present influence of the microcomputer in Canada's manufacturing environment.

2.3 Section III of the Survey: Technology Transfer

The human environment into which new technologies are introduced, depends on the judgement, abilities and emotions of corporate personnel and how they react to changes. Achieving mastery over the technical side of technology is often less difficult than the mastering the related human aspects (8).

Training and re-training personnel throughout the company structure in the philosophies and execution of AMS technologies demands a thorough step-by-step approach to bringing new systems on-line. Each step provides the education and tools needed to implement the next one.

System vendors, consultants, governments and learning facilities (universities and colleges) all represent agents that can aid the transfer of technology into the workplace both technically and financially. Canadian manufacturers must be made aware of the resource bases available to them to ease the often prohibitive learning curve of computer-aided applications (12). Justifying the up-front costs of AMS technologies is usually more difficult than traditional capital expenditures due to somewhat obsolete and inappropriate accounting methods. The step-by-step approach towards integrated manufacturing advocated in this paper alleviates the "all or nothing" costs of large system implementation. Although the introduction of an FMS may be applicable to only a small percentage of industries in Canada, the various stages of automation help provide the human and technical skills for each sequential step with costs in a range suitable even for these conservative cost justification procedures. Top level initiation of AMS technologies stresses the organizational strategic justifications of new systems so that the intangible benefits of new technology are also weighed against the long-term objectives of the company.

2.4 Section IV of the Survey: Results of Technology Implementation

As trade journals and papers continue publishing about cases of new automation successes, the survey must try and capture the real present benefits being experienced by Canadian manufacturers stepping into the AMS world. Tangible benefits such as higher productivity levels and reduced manufacturing costs, coupled with increased quality and marketshare play a hand in measuring the net effect of new systems on the success of the manufacturer.

Exhibits 2A, 2B, and 2C show a completed version of the survey for all three company sizes giving a better insight into how respondents filled out the survey.

EXHIBIT # 2A

1987
UNIVERSITY OF MANITOBA
INDUSTRIAL ENGINEERING PROGRAM
ADVANCED MANUFACTURING SYSTEMS
SURVEY

The following questionnaire is broken up into four sections;
1) Hardware Applications taken towards Integrated Manufacturing
2) Role of Microcomputer at the Factory Floor Level
3) Technology Transfer
4) Effects of Technology Implementation

PART I. STEPS TAKEN TOWARDS INTEGRATED MANUFACTURING

PRESENT OPERATIONS / FUTURE PLANS

ORDER OF INTRODUCTION	YEAR INTRODUCED		PROPOSED ORDER OF IMPLEMENTATION	TIMEFRAME 1-2Yrs.	TIMEFRAME 3-6Yrs.
6	1984	Computer System/Financial Database/Management Information System			
4	1983	Departmental Microcomputers			
2	1981 CORP.	Computer-Aided Design System	1	IN-PLANT	
1	1980 CORP.	Computer-Aided Engineering (PRODUCT)			
3	1982 CORP	1) Process Planning (MODEL OF SYSTEM)	2	IN PLANT	
3	1982 CORP	2) Materials Requirement Planning	N/A	IN PLANT	
		3) Other			
		CNC/ Machinery Operations;			
		1) ~~Mills~~ OVEN CONTROLS			
		2) ~~Drills~~ WELDING CONTROL			
		3) ~~Lathes~~ ASSEMBLY MACHINERY			
5	1983	4) Other MACHINE & CONVEYOR			
		Automated Storage/Retrieval System	3		X
		Robotics Applications			
5	1983	1) Material Handling			
		2) Quality Control			
5	1983	3) Assembly			
		4) Fabrication			
5	1983	5) Painting			
		6) Other			
		Workcell Configurations based on;			
		1) Cell Technology } TOTAL FLEXABLE			
		2) Group Technology } OR SYN-FLEX	1990		
		3) Part Families } SYSTEMS			
8	1987	Bar Coding 1) In-Process Control			
		2) Warehousing/Inventory Control			
		Communications Network			
5	1983	1) Factory Level } FACTORY INFORMATION SYSTEM			
5	1983	2) Office Level }			
		Automated Central Materials Handling			
5	1983	System 1) AGV			
		2) Conveyor System			
		3) Rail System			
		4) Other			
		Automated Quality Control Applications			
		1) Coordinate Measuring Machine			
7	1984	2) Vision Systems (GAGUE AND CRITICAL LOCATION) (LASER)			

NOTE - MAJOR RE-TOOL IN 1983 - $350 MILLION IN-PLANT

		3) Tactile Sensors	N/A		
		4) Other	N/A		
		Sensor Applications/Specify	N/A		
		Automated Tool Changing Capabilities	NA		

PART II. ROLE OF MICROCOMPUTER AT THE FACTORY FLOOR LEVEL

PRESENT OPERATIONS: ORDER OF INTRODUCTION	YEAR INTRODUCED		FUTURE PLANS: PROPOSED ORDER OF IMPLEMENTATION	TIMEFRAME 1-2Yrs.	3-6Yrs.
4	1983	Part Programming CNC			
5	1983	Cell Controller/Machines, Robots etc.			
5	1983	On-Time Scheduling, Part Routing			
5	1983	On-Time Data Acquisition			
5	1983	Word Processing			
5	1983	Storage Area/ Central Materials Handling			
5	1983	Tool Crib Control			
6	1984	Quality Control			
5	1983	Factory Communications Network/ Horizontal Flow of Information			
1	1980	Order Processing/Tracking			
2	1980	Inventory Control			
3	1980	Bills of Materials			

PART III. TECHNOLOGY TRANSFER

SYSTEM DESIGN AND EMPLOYEE TRAINING

How Long did it take to be fully operational 16 WEEKS (Timeframe)

	Yes	No	Other
Formal Courses in use of technology	✓		
In-House Training by courses	✓		
On-The-Job Training	✓		
Retraining of former workers	✓		
Hiring of new workers	✓		
Use of consultants in design of system	✓		
Use of consultants in implementation	✓		
Use of consultants in training	✓		
Use of government programs for training	MINOR		

Did you find the consultants useful? Comment YES, ESSENTIAL TO MAP OUT PLAN WHICH HAD TO BE TAILORED TO OUR NEEDS.

HOW TECHNOLOGY WAS OBTAINED

% of Company Funds/ Specify 95% PURCHASE AS PART OF EQUIPMENT CONTRACTS & CORP TRAINING FAC

% of Government Program Assistance/ Specify 5% CANADIAN INSTRUCTOR'S WAGES

INVOLVEMENT OF INTERNAL STAFF

Who initiated the introduction of the technology?

	Yes	No
Top Management	✓	
Engineering	✓	
Operators		✓

Do Workers participate in continuous operations?
Yes ✓ No ______

METHODS OF COST JUSTIFICATION

Rate of Return $720 Million on 1.2 Billion Total Investment
Payback Period 2 year payback from 1st day of operation
Organizational Strategic Justification First on market with product
Others [illegible] Wheel Drive Mini-Van capturing 40% of market [illegible]

MAJOR ROADBLOCKS
IN
SYSTEM IMPLEMENTATION

Financial (Specify) Shortage of available capital to finance new plant
Lack of Employee Training Total retraining improved level of 15% ([illegible]) added 50 new [illegible] skills.
Lack of In-House Expertise Learning curve to maximize production happened quickly to 90% [illegible]
~~Lack of Management Awareness~~ [illegible] 13 [illegible] takes years

Other(s) Reliability of new equipment [illegible] start of [illegible] — shutdown 20 [illegible] production run in [illegible] prior to shipment — [illegible] start [illegible] [illegible]

PART IV. RESULTS OF TECHNOLOGY IMPLEMENTATION:

EFFECTS OF NEW SYSTEMS ON COMPANY

Marketshare Improved Yes ______ No ______ N/A New market
Productivity Improvement/ Specify Was 50 JPH with 6000 employ — now 72 [illegible]
Customer Service/ Specify Quality improve 50% — [illegible]
Reduced Manufacturing Costs/ Specify ______
Increased Quality/ Specify ______
Others/ Specify ______

NET EFFECT ON EMPLOYMENT

Management Levels Increased Minor increase in indirect areas
~~Decreased~~ — maintenance, quality control
~~Steady~~ process control
Engineering ~~Increased~~
~~Decreased~~
Steady — Engineering held —
Operators Increased — in skilled trades maintenance
Decreased — in semi- and non-skilled
~~Steady~~ manual labour

ACCEPTANCE BY STAFF:

Top Management/ Comment Readily accepted
Engineering/ Comment Readily accepted
Operators/ Comment Skeptical — robots don't buy cars
Union/ Comment Safety and environment issues increased
GENERAL COMMENTS: By 300% — (Competition is not a recognized reason to improve productivity)

(11)

EXHIBIT #2B

1987
UNIVERSITY OF MANITOBA
INDUSTRIAL ENGINEERING PROGRAM
ADVANCED MANUFACTURING SYSTEMS
SURVEY

The following questionnaire is broken up into four sections;
1) Hardware Applications taken towards Integrated Manufacturing
2) Role of Microcomputer at the Factory Floor Level
3) Technology Transfer
4) Effects of Technology Implementation

PART I. STEPS TAKEN TOWARDS INTEGRATED MANUFACTURING

PRESENT OPERATIONS			FUTURE PLANS		
ORDER OF INTRODUCTION	YEAR INTRODUCED		PROPOSED ORDER OF IMPLEMENTATION	TIMEFRAME 1-2Yrs.	3-6Yrs.
1	79	Computer System/Financial Database/Management Information System			
4	86	Departmental Microcomputers(PC's)	1	X	
		Computer-Aided Design System			
		Computer-Aided Engineering			
		1) Process Planning			
5	86-88	2) Materials Requirement Planning			
		3) Other CAM	1	X	
		CNC/NC Machinery Operations;			
3	84	1) Mills			
		2) Drills			
2	80	3) Lathes			
		4) Other			
		Automated Storage/Retrieval System			
		Robotics Applications			
		1) Material Handling	3	X	
		2) Quality Control			
		3) Assembly			
		4) Fabrication (Deburring)	~~2~~	~~X~~	
		5) Painting			
		6) Other ✓	2	X	
		Workcell Configurations based on;			
		1) Cell Technology			
		2) Group Technology			
		3) Part Families			
		Bar Coding 1) In-Process Control	5		X
		2) Warehousing/Inventory Control	4		X
		Communications Network			
		1) Factory Level			
		2) Office Level			
		Automated Central Materials Handling System 1) AGV	6		X
		2) Conveyor System			
		3) Rail System			
		4) Other			
		Automated Quality Control Applications			
		1) Coordinate Measuring Machine	7		X
		2) Vision Systems			

Do Workers participate in continuous operations?
Yes ______ No ______

METHODS OF COST JUSTIFICATION

Rate of Return Yes
Payback Period Yes
Organizational Strategic Justification
Others

MAJOR ROADBLOCKS IN SYSTEM IMPLEMENTATION

Financial (Specify)

Lack of Employee Training Existing CNC Operators courses poor or non-existant

Lack of In-House Expertise To some extent.

Lack of Management Awareness To some extent.

Other(s) 1) Lack of time to devote to future planning 2) People (shop floor to the top) need a chnage of attitude and more of a common goal. More co operation and working together is required. In summary, people attitudes are not yet right.

PART IV. RESULTS OF TECHNOLOGY IMPLEMENTATION:

EFFECTS OF NEW SYSTEMS ON COMPANY

Marketshare Improved Yes X No ______ N/A ______
Productivity Improvement/ Specify Yes, Production times down
Customer Service/ Specify Yes, On time deliveries
Reduced Manufacturing Costs/ Specify Yes
Increased Quality/ Specify Yes
Others/ Specify

NET EFFECT ON EMPLOYMENT

Management Levels	Increased	
	Decreased	
	Steady	X
Engineering	Increased	X
	Decreased	
	Steady	
Operators	Increased	X
	Decreased	
	Steady	

ACCEPTANCE BY STAFF:

Top Management/ Comment Yes
Engineering/ Comment Yes
Operators/ Comment Limited - Not enough decision making has been pushed to floor level.
Union/ Comment

GENERAL COMMENTS: Technology is fine but, the most profitable investments are those which focus on people improvement. The benefits of technology are stifled if only some of the people are on board.

		3) Tactile Sensors			
		4) Other			
		Sensor Applications/Specify			
		Automated Tool Changing Capabilities			

PART II. ROLE OF MICROCOMPUTER AT THE FACTORY FLOOR LEVEL

PRESENT OPERATIONS | FUTURE PLANS

ORDER OF INTRODUCTION	YEAR INTRODUCED		PROPOSED ORDER OF IMPLEMENTATION	TIMEFRAME 1-2Yrs.	TIMEFRAME 3-6Yrs.
		Part Programming CNC	1	X	
		Cell Controller/Machines, Robots etc.	2	X	
4	88	On-Time Scheduling, Part Routing			
		On-Time Data Acquisition			
2	1987	Word Processing			
		Storage Area/ Central Materials Handling			
		Tool Crib Control			
1	1987	Quality Control			
		Factory Communications Network/ Horizontal Flow of Information			
		Order Processing/Tracking			
3	1987	Inventory Control			
		Bills of Materials			

PART III. TECHNOLOGY TRANSFER

SYSTEM DESIGN AND EMPLOYEE TRAINING

How Long did it take to be fully operational (Question incomplete) (Timeframe)

	Yes	No	Other
Formal Courses in use of technology	X		
In-House Training by courses	X		
On-The-Job Training	X		
Retraining of former workers	X		
Hiring of new workers	X		
Use of consultants in design of system	X		
Use of consultants in implementation	X		
Use of consultants in training	X		
Use of government programs for training	X		

Did you find the consultants useful? Comment Moderately

HOW TECHNOLOGY WAS OBTAINED

% of Company Funds/ Specify

% of Government Program Assistance/ Specify

INVOLVEMENT OF INTERNAL STAFF

Who initiated the introduction of the technology?

	Yes	No
Top Management	X	
Engineering	X	
Operators		

EXHIBIT #2C

1987
UNIVERSITY OF MANITOBA
INDUSTRIAL ENGINEERING PROGRAM
ADVANCED MANUFACTURING SYSTEMS
SURVEY

25

The following questionnaire is broken up into four sections;
1) Hardware Applications taken towards Integrated Manufacturing
2) Role of Microcomputer at the Factory Floor Level
3) Technology Transfer
4) Effects of Technology Implementation

PART I. STEPS TAKEN TOWARDS INTEGRATED MANUFACTURING

PRESENT OPERATIONS			FUTURE PLANS		
ORDER OF INTRODUCTION	YEAR INTRODUCED		PROPOSED ORDER OF IMPLEMENTATION	TIMEFRAME 1-2Yrs.	3-6Yrs.
2	1983	Computer System/Financial Database/Management Information System			
4	1985	Departmental Microcomputers			
		Computer-Aided Design System			
		Computer-Aided Engineering			
		1) Process Planning			
		2) Materials Requirement Planning			
		3) Other			
		CNC/NC Machinery Operations;			
		1) Mills			
		2) Drills			
1	1983	3) Lathes			
		4) Other			
		Automated Storage/Retrieval System			
		Robotics Applications ;			
		1) Material Handling			
		2) Quality Control			
		3) Assembly			
		4) Fabrication			
		5) Painting			
		6) Other			
		Workcell Configurations based on;			
		1) Cell Technology			
		2) Group Technology			
		3) Part Families			
		Bar Coding 1) In-Process Control			
		2) Warehousing/Inventory Control			
		Communications Network			
3	1981	1) Factory Level			
		2) Office Level			
		Automated Central Materials Handling System 1) AGV			
		2) Conveyor System			
		3) Rail System			
		4) Other			
		Automated Quality Control Applications			
		1) Coordinate Measuring Machine			
		2) Vision Systems			

Do Workers participate in continuous operations?
Yes ________ No ________

METHODS OF COST JUSTIFICATION

Rate of Return ✓
Payback Period ✓
Organizational Strategic Justification ✓
Others ________

MAJOR ROADBLOCKS IN SYSTEM IMPLEMENTATION

Financial (Specify) ✓

Lack of Employee Training ✓

Lack of In-House Expertise ✓

Lack of Management Awareness ✓

Other(s) ________

PART IV. RESULTS OF TECHNOLOGY IMPLEMENTATION:

EFFECTS OF NEW SYSTEMS ON COMPANY

Marketshare Improved Yes ____ No ✓ N/A ____
Productivity Improvement/ Specify REDUCED M/C CYCLE TIME
Customer Service/ Specify ________
Reduced Manufacturing Costs/ Specify ________
Increased Quality/ Specify CONSISTENTLY CLOSE TOLERANCE
Others/ Specify ________

NET EFFECT ON EMPLOYMENT

Management Levels	Increased	
	Decreased	✓
	Steady	
Engineering	Increased	
	Decreased	
	Steady	✓
Operators	Increased	
	Decreased	
	Steady	✓

ACCEPTANCE BY STAFF:

Top Management/ Comment OVERCONFIDENCE IN ULTIMATE IMPACT / INFLUENCE
Engineering/ Comment CONSIDERED HIGHLY RELEVANT TO SUCCESS
Operators/ Comment OLD GENERATIONS AGAINST NEW GENERATION FEAR
Union/ Comment PASSIVE

GENERAL COMMENTS:

		3) Tactile Sensors			
		4) Other			
		Sensor Applications/Specify			
		Automated Tool Changing Capabilities			

PART II. ROLE OF MICROCOMPUTER AT THE FACTORY FLOOR LEVEL

PRESENT OPERATIONS			FUTURE PLANS		
ORDER OF INTRODUCTION	YEAR INTRODUCED		PROPOSED ORDER OF IMPLEMENTATION	TIMEFRAME 1-2Yrs.	3-6Yrs.
		Part Programming CNC	3	✓	
		Cell Controller/Machines, Robots etc.			
		On-Time Scheduling, Part Routing	2	✓	
		On-Time Data Acquisition	1	✓	
		Word Processing			
		Storage Area/ Central Materials Handling			
		Tool Crib Control			
		Quality Control			
		Factory Communications Network/ Horizontal Flow of Information			
		Order Processing/Tracking			
1	1983	Inventory Control			
2	1983	Bills of Materials			

PART III. TECHNOLOGY TRANSFER

SYSTEM DESIGN AND EMPLOYEE TRAINING

How Long did it take to be fully operational 2 yrs (Timeframe)

	Yes	No	Other
Formal Courses in use of technology	✓		
In-House Training by courses		✓	
On-The-Job Training	✓		
Retraining of former workers	✓		
Hiring of new workers	✓		
Use of consultants in design of system	✓		
Use of consultants in implementation	✓		
Use of consultants in training	✓		
Use of government programs for training		✓	

Did you find the consultants useful? Comment Yes & No.

HOW TECHNOLOGY WAS OBTAINED

% of Company Funds/ Specify 100%

% of Government Program Assistance/ Specify

INVOLVEMENT OF INTERNAL STAFF

Who initiated the introduction of the technology?

	Yes	No
Top Management	✓	
Engineering	✓	
Operators		✓

2.5 Industry Sectors

Our objective to gather new and original data pertaining to the steps taken towards integrated manufacturing in Canada today relied on an industry population known to be a user of AMTechnologies. To cover the wide variety of advanced manufacturing applications as displayed in the survey (see Exhibit 2) required an assembly of manufacturers whose operations were potentially suitable.

Researching the application of new technologies by Canadian manufacturers has revealed that approximately 75% of major automation users fall within the metal working and machinery sector. Related industries include the automotive, aerospace, farm equipment, tool and die workers, and metal fabricators among others. Due to the diverse makeup of manufacturers united into one industry base, helped us to choose the MW&M Sector as an excellent database to tap.

2.5.1 Other Industries Needing Further Study

Other industries in Canada also stand to implement new technologies in the workplace. Foreign nations such as Japan have shown the importance of spreading automation through a wide variety of manufacturing industries (24). The industries listed below all can adopt applications of computer-assisted technologies applicable to their individual operating conditions:

- Electrical/Electronic
- Wood Processing/Furniture
- Textiles/Garment
- Primary Metal (e.g. Steel Processing)
- Plastics/Rubber
- Mining.

The electrical/electronics sector relies heavily on finite assembly operations focusing on very small parts and a required high degree of precision and quality. Robotics and Vision System technology represent two very viable opportunities for these industries to achieve higher productivity, greater product flexibility and increased levels of consistent quality. The garment industry has claimed successes in application of CAD/CAM, NC machine technology, together with a wide variety of automated material handling devices in their factories. Both above industry examples have centered on factory automation, inclusive of part handling and processing.

The area of computer-assisted information handling tasks is generally common to most manufactureres. Management typically divides the factory from the office, although shop floor supervisors must assist real-time production operations. To productively manage one's "system" that includes:

- processing of new jobs in finance, sales, engineering, and manufacturing
- engineering product design and drafting
- product bill of material development
- purchasing and inventory control
- production operations development
- quality assurance techniques for incoming materials and the in-process product
- production scheduling,

reducing the degree of manual input, and the number of hands information must pass through has a tremendous effect on overall product throughput time and customer service, coupled with greater control over all facets of the organization. AMS applicatons include CAD/CAM,CAPP, GT, MIS, and MRP as described previously in Exhibit 1.

2.6 Manufacturing Divisions

Two distinct operating characteristics exist for all manufacturing-based industries. These are:

- discrete manufacturing
- process manufacturing

"Discrete manufacturing" centers around the production of parts in prescribed lot sizes, while a "process orientation" is focused on the continuous production of a material or end-product such as plastics, steel, paper and wood. Operating parameters driving process manufacturing require different applications of automated hardware and factory layout concepts from those of the metalworking and machinery industry sector studied in this thesis.

2.7 Population Sample

In surveying a population either by random or biased sampling, one hopes to achieve results deemed worthy to represent the overall population. The 1000 MW&M manufacturers surveyed were all known to possess characteristics meeting the survey's objectives. Therefore, total random sampling was not performed in sending the survey out to the advanced manufacturers. Some bias is clearly involved when dealing with a known population, but in this case it helped assure a good sampling representation is achieved.

After sifting through returned surveys, 75 of the 1000 were found to be worthy of analysis. After conferring with the University of Manitoba Faculty of Engineering Graduate Statistical Aid Department, approximate random sampling standards were given regarding surveys of this nature. Confidence levels of 99% required a 10% return from the population. The 7.5% return generated from our Advanced Manufactury Systems survey approximates a 92% confidence level worthy of study. However, it is not fully certain that the 75 respondents are a completely random sample of the 1000 manufacturers surveyed. For example, if all 1000 surveys were filled out and dropped into a hat, the 75 surveys withdrawn would indeed represent a total random population sample.

2.8 Size of Manufacturers

Over the years as the development and application of AMS technologies has increased world-wide, industry leaders are expressing deep concerns about how small firms could raise the financial and technical resources needed for adopting new technologies. Fortunately the maturity of automated equipment, computer controls, and support software, coupled with declining prices, has brought the Advanced Manufacturing System much closer to the small producers. An increasing number of sources specifically established to assist with and facilitate the transfer of technology into the workplace also helps out the smaller firm. Sources include a growing educated group of automation vendors, consultants, university and college centres, and government-funded research facilities (Saskatchewan and Ontario CAD/CAM centres), as well as Winnipeg's Canadian Institute of Industrial Technology and the Industrial Engineering Program at the University of Manitoba.

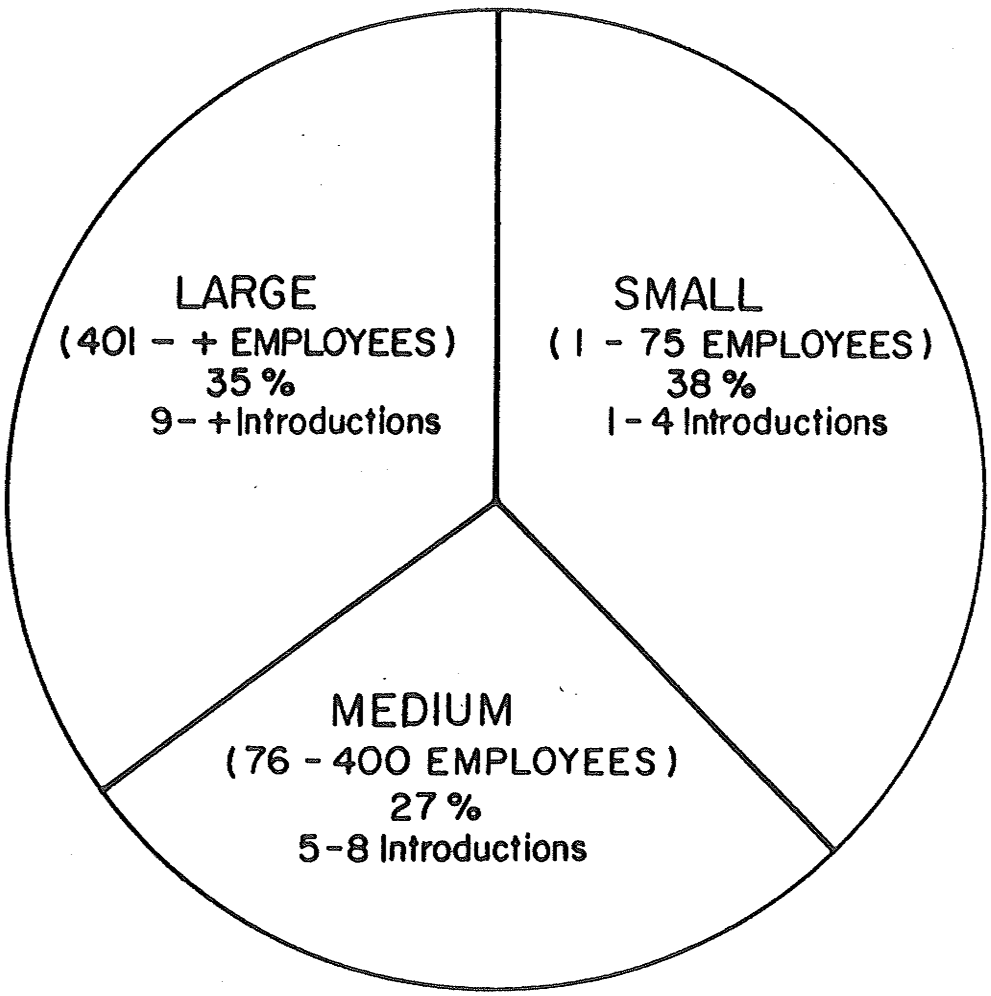
Huge system implementations of the past (FMS's, Automated Assembly Lines) are giving way to smaller cells, and new concepts of step by step integration of new technology (35). It is interesting that in phase with the primary objective of this thesis to develop a logical model of AMS integration for the small manufacturer in particular, but also suitable for the larger manufacturer, a near equal size distribution of the 75 respondents was found. (See Fig. 1.) Surprisingly enough, the highest percentage of advanced manufacturers, 38%, fell within the small sector, 1-75 employees, while 27% and 35% represented medium, and large companies respectively. It is not known what the total distribution of the 1000 advanced manufacturers in the Canadian MW&M industry sector is, but the distribution of respondents gives an excellent picture of how all sizes of manufacturers are adapting to new technologies.

The number of employees with respect to each size category was obtained through contact with the 75 manufacturers, as well as through the correlation found between the number of steps taken regarding AMS application, and the number of employees in the company. The relationship, as shown in Fig. 1, indicates that indeed the larger manufacturer has introduced more applications of AMTechnologies than the smaller company.

Although the smaller sized manufacturers have implemented a lesser number

FIGURE 1

SIZE DISTRIBUTION OF SURVEY RESPONDENTS



of AMS applications (1 to 4), very positive signals are revealed from the 38% return that have made the first step into the "uncharted waters" of automation. Since industry figures indicate that the average number of employees of manufacturers in Canadian metalworking and machinery related industries is 75, (24), extra emphasis must be put on applicable system integration suitable for the smaller organizations. Integration through a building block application approach may thus provide an affordable and effective answer.

2.9 Geographical Distribution

Manufacturing centres have predominantly co-existed in southern Ontario and Quebec areas. Fig. 2, reveals a breakdown of the sample from province to province, illustrating that indeed Ontario holds title to the largest percentage of advanced manufacturers in the MW&M related industries. Industry studies have documented that approximately 62% of MW&M related inudstries are situated in Ontario (24). The excellent correlation between survey findings and stated industry figures gives credence to the representativeness of the distribution of our 75 respondents.

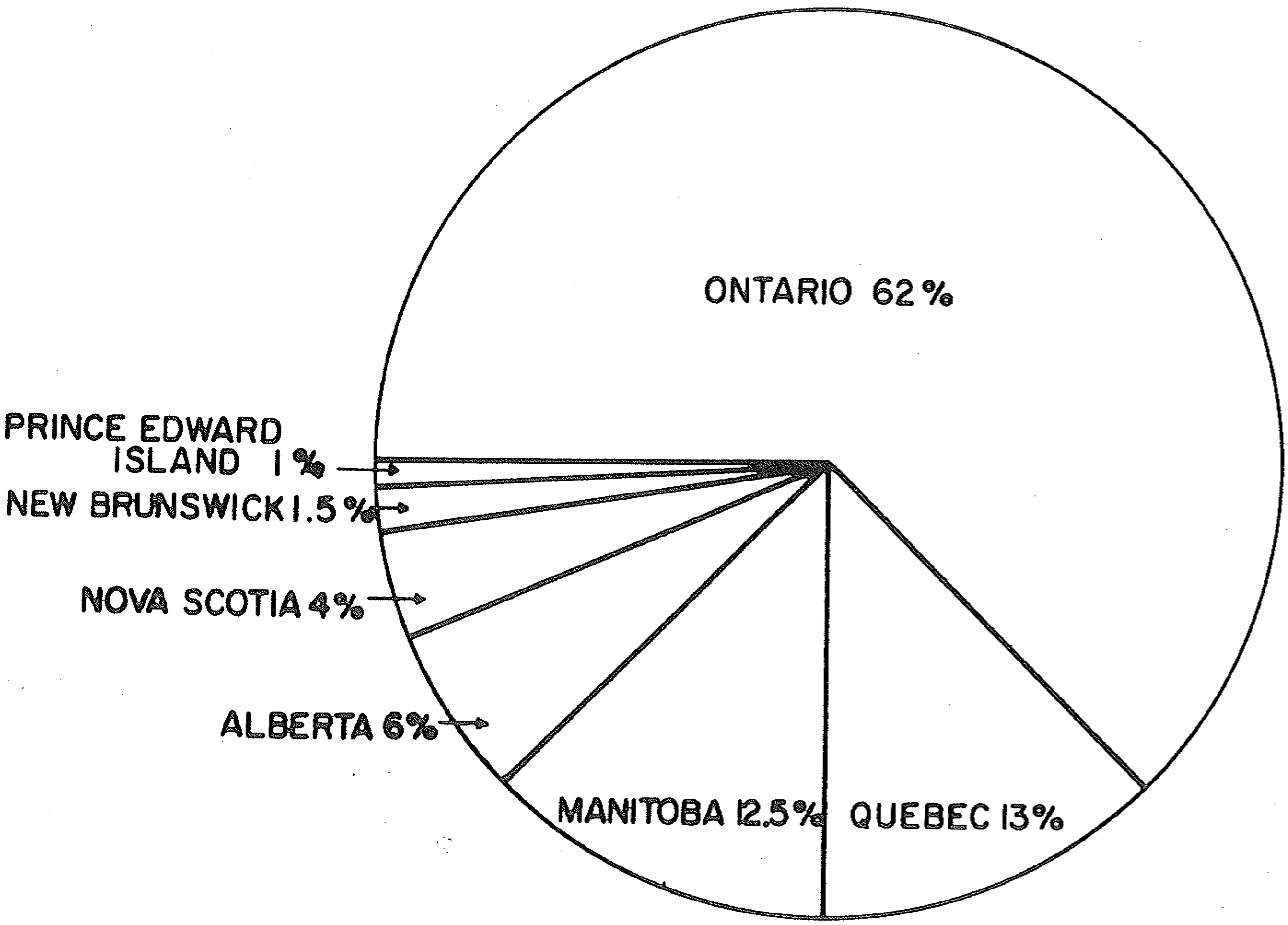
A strong showing in Manitoba points out the tremendous gains that Winnipeg, in particular, has made in recent years with respect to application of AMS technologies, and development of a strong manufacturing base. (There may, however, have been some bias regarding the response of Manitoba companies since the survey originated at the University of Manitoba).

The 4.5% figure for Nova Scotia can be associated with the state of the art FMS facility in Pratt and Whitney's Halifax factory. It is highly probable that the competitive edge exhibited by this new ~~a~~ facility will inevitably spin-off to local industry.

Alberta's 6% representation is suprisingly high in light of that province's "process oriented" manufacturing base relying heavily on spin-off industries of its' oil-based economy (Polymers, synthetics, plastics).

FIGURE 2

GEOGRAPHICAL DISTRIBUTION OF SURVEY RESPONDENTS



CHAPTER 3: INTERVIEWS WITH MANUFACTURERS

In an effort to open up AMS technologies to all sizes of manufacturing firms through integration, interviews and plant tours were conducted in a variety of small, medium and large manufacturing industries. To capture the vision of any particular manufacturer's methods of dealing with new business climates and technologies, nine manufacturers, as indicated graphically in Fig. 3, were consulted.

3.1 Speaking With Industry

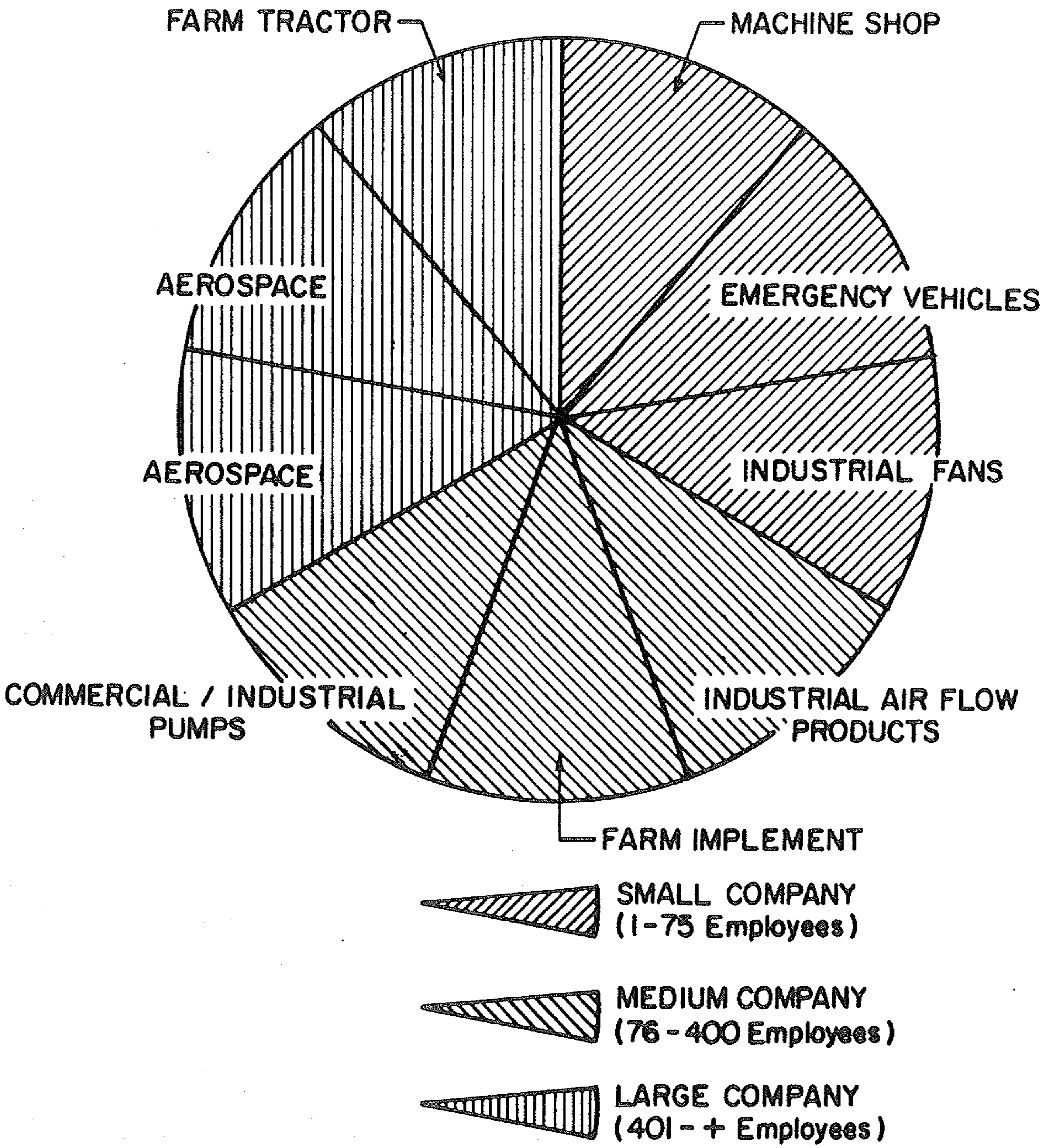
3.1.1 Flexibility A Key

It was found that common concerns were shared amongst all of the manufacturers. They all found it increasingly important to reduce lot sizes on the shop floor in an effort to accommodate changing markets and products. Smaller work-in-process inventory levels and quicker production throughput time also were common objectives. Efforts to achieve smaller lot sizes hinged on greater information and part handling flexibility. All manufacturers agreed that greater flexibility could only be achieved by introducing some degree of automation to management as well as factory levels, and in each case of the nine producers consulted, expand upon the present advanced manufacturing attributes.

Expansion of computer-aided technologies includes establishing flexible material handling systems, increasing the number of present NC machineries, as well as CAD systems to increase design/drafting productivity and flexibility. Flexibility is a key ingredient of new computer-assisted applications for the manufacturer. With increasingly shorter product life cycles, coupled with larger size factories sub-contracting out more and more work to the smaller producer puts the onus on the support staffs of production control, design and manufacturing engineering to accommodate changes with minimal production slowdowns and associated costs.

FIGURE 3

BREAKDOWN OF MANUFACTURERS INTERVIEWED



3.1.2 Pockets of Group Technology

Many of the toured plants revealed small informal pockets of group and cell technology, but without a structured GT technique. In some cases, physical groupings of machinery corresponding to similarities in product attributes were observed, but without integration with the rest of the plant due to poor layouts, and inflexible material handling. This defeated potential global plant benefits.

The rudimentary stages of group technology witnessed showed that positive effort was being made by manufacturers of all sizes to gain better control over production. Further evolution of GT through computer-aided process planning, introduction of bar coding, and flexible hardware on the shop floor will prove economically beneficial. Integration of the conceptual level (CAPP) and the execution level (shop floor) is the key.

3.1.3 High Utilizations of Computer-Aided-Design

Of the nine manufacturers contacted, six possess CAD systems, and two were in the process of installing them. Users of computer-aided design expressed their surprise about the incredible tool CAD offered in the areas of facilities planning through visual simulation of plant layouts. The ability to change layouts quickly and accurately to visualize optimum material and work flow proved to be an extremely valuable addition to their manufacturing techniques. Although CAD systems were initially introduced to increase drawing and design productivity, flexibility, and quality, positive benefits in the areas of plant layout, part bill of materials, and simulation of critical path scheduling became apparent.

3.1.4 Increasing The Flow of Paper

The efforts to reduce lot sizes stood out as a major concern of most of the manufacturers, but a few expressed a high priority for quicker customer product delivery through automation of paper flow. Every company operated within their so-called "system" that slows down the throughput of new job orders, as well as product and process changes. The amount of clerical work, and number of manual operations required to process a sales order all the way through to the release of the production packages on the shop floor, constitues a bottleneck for eventual customer delivery dates. Figure 4 shows the typical flow of new sales orders proceeding through design and manufacturing engineering, production control, and finally to the factory floor. The logical model of integrated manufacturing outlined later addresses directly the need to standardize and automate the role of information handling.

The manufacturers found that the development of an MRP system helped in relieving bottlenecks of paperwork. Tackling a diverse range of computer-assisted manufacturing systems such as MRP (Bill of Materials to Master Production Scheduling and Inventory Control) serves as a learning device for future applications, as well as determining the degree of system applicability to individual operations. Maturity of computer-assisted information handling tasks such as CAD, MRP, CAPP, Accounting and GT has increased greatly over the past 5 years. Off the shelf computer software does, in most cases, establish a base for individual company applications, but in-house modifications are almost always necessary to achieve optimum system performance.

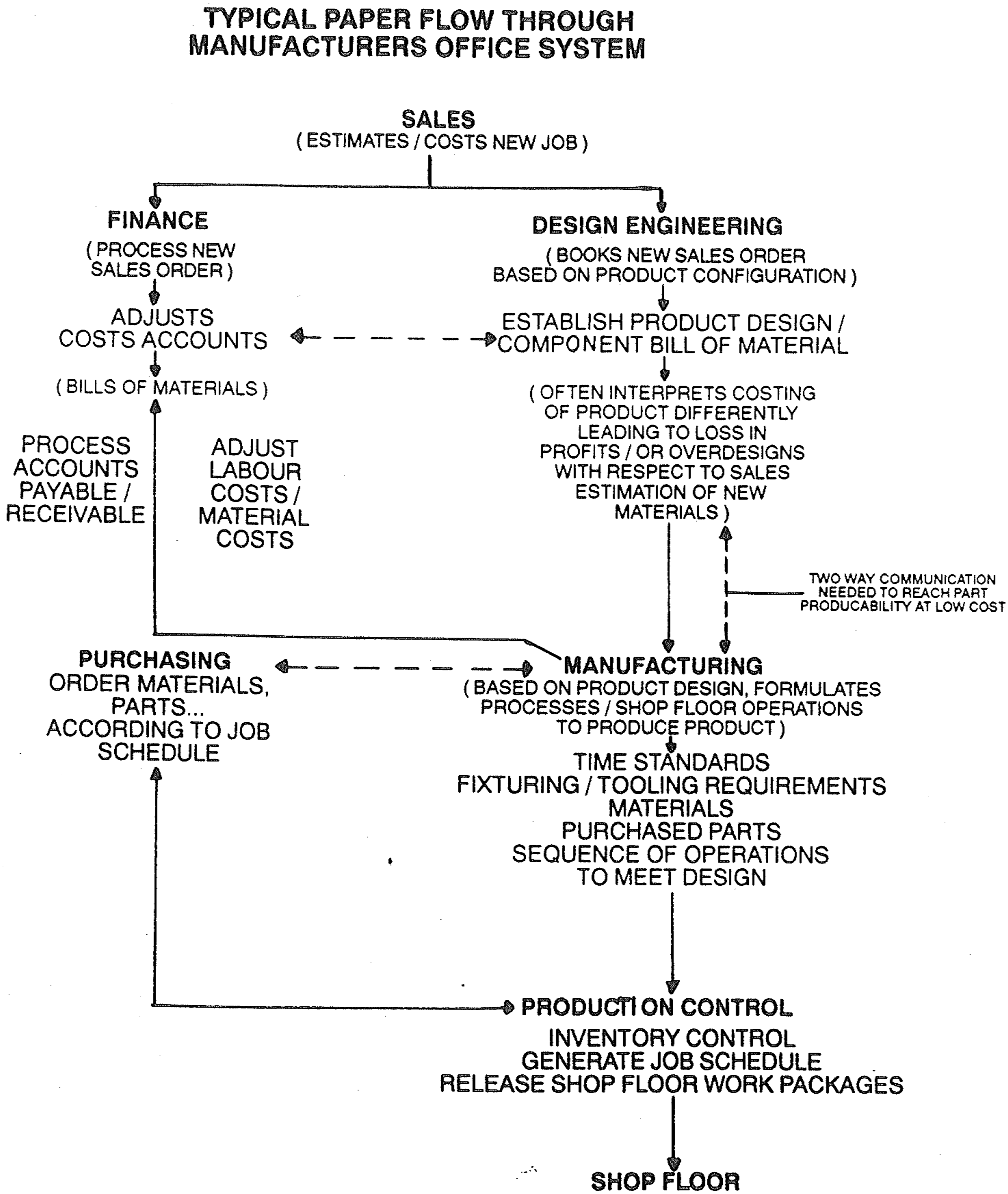
3.1.5 Preventive Maintenance

Another important area of production that was often mentioned was preventive maintenance, and the role of the computer in developing a plant-wide program. Operation slowdowns and inconsistent quality were seen as results of insufficient maintenance scheduling. Increased awareness of preventive maintenance microcomputer software packages coupled with changing philosophies about plant engineering's importance and responsibilities indicated these manufacturers were including one more member within the family of AMS technologies.

3.1.6 NC Workcentres

Of the seven of nine manufacturer utilizing NC machinery, new attention was being given to automated tool monitoring systems. Because of defects in part quality and unforeseen production delays, one-to-one operator to machine ratios dedicated primarily to listening to and watching NC machine tool operation parameters

FIGURE 4



<u>NOTE</u>: OFTEN BILL-OF-MATERIAL IN FINANCE, DESIGN, AND MANUFACTURING OPERATE ON DIFFERENT SYSTEMS ADDING TO PAPER GENERATION.

were observed. Continuing research and development in the area of NC tool monitoring has still to issue a finely-tuned cost effective package for all sizes of manufacturers to implement. Future introductions of better machine monitoring systems coupled with flexible material handling systems will reduce the one-to-one manpower to machine ratio to a more efficient level.

3.1.7 Bridging A Decentralized Approach to Automation

Of the interviewed manufacturers, those who had adopted automated machinery first, (NC machinery, Robotics) now faced the problems of building communication bridges to the islands of automation that had evolved in the shop, in order to help integrate and streamline production. Only one of the nine manufacturers interviewed was actively pursuing distributed numerical control in the plant, and an organizational networking of computer and equipment workstations. The costs, and lack of in-house expertise seemed to deter pursuit of communication links. In addition to communication gaps throughout the organization, a decentralized approach to application of different computer-assisted functions have led to information barriers between different departments of the organization. For those manufacturers who used a management information system in the office, continual upgrading was found to be necessary as the company and amount of data grew. The cost to performance ratio also had a tremendous impact on computer hardware and systems software upgrading. The above points indicate how modularity must be an important objective to initial purchases so that present and future systems can be combined cost effectively.

To illustrate this point, the following situation is presented: a manufacturer buys a cheap computer and CAD software package with a closed proprietary operating system for the design engineering department. As company growth and user expertise is gained at the workstation, the increase in drawing, storage and number of users multiplies. Upon attempting to expand the single workstation to newer, more powerful computers at a lower cost, problems with hardware and software communications are encountered. Manufacturers must attempt to consolidate or centralize new technology applications so that long-term integration is achieved between introductions.

3.1.8 Suitability of Technology to Individual Operations

All nine manufacturers commented on the applicability of Advanced Manufacturing Technologies with respect to their operations. Examples range from trial and error of particular robotic applications, to fundamental group technology, and full-blown automated storage retrieval systems. Capital, product groups or lack thereof, and process efficiency all deterred implementations of such proposals. A manufacturer must thoroughly analyze present manufacturing operations with an eye for suitable components of factory automation before actual execution.

3.1.9 Total Quality

"Design to Produce" as the Japanese have shown, has tremendous effects on the total quality and producibility of a product (26). The manufacturers visited spelled out problems bringing design engineering and manufacturing functions closer together in order to build quality and ease of operations into their products.

One manufacturer commented on the concept of "Totaly Quality Assurance" starting from the way inter-departmental memos are written to incoming vendor material, design, and operator self inspection. Higher levels of consistent part quality were indicated by producers having introduced automated hardware on the factory floor as were increases in the quality of drawings due to CAD systems.

3.1.10 Microcomputer Application

From all indications of interviews held, adaptation of the microcomputer on the shop floor is still not present, but the continually dropping costs of hardware, their capacity of data retrieval, transmission and processing versus performance will surely spell a difference in coming years. As management information handling systems increase, the demands for vertical flow of data from the shop floor will inevitably bring an increased use of the microcomputer.

3.2 Aerospace Manufacturer Takes on Integrated Manufacturing: A Case Study

A prime example of modularity, as defined earlier, was provided by a large aerospace manufacturer who was adopting new technologies company-wide at a very rapid rate. The main push into AMS technologies started in 1980 with NC machinery and CAM applications used for programming. As the number of NC machines grew on the shop floor, CAD was linked to CAM and eventually distributed numerical control evolved in 1986 integrating the design of a part directly with the machine's controller on the shop floor. Greater shop floor control over machine utilization and programming was finally recognized.

Over the span of seven years, three machine shops totalling some 45,000 square feet scattered throughout the plant with 75 machines all under individual machine loading and programming systems were transformed into one single facility taking up 25,000 square feet and 110 machines. The new shop was laid out utilizing CAD to optimize material and worker flow with respect to machine centres based on product-line forecasts. Provision for a flexible material handling system was built into the new layout.

An AGV route introduced to the facility in 1987, increased overall production flexibility, and shop productivity. Modularity of the AGV system was considered during the planning stage from a programmability standpoint. On-board programming was selected to allow easy transfer of the AGV technology to the operators on the shop floor and to production planners. Programming of the AGV's can be done by an operator at a machine-centre or loaded prior to, or during a shift by the production planner. In addition to providing a means of transporting work-in process, the AGV system also offers the option for off-line programming via higher level computers.

Implementation of a computer-assisted labour/part tracking system was brought on-line in 1985. Operators using credit-card type identifiers downloaded employee number, and corresponding jobs completed into the company's mainframe computer. Future intentions are to initiate a microcomputer-based data management system on the shop floor linked to bar code technology for real-time part tracking and routing control. We see that once again, introduction of a rudimentary system has evolved into a significantly more advanced one giving the manufacturer a new production tool.

Modularity, along with the integration of AMS technologies, has two major aspects. The first consists of the systems hardware and software for driving the state-of-the-art office and factory, but an equally important second aspect is concerned with the transfer of technology and education of top management, supervisors, as well as workers about the new systems. This company illustrates clearly both facets of integrated manufacturing as well as their mainframe-assisted labout/part tracking converted to on-line microcomputer-based bar coding. The organization's modular approach to an MRP system outlines the importance of a building block approach to successful integrated manufacturing helping educate personnel of new technologies.

3.3 Technology Transfer

Technology transfer is an important issue today in light of the impact AMS technologies are having on competitive manufacturing in domestic and international markets. All of the companies interviewed acknowledged that a lack of awareness of available computer-assisted technologies was not a deterent to application, but simply felt that some new technologies could not be readily adopted until they put out the fires affecting present-day plant operations. No comment on office-level automation was given, but as the logical model to integrated manufacturing will point out, the absence of a fire-fighting production environment at the management level gives rise to more time for planning strategies and adaptation of computer-assisted information handling tasks (i.e. CAD, CAPP, GT, MIS, CAM).

Comments were also given regarding difficulties in finding experienced operators such a machinists and welders to run both automated and manual equipment. They noted that the colleges were not adequately producing operators for today's technology, forcing in-house training by the manufacturer to reach necessary skill levels. Importance was also given to increasing the flexibility of today's and tomorrow's workers, enabling adaptability to a wide variety of equipment as products and technologies change.

Technology did not replace personnel in areas of AMS application in the nine manufacturers under study, but changed the role of the operators, supervisors and managers in production, manufacturing, engineering and top level management. The new roles included process monitoring, workcentre part loading and unloading, programming new areas of responsibility. Reduced fire fighting allows more long-term planning to take place.

3.3.1 Survey Results: Roadblocks to Automated Systems

Figure 5 shows the percentages of survey respondents indicating that certain roadblocks did, in fact, play a role in obstructing implementation. Of the four points shown in Fig. 5, a lack of employee training, (34% return) represented the lowest percentage. It is a fact that the average worker is going to increase his/her skills as new technologies are inevitably introduced, and new operation roles are created. Survey results pertaining to the training and effect of new technology on workers show that 92% of the respondents are, or have undertaken on-the-job training, while 77% have retrained workers for new conditions, and only 43% have had to hire new workers to fill either new roles or replace previous operators. The net effect of system introduction on the shop floor revealed that 38% of the 75 respondents witnessed a decrease in operator employment levels and 19% showed an increase (see Fig. 6).

From these figures, support is given to the theory that automation does indeed not necessarily replace the worker, but opens up new player roles that provide a support mechanism to a particular technology. Japanese factories that are among the more automated in the world illustrate this point dramatically. Observers of Japanese plants are amazed at the number of workers on the floor. One must remember that the computer and its control equipment require human interaction for programming, maintaining, monitoring, and part loading/unloading.

FIGURE 5

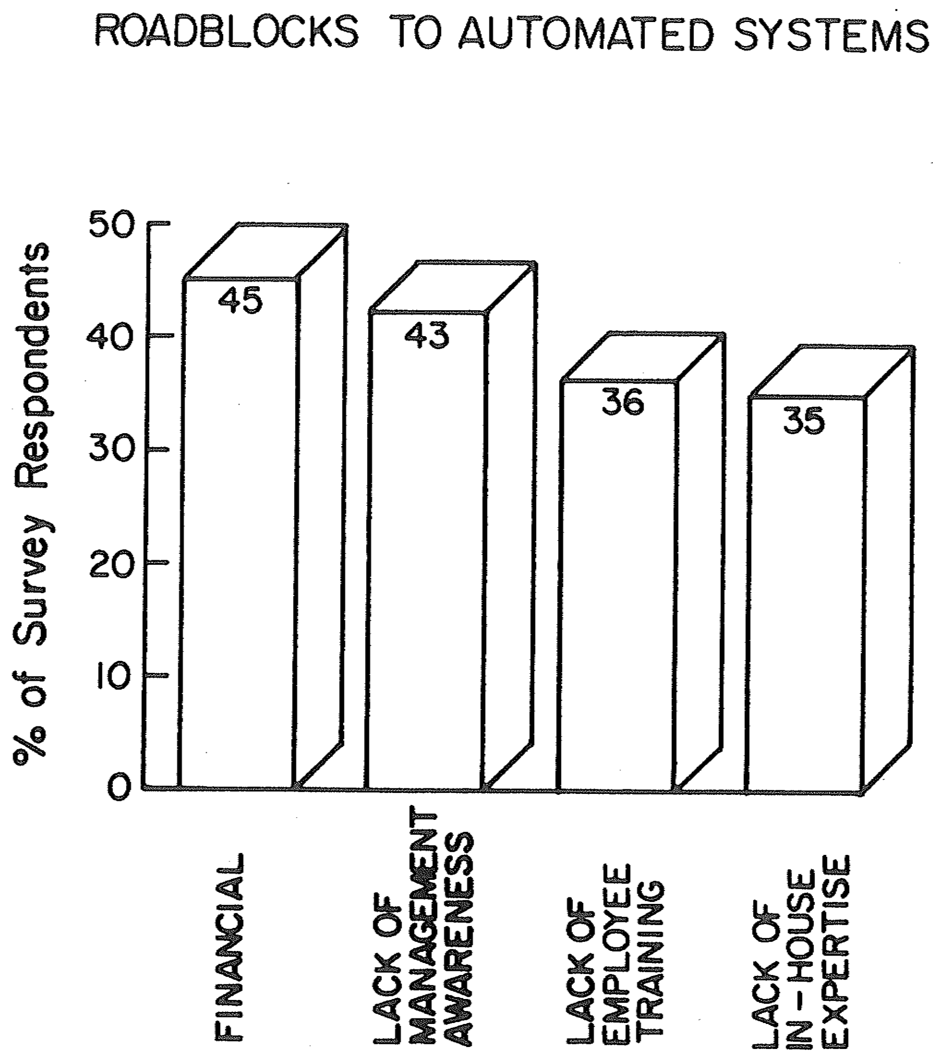
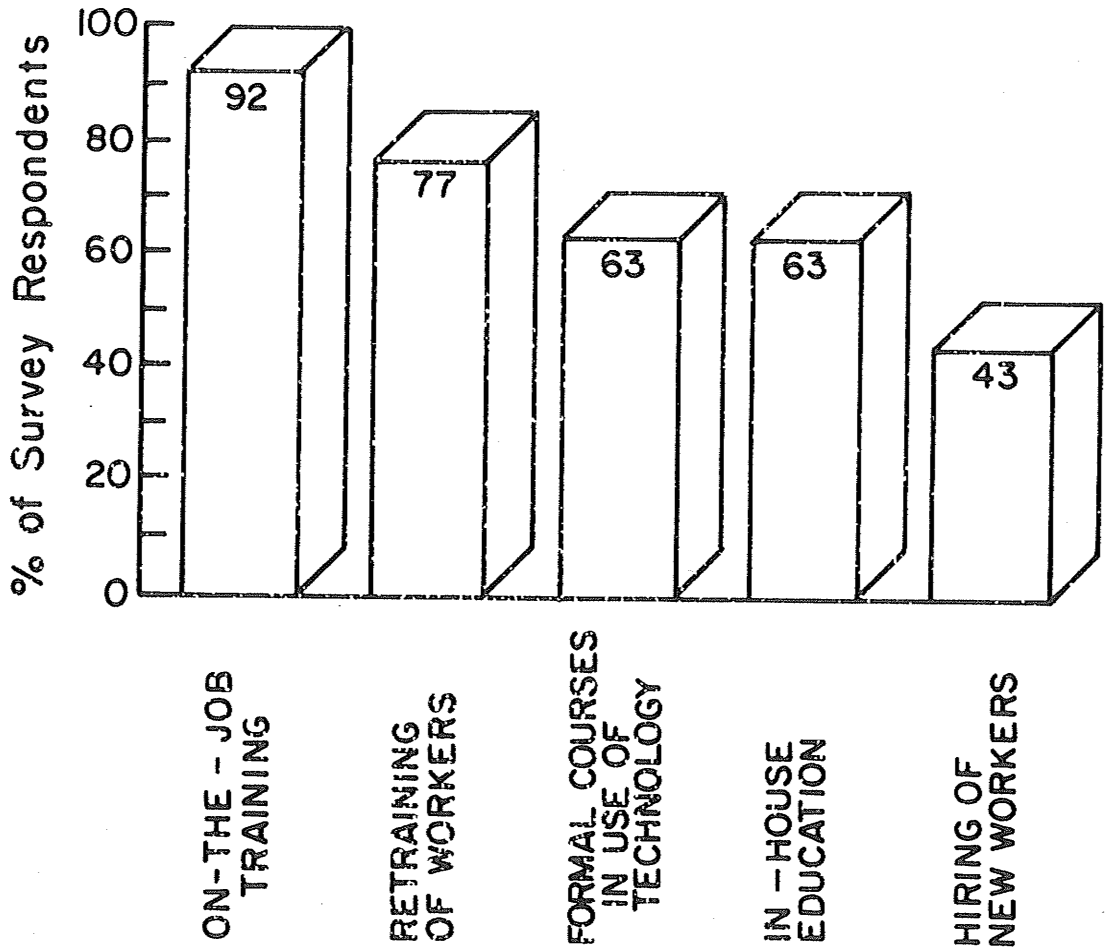

ROADBLOCKS TO AUTOMATED SYSTEMS
% of Survey Respondents
50
40
30
20
10
0
45
43
36
35
FINANCIAL
LACK OF MANAGEMENT AWARENESS
LACK OF EMPLOYEE TRAINING
LACK OF IN-HOUSE EXPERTISE

FIGURE 6

IN-HOUSE TECHNOLOGY TRANSFER



3.4 Managing Financial Justification

Most of the manufacturing managers consulted generally declared that most single applications of technology were financially justifiable by either traditional or strategic methods. Small and medium sized manufacturers indicated that a wide variety of computer-assisted tasks were viewed as financially infeasible as opposed to unsuitable to their operations. Of the four implementation roadblocks outlined in the survey shown in Exhibit 2, financial constraints received the highest return, some 45% of the respondents. This figure does not correspond to the high figures publications have stated as costs being a principal deterrent to new technology introduction (24). The four roadblocks highlighted in the survey were:

- financial
- lack of employee training
- lack of in-house expertise
- lack of managment awareness.

3.5 AMS In Canada: Initial Steps Are Indeed Being Taken

An inside look into nine of the advanced manufacturers from the small machine shop converting NC to DNC machinery for greater process control, to state-of-the-art central AGV material handling employed by the large aerospace manufacturer, and a part recognition, robotic paint system introduced by a medium-sized producer of air-flow products has shown that AMS technologies are alive and well in all sectors of Canada's MW&M industry. It is up to the present day manufacturer to grasp the coming age of automated information handling that will integrate with existing and future shop floor part handling and processing hardware.

CHAPTER 4: AMS TECHNOLOGIES IN THE CANADIAN SECTOR: A USAGE PROFILE

4.1 Automated Information Handling

The maturity of the computer, and its many sizes and capabilities, combined with giant steps in software driving new data systems, has brought new levels of productivity to managing corporate, engineering, and production information typically impeded by labour-intensive clerical work. By first optimizing the flow of present paperwork from finance and sales to design engineering, manufacturing, and finally onto the factory floor reduces the number of hands through which information must pass. Standardizing and organizing current methods of handling both data, and parts on the shop floor as a prelude to automation helps identify problem areas, as well as reduce the learning curve of new technology through proper planning and documentation.

Information and part handling groups make up two classes of automation that co-exist within the new era of manufacturing. To clearly illustrate and understand the relationships between AMS attributes, and trends captured by the survey, the following applications of the advanced manufacturing system have been grouped into automated information handling tasks:

1) Management Information System
2) Departmental Microcomputers
3) Computer Aided Design
4) Computer Aided Process Planning
5) Material Requirements Planning
6) Computer Aided Facilities Planning
7) Group Technology
8) Communications Networking Technology
9) Bar Code Technology

It is important to note that the word automated does not mean human interaction is not involved with each application, but that the computer is used as a tool to quickly access, manipulate, and transmit data (10).

4.2 Automated Part Handling

Automation of part handling on the factory floor found its origins in numerically controlled machinery (i.e. milles, drills, lathes) able to automatically machine more complex part configurations at high levels of consistent quality with greater flexibility and lower setup times. In an effort to integrate the NC machine with in-process parts both locally and throughout the plant, and to automate other critical processes, new developments in computer assisted and microprocessor based hardware entered the production setting.

The following applications of the advanced manufacturing system have been grouped into automated part handling tasks:

1) NC Machinery
2) Robotics
3) Quality Control Applications
4) Material Handling Systems
5) Automated Storage/Retrieval Systems
6) Sensor Technology
7) Automated Tool Changing
8) Group Technology

Computers have established a medium for transferring critical operational data to factory floor hardware, while monitoring work-in-process movement and machine performance. The microprocessor has given a variety of shop floor devices new abilities to interpret and execute relayed information.

To further simplify the analysis of all AMS applications detailed in the survey, both automated part and information task groupings are redefined based on similarities of operations. The following groupings will be used to create a present-day model of advanced manufacturing utilization in Canada's MW&M sector, based on the combination of both computer-assisted information and part handling.

1) The Management Information System
2) Information Transfer From Design To Manufacturing
3) Laying The Groundwork For Factory Layouts And Data Acquisition
4) NC/CNC Machine Centres
5) Robotics
6) Automated Handling And Storage Of Materials In The Plant
7) Quality Assurance On The Shop Floor
8) Sensor Technology

4.3 Principal Findings Regarding AMS Utilizations

Reporting on the principal findings of computer-assisted data systems, hardware, and related manufacturing concepts in the Canadian MW&M sector requires discussion of three points. Applications of AMS technologies introduced by small, medium, and large manufacturers will be analyzed based on:

i) Percentage of users
ii) Order of introduction
iii) Year of introduction

4.3.1 Management Information Systems

Acting as a database systems manager, the management information system introduces the computer to the corporate sales, marketing, and finance entities of the manufacturing organization.

Depending on the extent and structure of computers within a company, the

MIS may control database systems management in other departments, and even on the factory floor. Because the management information system has far-reaching influence throughout the organization, analysis, independent of other information handling tasks is undertaken. Our figures show that 87% of the manufacturers indicated they have introduced a computer system controlling some facet of their management functions.

As Fig. 7 depicts, 100% of large manufacturers, 90% of medium, and 73% of small producers have implemented some form of an MIS. Although the survey did not address the various subcomponents of a management information system, experience has shown that smaller manufacturers typically begin with the computerization of financial procedures such as accounts receivable/payable, and order processing.

It is encouraging to note the strong adoption of an organizational computer system in all sizes of the manufacturing sector. After all, the top level of a company must be supportive of new technologies at both the information and part handling stages of automation with hands-on understanding of the benefits that computers can have on quick, and responsive management of critical facts and figures. Obtaining top level management support for initial AMS integration is important in overcoming barriers to technological change.

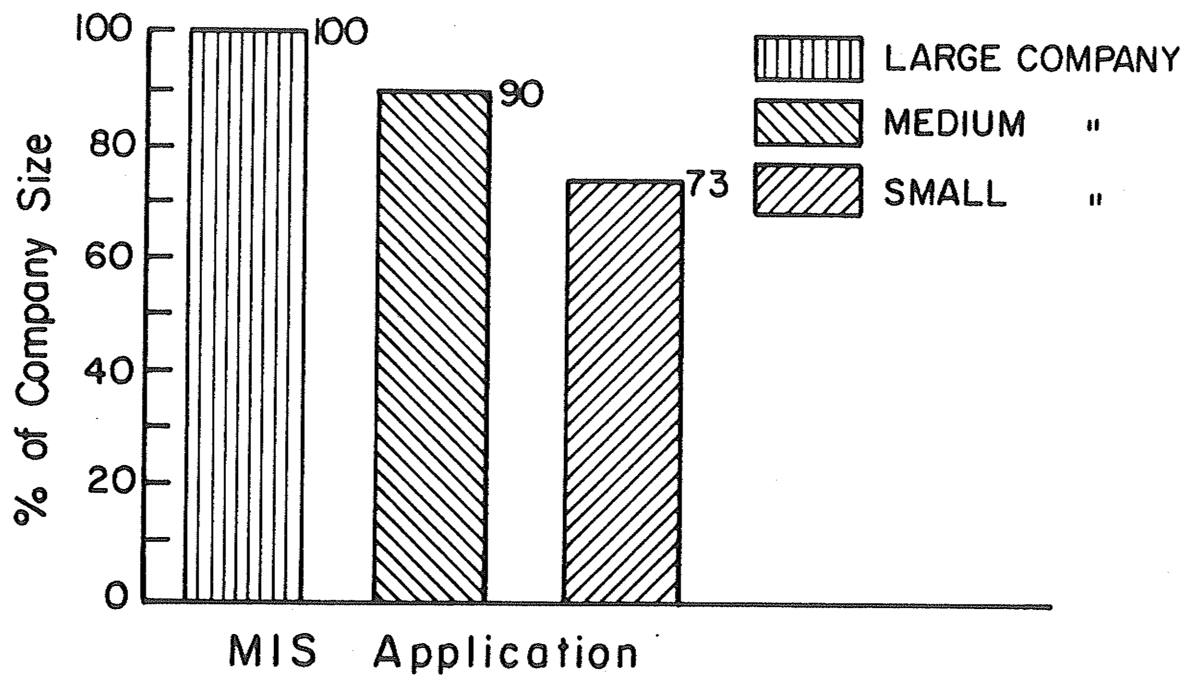
4.3.2 Information Transfer From Design to Manufacturing

Computers possess the ability to quickly acquire, correlate, and transmit data to and from centers of knowledge. Various areas of the organization can benefit from them because of the ability to act quickly on computer accessed information regarding real-time operations.

Figures 8 and 9 compare the percentages of utilization of various computer-based data management functions. Both Figures 8 and 9 show trends of decreasing order of application from large to small manufacturers regarding the utilization of all six computer-assisted hardware and software applications.

FIGURE 7

APPLICATION OF MANAGEMENT INFORMATION SYSTEMS



4.3.2.1 Departmental Microcomputers

The evolution of the microcomputer has brought new information handling capabilities to all departments of an organization. The low cost, small processing times and more than adequate data storage capacity provide word processing, spread sheets, job costing, sales forecasting, staffing, and custom software packages such as graphical representations able to compose various detailed charts and tables for professional presentation of data for department managers and personnel.

In our survey, 88% of large manufacturers, 60% of medium, and 35% of the small sized respondents indicated that application of the cost effective microcomputer brings to life unrealized levels of personnel productivity. Employing the microcomputer as a departmental timesaver exceeds other information handling applications outlined as shown in Fig. 8. However, the microcomputer is strictly a tool enabling quick and responsive management of data. Other attributes of information management outlined are strictly methods or concepts of organizing and standardizing data. CAD, CAPP, MRP and Group Technology represent fundamental techniques to the manufacturing environment, but the computer integrates a wide spectrum of information not possible before computer technology.

4.3.2.2 Computer Aided Design

Figures 8 and 9 indicate that large manufacturers seem to be more experienced users of automation. CAD technology applications follow this trend.

Industry publications in Canada have been quoted as saying computer-aided-design is the highest utilized AMS computer technology, reaching upper limits of 70% usage (6). Results of our survey support this statement since CAD established an overall 60% usage by all described industry manufacturers. This utilization figure was the highest of all computer-aided information systems outlined in the survey.

The numbers shown in Figure 9 reveal a closer equality amongst all sizes of the respondents regarding CAD implementations. Computer-Aided Design increases

FIGURE 8

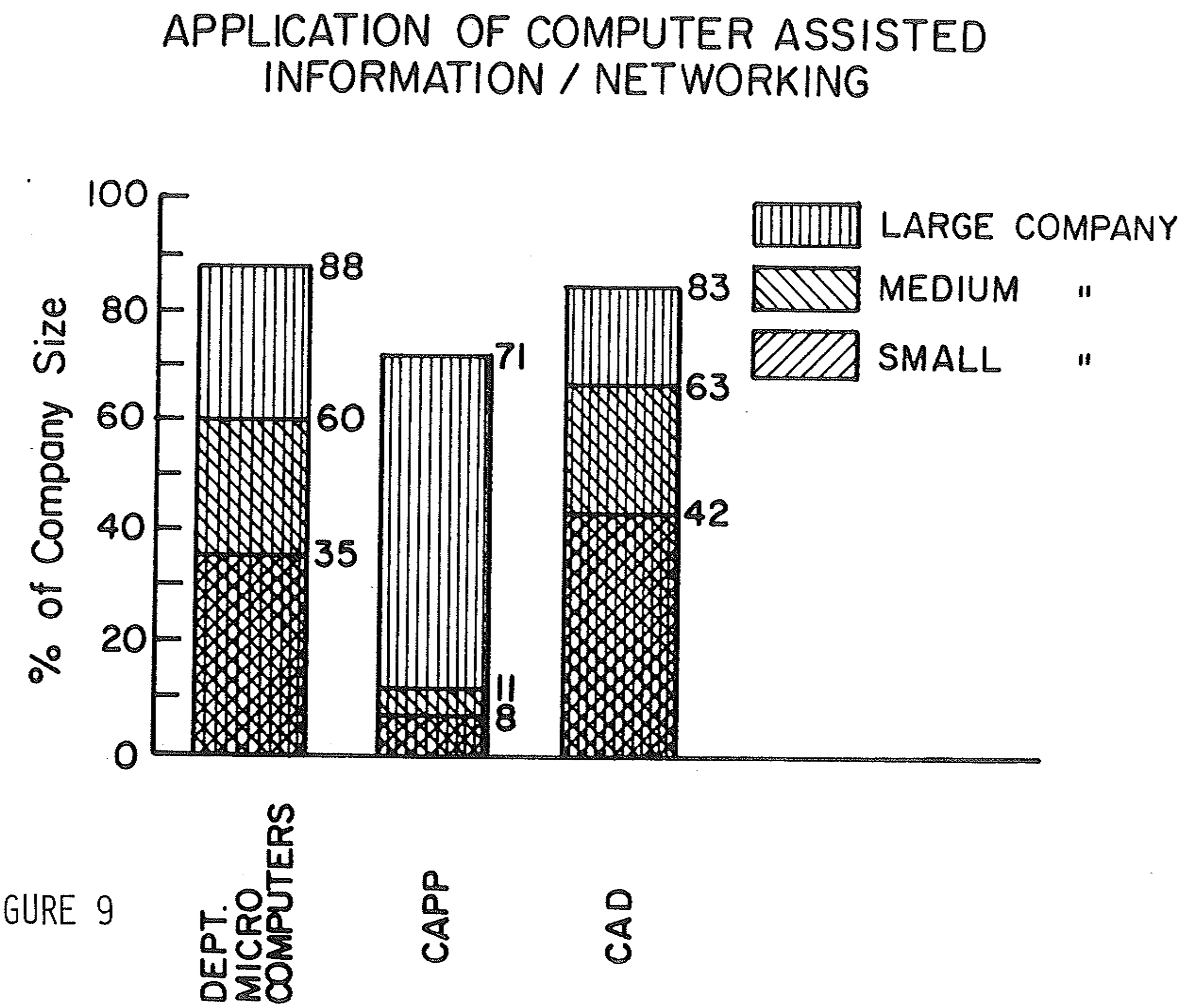
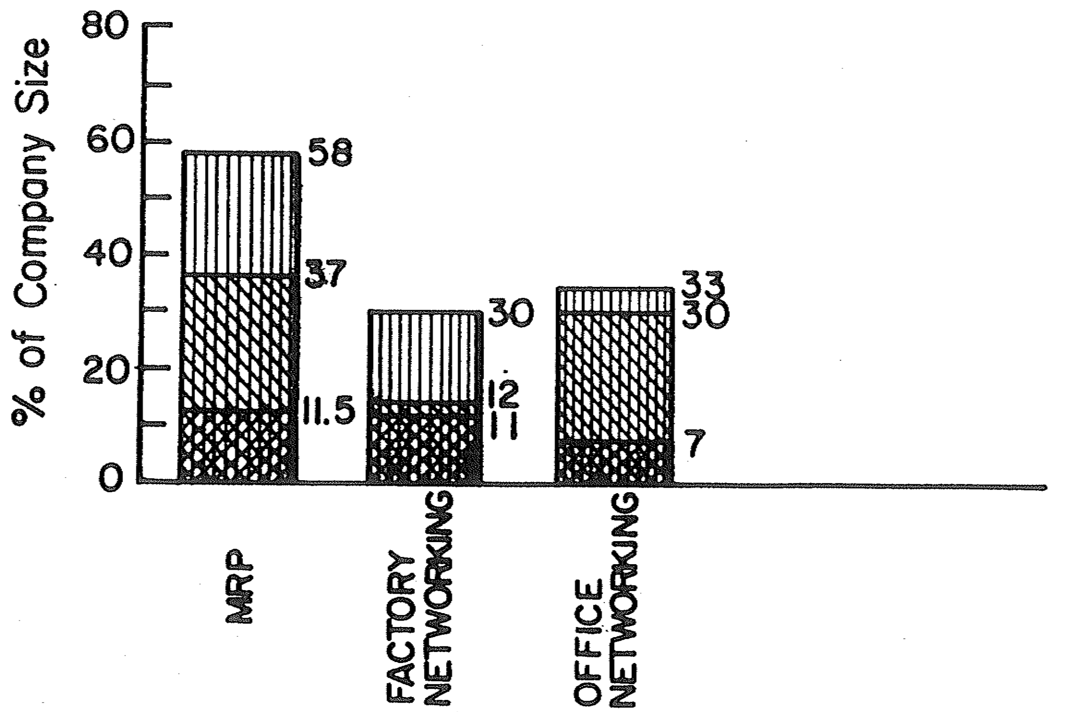


FIGURE 9



the quality and generation of part design drawings, while establishing a drawing database quickly accessible for modifying old drawings for new jobs, or engineering changes initiated at the shop floor, or in engineering.

4.3.2.2.1 The Input of Factory Personnel in New Systems

Factory floor operators and supervisors taking an active part in the continuous operations of production can have a significant impact on a part's producability as well as introducing more efficient methods to perform operations and handling of information. The survey asked advanced manufacturers, who, in their organization, initiated new technologies and whether factory operators actively participate in the operations of new systems. Values shown in Fig. 10 display encouraging results from all levels of the manufacturing organization regarding initiation and on-going input. Management must establish a circle of participation amongst all employees so as to permit the exchange of ideas leading to a more productive and profitable working environment.

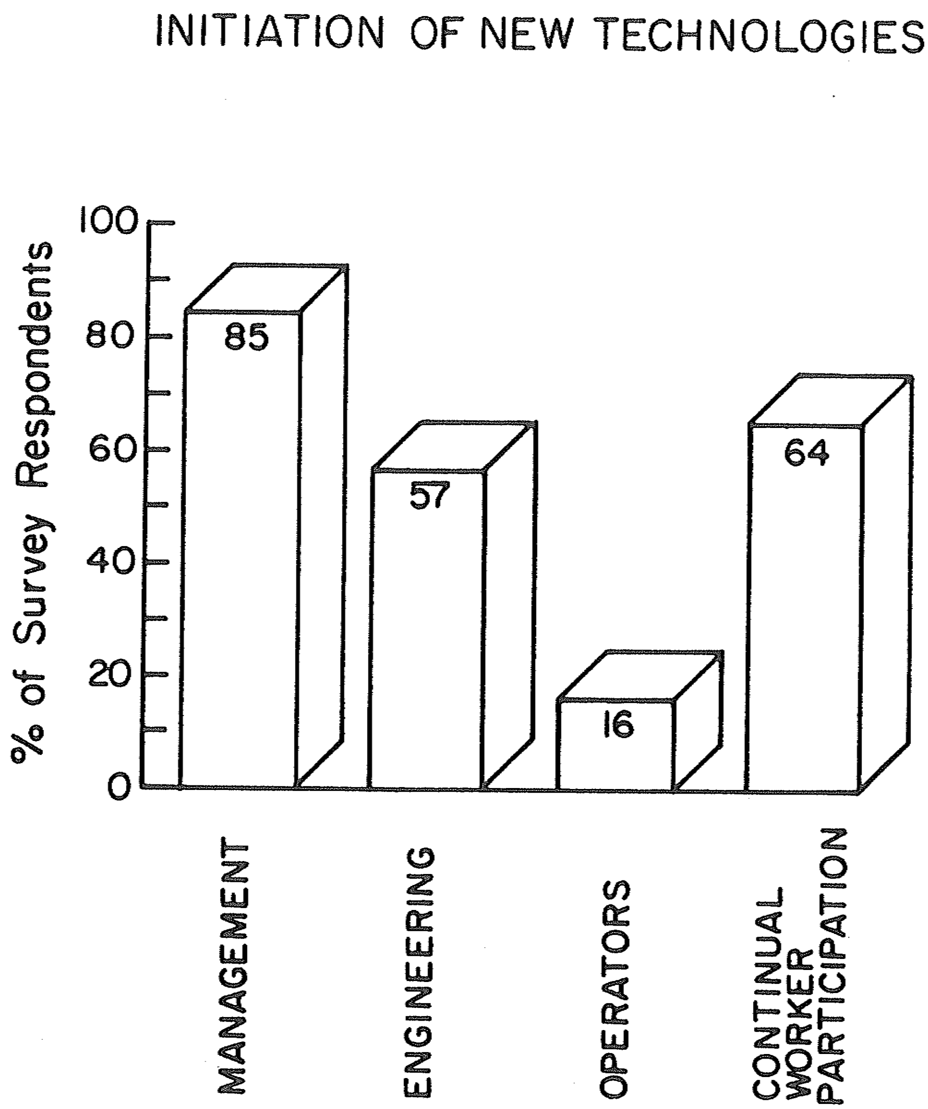
4.3.2.3 Materials Requirements Planning

Lower utilizations of MRP depicted in Fig. 8 illustrates that although the maturity of MRP " off the shelf" software packages is reaching a peak, advanced manufacturers are not adopting the production control system at a high rate.

MRP has far-reaching effects on areas of inventory control, production planning and materials management. The need for integrating scheduling, bill of materials, and inventory control often handled independently of one another within a company's infra-structure may reflect the low rate of introduction of MRP systems. Achieving a cohesive unit from top management to design and manufacturing engineering, enabling system integration, is so often a roadblock to the successful transfer of technology.

Industrial experiences and documentation have shown that manufacturers purchasing MRP packages tend to believe it is simply a turn-key system that requires no more than a computer, and a power outlet! Manufacturers must not be drawn into

FIGURE 10


INITIATION OF NEW TECHNOLOGIES
% of Survey Respondents
100
80
60
40
20
0
85
57
16
64
MANAGEMENT
ENGINEERING
OPERATORS
CONTINUAL WORKER PARTICIPATION

the mistaken belief that automation corresponds to elimination of human intervention. Exchanges between new technologies and employees is essential to the operation of new systems.

4.3.2.4 Computer-Aided Process Planning

Standardizing shop floor operations containing labour standards, routings, tooling and process descriptions in a computer database has a significant impact on the timeliness of relaying information between the factory and the manufacturing department critical to production. Figure 8 reveals a strong application of CAPP by large manufacturers with very little by the other two groups. Computer-Aided Process Planning is a critical facet of information handling tasks emphasizing future application by smaller manufacturers.

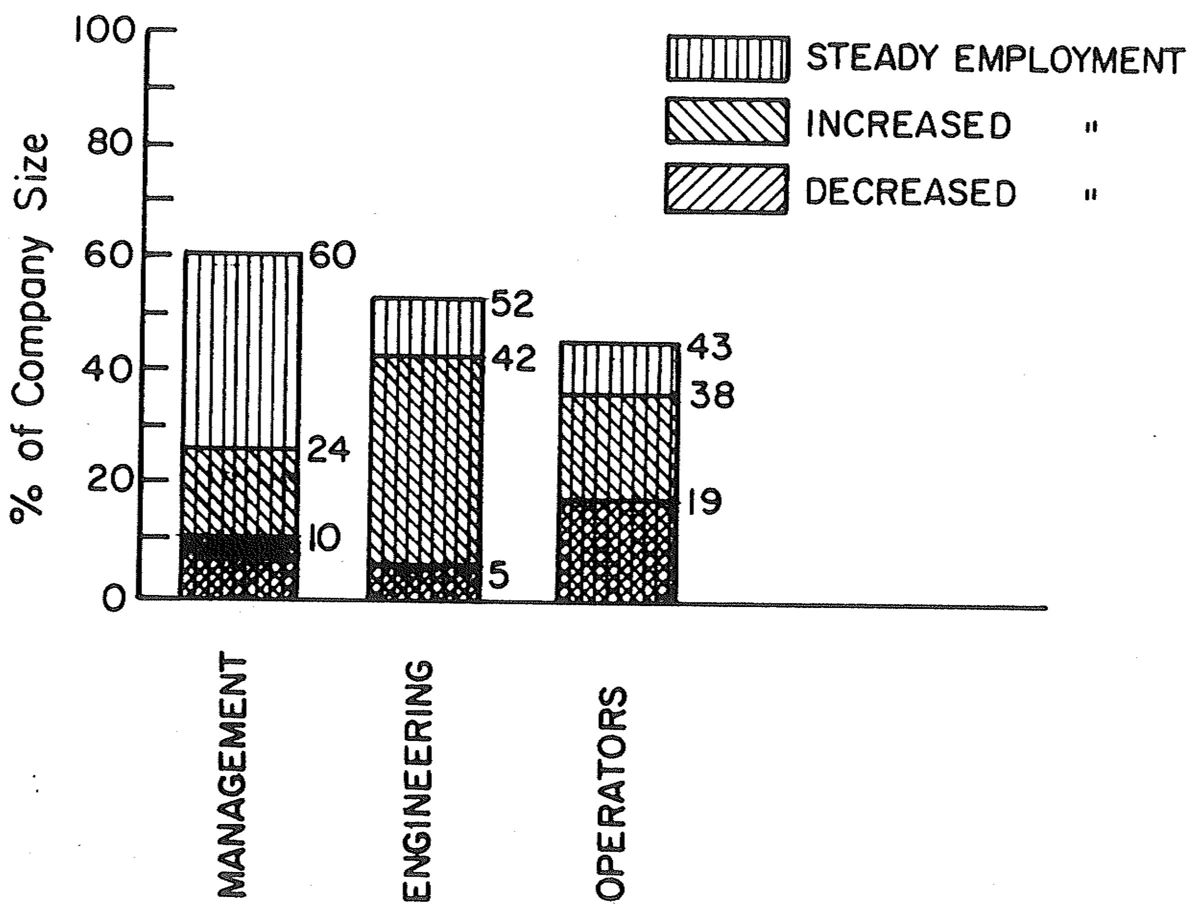
4.3.2.5 Technology's Effects on Employees

Further testimony to the necessity of human interaction with technology is the survey's results pertaining to the net effect of introducing new systems on employment documenting by showing an overall increase in management and engineering levels. Japanese experiences with factories of the future have shown the world that the changing dimension of work roles, and not the elimination of jobs results from application of new technologies. 77% of the respondents indicated they had to re-train workers, and 43% noted they actually hired new workers with the introduction of office or factory automation. (see Fig. 11) Operators, replaced on the shop floor by robots and NC machines, are often retrained to help support mechanisms to new information and part handling systems in the following possible capacities:

- i) Programming
- ii) Monitoring (i.e. tools, coolant, accuracy of program.)
- iii) Part to Fixture loading/unloading
- iv) Integrating with material handling devices
- v) Diagnostics
- vi) Accessing of information

FIGURE 11

NET EFFECT TECHNOLOGY HAS HAD ON EMPLOYMENT



vii) Machine maintenance

viii) Feeding expert system knowledge into computers, and machine controllers.

4.3.2.6 Factory/Office Communications Network

The increase in computers, and the tremendous information flow generated demands an effective traffic controller. Networking of computers between shop floor workcenters and office departments provides a communication link between production processes and data management systems in real-time. Monitoring machines and processes, tracking work-in-process and labour, as well as transmitting part/process changes, and critical production control information (i.e. schedule dates, inventory on hand) are all applications using a communications technology that has quickly evolved from the maturity of computers and factory automation. Technology, like research, is an evolution in itself that creates new and exciting ideas that may be used to expand upon systems leading to integrated manufacturing.

In line with trends being established, utilization of communications networking of computers in both the factory and office by medium and small sized firms are quite low, 21% and 22% respectively overall. This result is only logical because of the witnessed lower introductions of computer-assisted AMS applications by the small producer correlating with a lower demand for networking of fewer computer and equipment workcenters. As manufacturers' usage of computers increases, so will the need for a communications network able to move information quickly and cheaply to a growing number of knowledge centers located laterally and vertically throughout the company.

4.4 Laying the Foundation for Factory Floor Processes and Data Acquisition

Through computer control, many manual modes of information and part handling can be automated to increase the productivity and quality of managing operations.

4.4.1 Group Technology

The fundamental link between the two areas of automation, both for information, as well as part handling, is provided by group technology, or GT. GT utilizes the commonalities in part designs, processes, and tooling information to first configure part families, and secondly, the plant layout that optimizes material and worker flow based on the family of parts being produced. Group technology exploits the fundamental industrial engineering technique of plant layout and standardization of manufacturing attributes to increase plant-wide productivity.

4.4.2 Cell Technology

The development of automated guided vehicles has brought about the concept of cell technology. Cell technology (or CT) is simply an extension of group technology, offering the manufacturer more flexibility because of the accessibility to an automated material handling system. Work cells processing specified part groupings can change from period to period due to flexibility of both the AGV and in-cell machine automation.

Although cell technology represents a very new concept in the physical distribution of machinery and handling devices on the factory floor, our survey results indicate that 33% of the large manufacturers, or 11.5% of the overall sample have adopted the new technique. Figures on the employment of AGV's by firms of the same size is 30%. The correlation between the two applications is almost equal, but misunderstanding of the true meaning of cell technology on behald of the respondents may have had a impact on the high utilization rate. Cells, or groupings of machinery, operations/processes, and material handling devices are often formed based on the generation of part families.

Figure 12 reveals that the usage of group technology and the formation of part families is very low. Overall, only 1.5% and 7.3% of the advanced manufacturers responding have introduced either GT or part families respectively. These two manufacturing techniques produce a simple logical approach to standardizing and improving factory productivity for even the very smallest of companies. It is possible that ambiguity may have been a factor in the high utilization of cell technology replacing what is actually group technology, or strictly part family development.

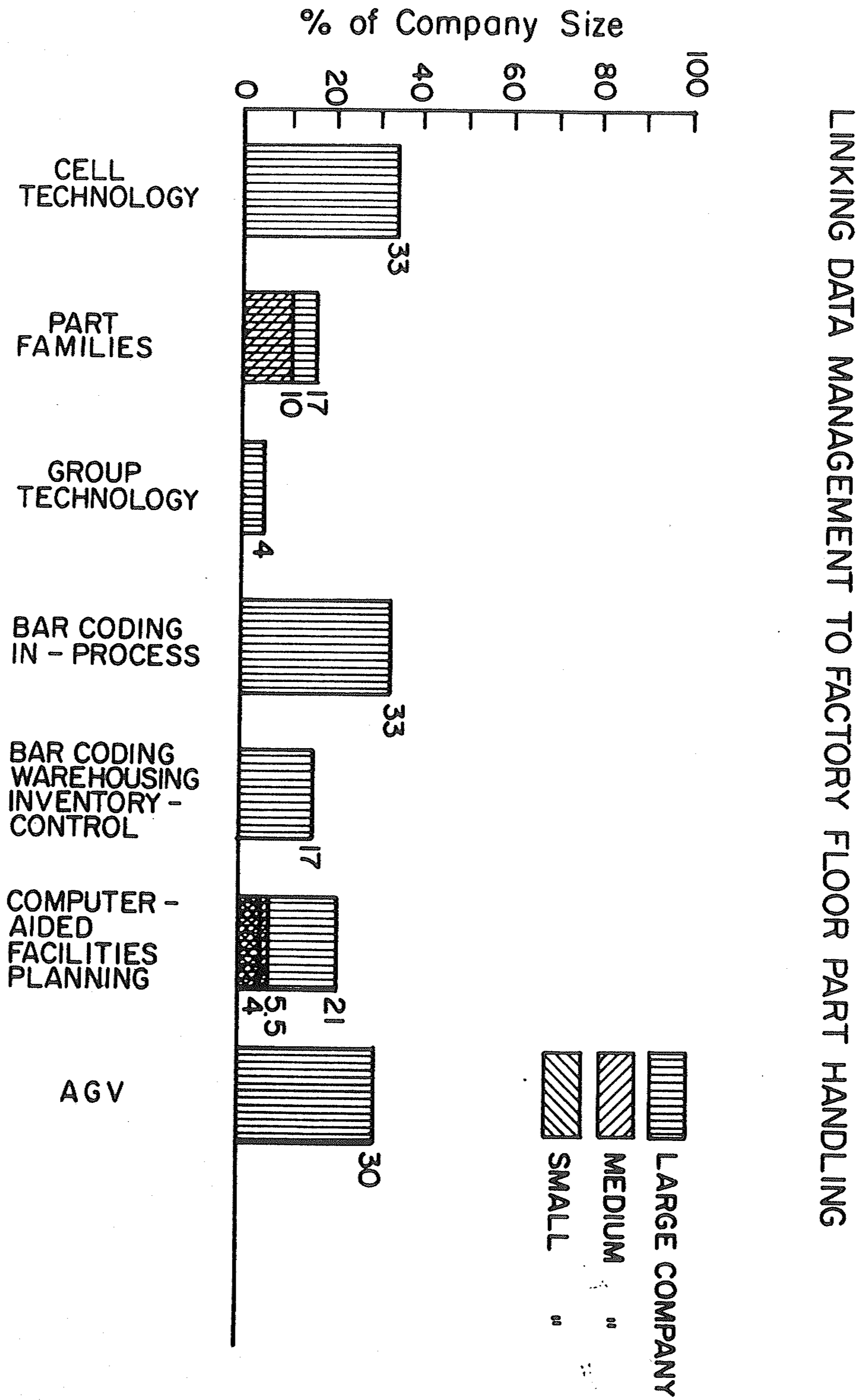
4.4.3 Bar Code Technology

Bar Code Technology and part family classifications integrate with the group technology concept. Bar coding is a means of acquiring real-time data of work-in-process by means of standardized computer-read symbols in order to update production control. The faster and more efficient in-process parts and labour can be tracked, coded, and transmitted to critical centers of knowledge, the quicker more responsive decisions can be made regarding the dynamics of the production environment. Quicker decision-making means a reduction in bottlenecks and ultimately increased customer service levels through shorter production time.

Without automated data acquisition capabilities, the advanced manufacturing system will not be achieved (30). Based on the simplistic framework of group technology, and part groupings, codes are developed that correspond to each part group. A code characterizes a physical or process attribute of a part family. The codes are integrated with standard bar codes and bar code readers are used to interpret the codes and corresponding part family, for the central computer processor.

Figures show that 33% of large manufacturers, or 11.5% of the entire sample have introduced bar coding to track work-in-process and labour. The difference between bar coding on the shop floor and group technology adoption (11.4% vs. 1.5%) shows a lack of integration between the two technologies. Group Technology is an essential framework before automatic data acquistion on the shop floor. Bar coding used in warehousing applications for controlling either raw materials, in-process, or finished inventory showed a usage of 16.6% for large manufacturers, or 6% of the respondents. Inventory and tool crib control play an important role in daily production operations, and bar code technology can easily integrate into these functions of shop floor control.

FIGURE 12


LINKING DATA MANAGEMENT TO FACTORY FLOOR PART HANDLING
% of Company Size
0
20
40
60
80
100
CELL TECHNOLOGY
33
PART FAMILIES
17
10
GROUP TECHNOLOGY
4
BAR CODING IN - PROCESS
33
BAR CODING WAREHOUSING INVENTORY - CONTROL
17
COMPUTER - AIDED FACILITIES PLANNING
21
5.5
4
AGV
30
LARGE COMPANY
MEDIUM "
SMALL "

4.4.4 Computer-Aided Facilities Planning

Plant layout, or facilities planning lies at the heart of group technology. The development of computer graphics technology has provided the manufacturer a new medium for transposing an old engineering concept. Plant layout has been used for years in the manufacturing industry to try and capture the optimal layout of equipment and worker integration to meet production requirements. Computer-Aided-Design (CAD) systems enjoy a high utilization rate of 61% by the Advanced Canadian MW&M sector surveyed, but the use of CAD for alternate applications, such as facilities planning, has evidently not ocurred at the same rate. Figure 12 shows that only 21% of large, 5.5% of medium, and 4% of small manufacturers have utilized CAD systems for purposes of simulating plant layouts (10% of respondents).

Computer graphics gives the manufacturer the ability of simulating the physical layout of the plant corresponding to different workcenter and process groupings so as to optimize material flow through the plant. When evaluating the effect of new products on plant resources the use of computer graphics to clearly illustrate changes necessary to accompany new products, can mean the difference between cost-effective production of part groupings.

GT, CT, part families, bar coding, and computer-assisted facilities planning illustrate how various applications of AMS technologies can be integrated achieve optimum results. Unfortunately, results indicate a low utilization of these fundamental and quite available technologies by the respondents.

4.5 NC/CNC Machine Centres

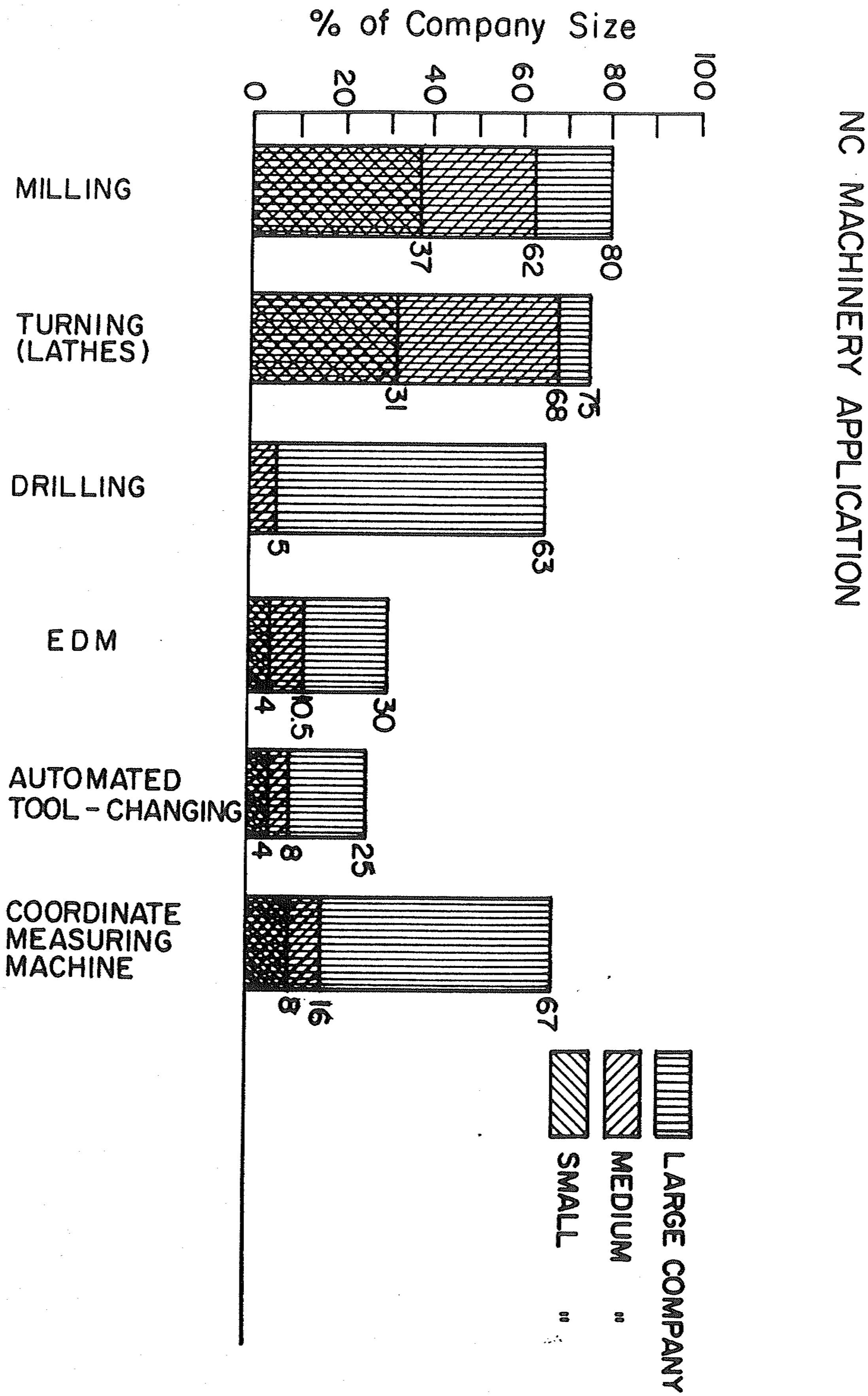
Advanced manufacturing technologies centered around the automation of part handling (e.g. NC machinery and robotics) have witnessed a faster acceptance than that of computer-assisted information handling. With growth in microprocessors, computers and support software development, a new dimension has been added to the realm of automated part handling, off line programming, and adaptive feedback controls.

For purposes of standardization, the survey did not attempt to identify differences between NC, CNC, and DNC operated machinery. Historically, numerically controlled machinery was the first to step towards automating machining operations. Programming of the various parts to be machined was performed off-site on punched tape. This form of communications with the machine was slow in processing time, limited in complexity of part designs, and generated a significant amount of tape for each part produced. As NC technology matured, CNC and DNC controls entered the picture. Computer numerically controlled, and distributed numerical control have utilized a maturing communications technology to generate and transmit part programs to the machine's controller. New adaptive and feedback controls for monitoring processes in real-time have been established coupled with greater machining flexibility allowing greater part complexity also.

4.5.1 Utilization of NC/CNC Machine Operations

Of the three machining operations listed in the survey, the usage of mills exceeded all others. Figure 13 shows that 80% of large manufacturers, 37% of medium and 62% of small respondents have installed NC/CNC milling machines. The high utilization by small producers of NC/CNC machinery is opposite to the low values for information management technologies (i.e. CAD, CAPP, MRP, Networking). Milling represents the most common machining operation, and small firms buying NC equipment would tend to invest in hardware that suits their most common operation. The low use of NC/CNC drills, (63% of large, 5% of medium, and 0% of small producers) points to the fact that milling and drilling are often performed on the same machine as opposed to having dedicated machinery for drilling operations. The higher percentage of large manufacturers using NC/CNC drills is indicative of the maturity of numerically controlled machinery. The trend is now towards machining centers where a number of operations (i.e. milling, drilling, boring) are performed to increase uptime of machinery, and reduce setup times. Larger manufacturers who are established as more experienced users of automation, as survey results have indicated, have tended to introduce AMS technologies earlier, supporting the higher use of traditionally dedicated NC drilling operations. EDM machinery performing material removal operations

FIGURE 13


% of Company Size
0
20
40
60
80
100
NC MACHINERY APPLICATION
MILLING
37
62
80
TURNING (LATHES)
31
68
75
DRILLING
5
63
EDM
4
10.5
30
AUTOMATED TOOL - CHANGING
4
8
25
COORDINATE MEASURING MACHINE
8
16
67
LARGE COMPANY
MEDIUM "
SMALL "

similar to a lathe is typically used in tool-making, and less for mainstream production. Numbers shown in Fig. 13 support this statement indicating a low utilization of these machines (30%, 10.5% and 4% respectively amongst large, medium, and small respondents).

The very low utilizations of NC/CNC flame cutters, punch presses and lasers cutters reported indicate a strong focus on milling, drilling and turning operations within the Canadian MW&M sector. The survey did not address the number of axes each machine possesses. A machine's ability to machine more complex parts at lower costs is directly related to the number of axes, or movements of machine tools and work tables. Industry studies have shown Canada to be only a "2 1/2 axes" machining nation. This significantly impedes greater machine performance and productivity (24).

4.5.2 Automated Tool Changing

Integration of automated tool changing capabilities with NC machinery is critical to the efficiency of a machine center. Machine downtime and setup times are directly affected by an automated tool magazine or carousel close to the machine or manufacturing cell. Today's NC/CNC machines come with the option of automated tool changing with a magazine offering a number of tools stored on-site. Many experienced users of NC equipment using older machines without the presence of automated tool changing capabilities either develop in-house quick change tooling procedures for both manually operated and NC machinery, or establish tooling carousels accessible manually or by a robot within a machining cell.

Tooling carousels integrated with a handling robot can be more cost-effective than equipping each NC/CNC machine with individual automated tool changes. Using group technology concepts, a number of machines may be grouped around a carousel permitting a robot to load tools into each machine's chucking devices. Such a configuration puts more stress on the communications network between the hardware components of a workcell and increases the need for local-area-networks.

Significant differences between the use of automated tool changing and NC/CNC equipment in all sizes of manufacturers was indicated. Figure 13 shows the comparison between these two sources of potential integration. It is evident from the figure that many producers do not possess automated tool changing capabilities. This results in increases in machine downtime and setup costs associated with NC machines. Once again, integration could play a significant role in achieving maximum productivity out of each step of automation. Without systems integration, new technologies fall short of their potential.

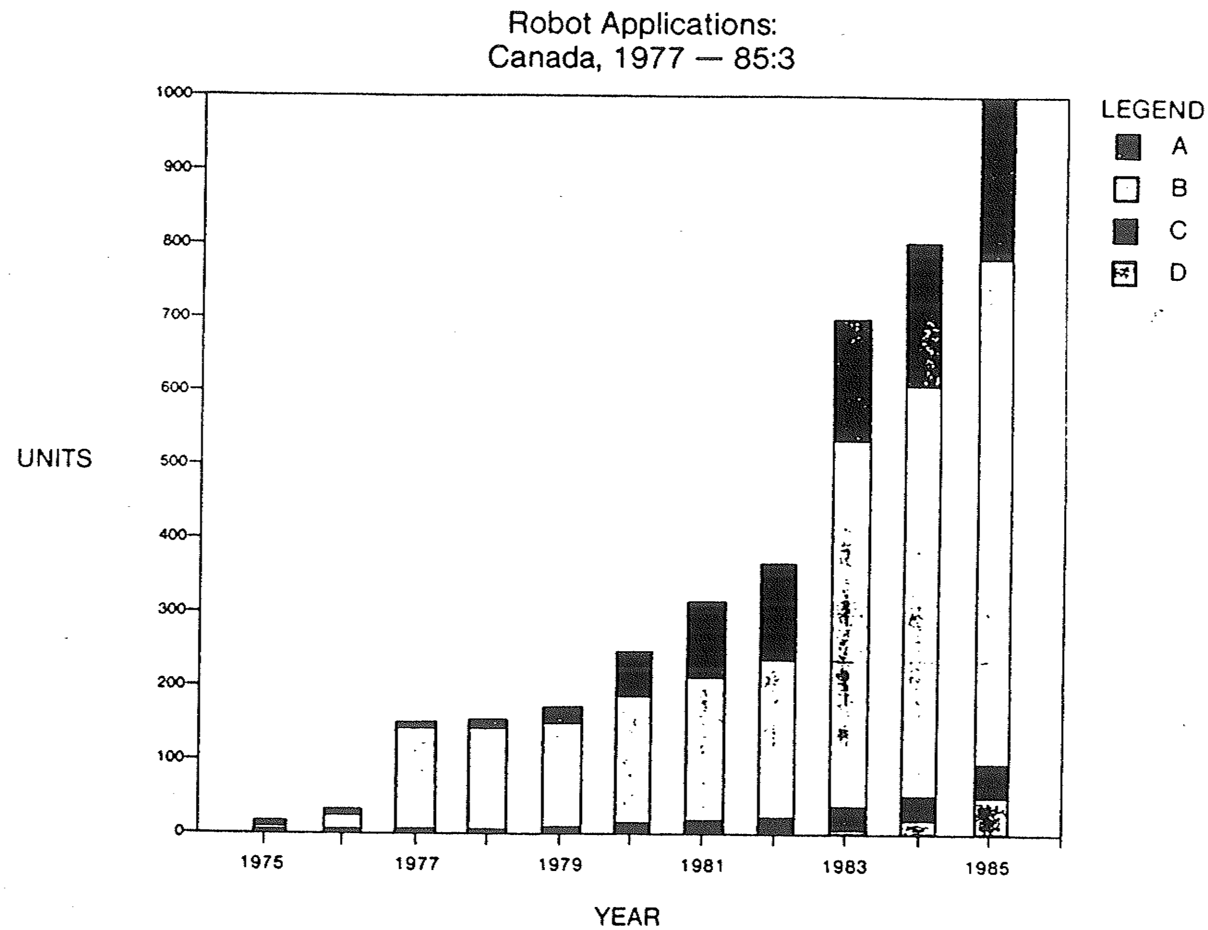
4.6 Robotics

The term "industrial robot" has been defined as a "reprogrammable multi-functional manipulator designed to move objects through variable programmed motions for the performance of a variety of tasks" (27).

As the robot gains more recognition in the manufacturing environment, the variety of tasks are becoming more diverse. Like many technologies, the experience obtained from initial introductions provides the user with the learning tools and ideas necessary to tap new sources of applications. Since the mid 1970's when robotics came onto the scene of Canadian manufacturing, approximately 1400 robots have been installed in a variety of industries (24). The automobile industry makes up a large percentage of robot users. Material handling and process applications have formed the largest percentage of robotic usage in the past, but assembly and quality control areas are beginning to take shape as larger factories trim down to "assembly orientated" operations, and manufactures pushes for greater quality. (See Fig. 14).

Figure 15 shows the relationship between assembly, process, material handling, and quality control applications found from the results of the survey. Twelve percent of the respondents have introduced a robot into their assembly operations. This parallels present industrial statistical trends as larger plants downscale to "assembly oriented" operations. Of the total 39 robots introduced by the 75 manufacturers, 45% were process-based, 28% in material handling, 20% in assembly and 7% in the area of

FIGURE 14



Note:	Applications code:
	A: parts and material handling
	B: tool handling and process applications (including welding, spray painting, grinding, polishing and de-burring)
	C: testing and inspection
	D: assembly
Source:	Ontario Innovation and Technology Division Survey, 1985.

quality control. The realm of robotic use is dominated solely by the large manufacturer group indicating that smaller companies do not feel they have the knowledge or confidence to utilize a robot effectively. Although today's transfer of robotic technology into the workplace has been much simplified, the smaller production shops must begin to treat a robot like any other machine so that its benefits of increased productivity, higher consistent quality and repeatability are recognized.

4.7 Automatic Handling and Storage of Materials in the Plant

4.7.1 Getting Started: Conveyors, Overhead Rails and AGV's

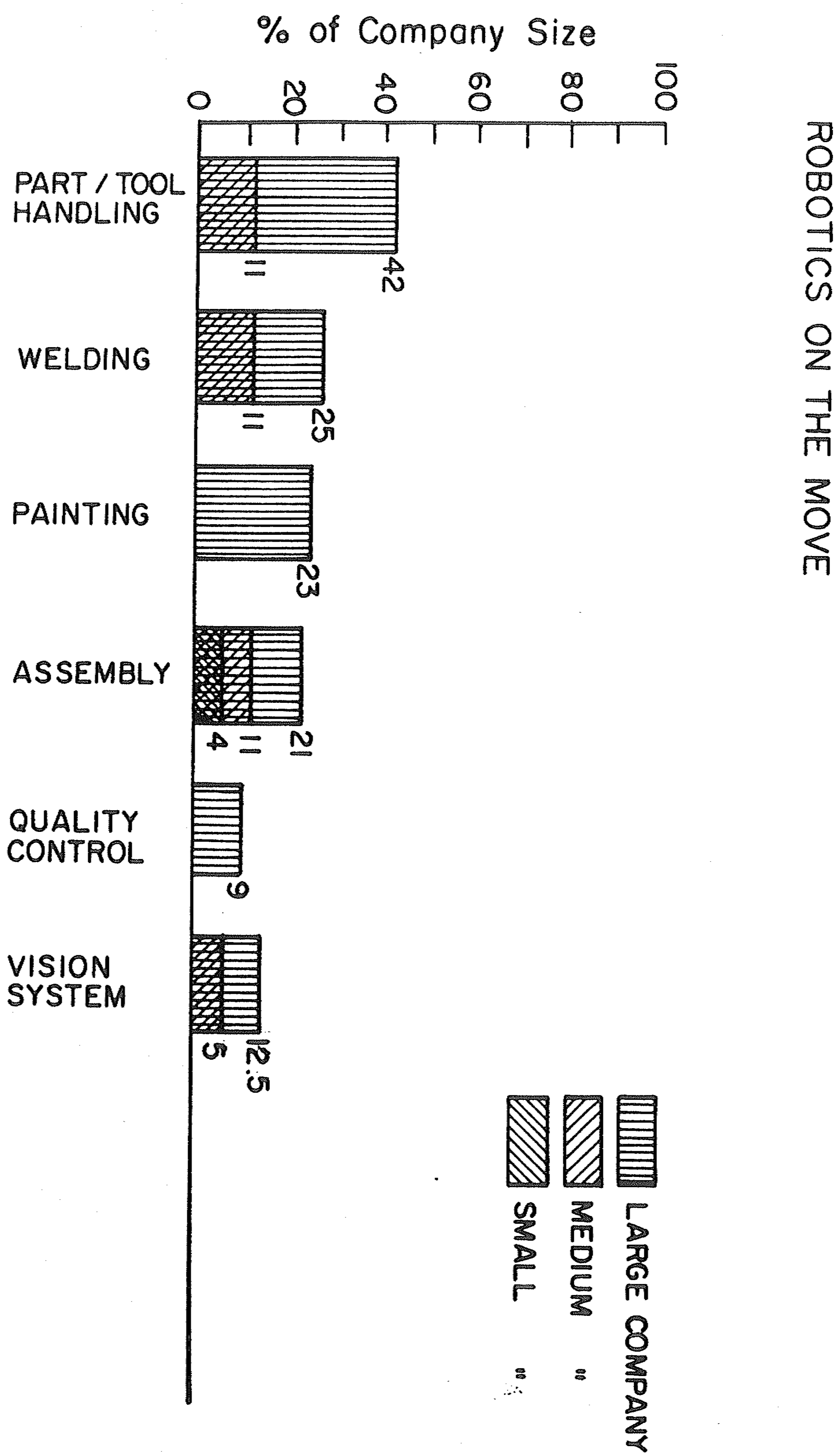
Moving and storing materials either locally or throughout the plant in an efficient manner has positive effects on the entire manufacturing process. Getting raw materials, work in-process and finished goods to and from workcentres on time increases workcenter uptime and reduces in-process inventory. The introduction of computer-aided controls and programmability to the movement of overhead rails and conveyor systems coupled with automated guided vehicles (AGV) provide the manufacturer with potentially greater material handling performance.

Survey results indicated a low utlization of automated conveyors, overhead rail systems, and AGVs, as well as other means of managing the movement of parts and materials. 30% of large manufacturers have specified the introduction of AGV's to date with no such specification given by medium and small producers. Only 19% of the "large" sector have employed automated conveyors.

4.7.2 Automated Storage/Retrieval Systems

The arrival of the automated storage retrieval system (AS/RS) in the late 1970's and early 1980's and integration of the warehouse to the factory floor did have its pluses, but the high hardware costs of stacker cranes, tracking and plant reorganizations have to be considered. Today, with the high cost of carrying large inventories in the factory and the efforts being put into producing just-in-time, the large AS/RS's of yesterday are losing their applicability within the production setting. Survey findings show that 21% of the larger firms or only 8% of all 75 respondents

FIGURE 15



% of Company Size
0
20
40
60
80
100
ROBOTICS ON THE MOVE
PART / TOOL HANDLING
11
42
WELDING
11
25
PAINTING
23
ASSEMBLY
4
11
21
QUALITY CONTROL
9
VISION SYSTEM
5
12.5
LARGE COMPANY
MEDIUM "
SMALL "

have applied the AS/RS to shop floor operations. However, the full-blown AS/RS will no doubt continue to find a home in dedicated warehousing operations.

It should be noted that smaller systems such as tooling carousels, and local fixture storage centres can be used effectively to reduce machine centre setup costs.

4.8 Quality Assurance on the Factory Floor

Highly competitive domestic and international markets, coupled with increasing consumer demands have led to corporate goals of a low cost, high quality producer.

From a plant-wide perspective, each area of production must achieve prescribed quality levels before moving the work-in-process forward. In order to automate one process, or facet of production, it is important that in-coming consistent quality be obtained so that the new automated hardware can perform a particular operation accurately without problems. To illustrate this, consider a 40 year old punch press producing lift arms for an industrial tractor bucket. The lift arms are taken to the welding area where other components are welded onto the two arms. If a robot were introduced into the welding process enabling greater productivity and quality, the configuration of the arms would have to be 100% consistent so that the robot's program welds the proper seam each and every time. Developments of vision systems integrating with robotic installations would reduce such a problem, but involves higher costs and still another learning curve for the small manufacturer to overcome.

4.8.1 Utilization of Automated Quality Hardware

The effect of automation has even reached the realm of quality assurance. Coordinated measuring machines, vision systems, sensors and lasers all make up the family of automated instruments dedicated to improving product quality. Figure 16 shows the scope of quality control applications the survey respondents have introduced to date. Usage of coordinate measuring machines (C.M.M) amounted to 30% of all 75 manufacturers. A breakdown within the three group sizes was: 6.7% large, 16%

medium and 8% small. Only four introductions of vision systems were reported.

The relatively higher level of C.M.M. application reported can be attributed to the even higher levels of NC/CNC machinery usage as previously outlined. A logical route to automation beckons the call for C.M.M./NC integration. In an effort to machine highly complex and precise parts through introduction of NC/CNC machinery, a manufacturer wants to monitor the quality of these parts coming out of machine centres. Numerically controlled machinery does not replace the operator, and problems can still arise due to tool, coolant, fixture and part program problems. To minimize these problems and make sure part defects are caught where they originate, linking a coordinate measuring machine to NC/CNC hardware will ensure quality is achieved before moving on to other factory locations or to the customer. Data feedback from the C.M.M. can be accessed by various areas of the factory to monitor and take corrective action on operational problems.

Vision Technology offers a replacement to the human eye enabling accurate examination of finished work-in-process such as assembling a window to a car, or tracking a seam for an arc weld. Vision systems are reaching manufacturing and financial flexibility, but still represents a whole new world of technology to the inexperienced users of flexible automation.

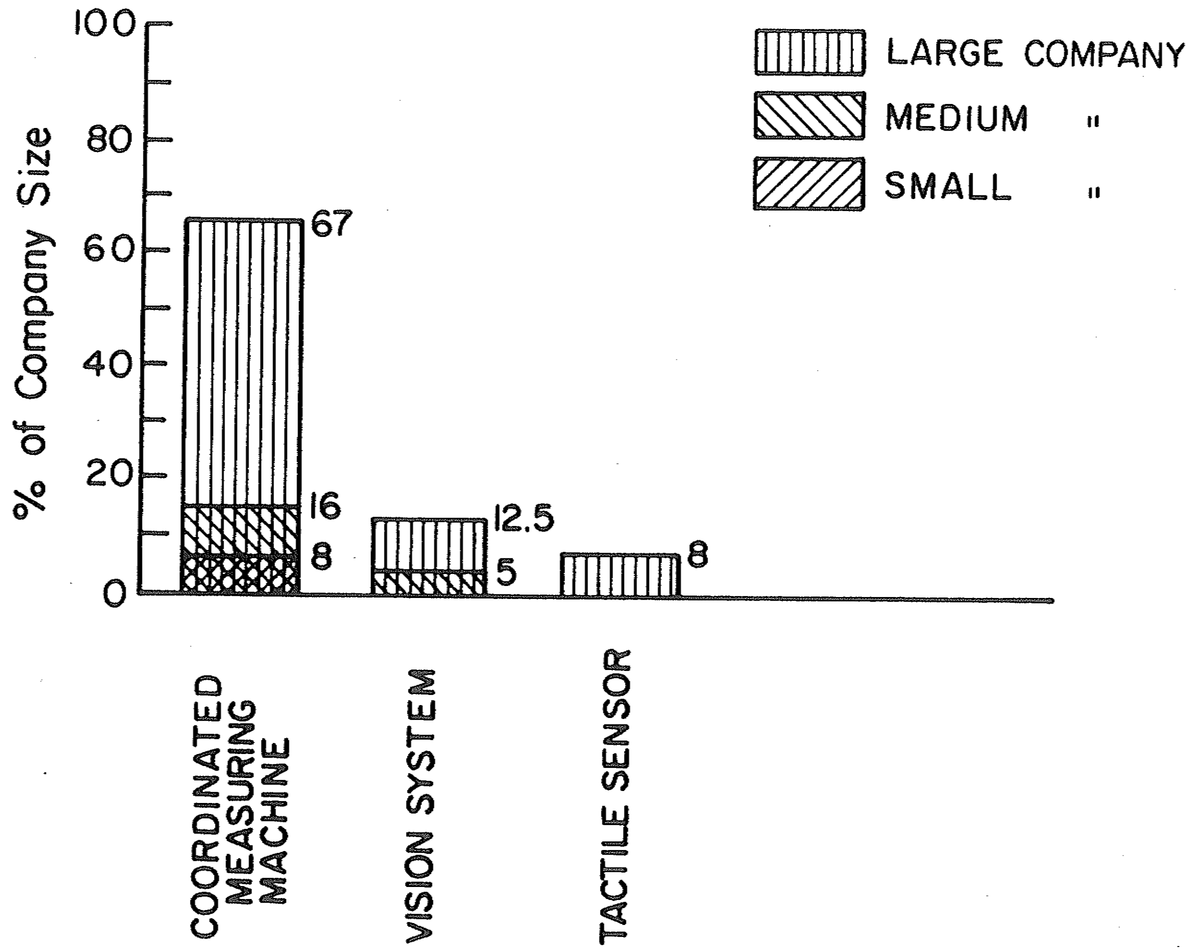
4.9 Sensor Technology

Sensors play a key role in process automation, quality control, part verification and shop floor data acquisition. Ranging from semi-onductors reacting to environmental conditions, ultrasonic sensors for measuring distances without physical contact signalling the arrival of parts to a workcell, or optical and tactile sensors used for positioning and dimensioning work-in-process, sensors can provide a simple solution to a shop floor problem: the attainment of real-time control over process flow, acquisition of production data and monitoring in-process quality, all assisting system integration.

Sensor technology usage as indicated by the survey was negligible,

FIGURE 16

QUALITY CONTROL HARDWARE ON THE SHOP FLOOR



revealing that advanced manufacturers of all sizes in the Canadian MW&M sector employ neither basic nor more advanced sensor applications to help attain real-time control feedback. This may be attributed to the lack of new technologies introduced in Canada to-date needing the potential support of a sensor, or ignorance on the part of manufacturers regarding sensor devices.

4.10 Summary of AMS Technology Usage

This section of the thesis has illustrated, in some detail, the usage of the wide spectrum of AMS technologies, and their applications in the Canadian manufacturing environment. It was important to outline the roles automation of information and part handling play in the evolution of computer integrated manufacturing (CIM).

Survey results have confirmed what has been documented in manufacturing media publications: large manufacturers are indeed on the forefront of technology application. However, it is encouraging to see the computer is being introduced to some extent by smaller producers to aid in developing information handling tasks. The utilization of computer technology and the resulting ability to acquire, transmit and correlate data effeciently at the organizational level lays the groundwork needed for entering the world of factory automation. Automated part handling applications, except for NC machinery, were quite low in the case of small and medium sized manfacturers.

With large plants changing their focus of operations to the assembly of end-products, the shift of work to the smaller factories will have a significant impact on the adoption of AMTechnologies by smaller sized firms. A new level of competitiveness, coupled with high demands on quality from manufacturers in the midst of factory automation will become a reality for Canada's small plants. It is hoped that the birth of research studies focusing on identifying a logical route to integrated manufacturing will provide the learning tools necessary for Canada's small companies in their competitive struggle for survival and growth.

CHAPTER 5: SEQUENTIAL STEPS AND YEAR OF AMS IMPLEMENTATIONS

This section of the paper analyzes the survey's results pertaining to the sequence of steps towards automation that have been taken by the three sizes of Canadian MW&M producers. The illustration will provide for a better understanding of the integration process being taken by manufacturers to date or to the lack thereof. Importance is given to the year of each new technology application so as to document a relationship between the maturity of these technologies versus the time of introduction.

5.1 Management Information Systems

The results regarding the introduction of management information systems show a decreasing sequence or oder of application from large to small respondents over an increasing timeframe. The table below shows the relationship between order and year of MIS introductions.

TABLE 1

THE MANAGEMENT INFORMATION SYSTEM

	Company Size		
	Small	Medium	Large
AVG. ORDER	1.65	1.7	2.5
AVG. YEAR	83	80	76

The inverse relationship between year and steps taken can be directly related to the growth of the computer age, and the increasing capabilities of smaller and smaller computers. It is very important to note that although the larger sized survey respondents have been confirmed as the more experienced users of AMS technologies, on average, the smaller firms have introduced the corporate level of computer-assisted data management before their larger counterparts did. Such results can be associated with the maturing rates of computers in recent years and the necessity to get top management actively involved in the transfer of new technologies as part of new corporate objectives.

5.2 Information Transfer From Design to Manufacturing

The extraordinary developments in recent years relating to microcomputer and graphics technology, their costs and capabilities, have opened the doors to greater productivity and quality to a much wider group of producers.

The use of the microcomputer as a productivity enhancer of company departments has evidently grown dramatically. Survey numbers shows a trend similar to that of MIS applications. The order of microcomputer introductions decreases from 5.5 for large producers to 3.7, and 2.5 for medium and small manufacturers respectively. Year of application ranged from 1983 to 1985 to 1983.5 for the three sizes of advanced Canadian MW&M industrialists. The average year of application are near to the present due to the slower development of microcomputer technology gaining a cost-effective and highly capable means of manipulating data.

Figure 17 documents the growth of the microcomputer from the origins of the IBM PC and Apple II to today's advanced models. Importance must be given to the increase in performance coupled with a decreasing cost. With the drive for real-time production diagnostics, microcomputer operating systems have also witnessed a tremendous growth to the development of present-day real-time operating systems. Their ever-increasing performance makes them very appropriate for the factory floor and for a wide variety of potential uses.

Other computer-assisted information management tasks shown in Table 2 reveal similar trends to microcomputer adaptation.. An inverse relationship between sequence and year of introduction is documented in Table 2. The relationship shows that the larger and more experienced manufacturers are indeed applying the computer to the manufacturing setting first, but at a later order of application than that of the medium and small producers.

It is common knowledge that automated hardware for part handling tasks has matured quicker than that of computer technology. NC machinery, and robotic installations came to the forefront of practical application to the user before the age of computers and support software became user-friendly on a wide scale. Without user-friendly software packages integrating with computer hardware for use in a wide variety of manufacturing techniques, a continual growth in manufacturing acceptance as shown in Table 2 would not have ocurred.

The ability of a computer today to easily interact with users represents an excellent opportunity for those Canadian manufacturers considering new technologies as a means to cost-effectively manage information and factory floor processes.

TABLE 2
COMPUTER ASSISTED INFORMATION HANDLING

APPLICATION	COMPANY SIZE					
	SMALL		MEDIUM		LARGE	
	YR.	ORDER	YR.	ORDER	YR.	ORDER
CAD	86	3	84	4.3	82.5	5.5
CAPP	85	2.5	83	4	82	6
MRP	86	2.5	83	5.5	81	4.5
FACTORY NETWORKING	84	3	85	4.5	83	7
OFFICE NETWORKING	85	3	86	5	85	7

5.3 Laying the Groundwork for Factory Floor Processes and Data Acquisition

Table 3 points out the domination of data acquisition and shop floor layout concepts by large manufacuturers of the survey respondents.

FIGURE 17
Microcomputer Growth: (Cost and Performance)

		HARDWARE		SOFTWARE (OPERATING SYSTEM)	
YEAR	COST ($)	MODEL	PERFORMANCE	MODEL	PERFORMANCE
1977	4,500 (600 now)	Apple II 6502 Processor	64 K Bytes of RAM 2 Floppy Discs (160 K each)	Apple DOS (Crude O/S)	64K Memory (Maximum)
1981	3,500 (800 now)	IBM PC Intel 8086/8	640 K Bytes of Ram 2 Floppy Discs) (360 K each)	IBM DOS 1.0	Up to 640 K Memory
1983	4,500 (1,200 now)	IBM PC/ST Intel 8088 Processor	1 Floppy Disc 640 K Bytes 1 Hard Disc 10 MBytes	IBM DOS 2.0	Hard Disk Additions Directory Support
1984	5,500 (2,500 now)	IBM PC/AT Intel 80286 Processor	1 Floppy Disc 1.2 MBytes 1 Hard Disk 20-40 MBytes Mass Storage	IBM DOS 3.0/ 3.1	Network Support Multi-tasking Origins real and Protected Mode of Memory Access
1987	4,500	IBM/PS/2 Model 30-XT Model 50/60-AT Model 80 Intel 80386 Processor Almost VAX Workstation Compatible	Faster Processing Capabilities Greater Memory Correlates Multi-user Environment where more than one shop floor machine/user can access computer simultaneously	OS/2 1.0	16 MBytes Virtual Program-ming Real-time Multi-tasking control of real-time Shop Floor Processes

TABLE 3
DATA ACQUISITION AND FACTORY FLOOR LAYOUTS

APPLICATION	COMPANY SIZE SMALL YR.	SMALL ORDER	MEDIUM YR.	MEDIUM ORDER	LARGE YR.	LARGE ORDER
CELL TECHNOLOGY	0	0	0	0	84.5	7
GROUP TECHNOLOGY	0	0	0	0	87	11
PART FAMILIES	0	0	87	6	83	8
BAR CODING IN-PROCESS	0	0	0	0	85.5	8
BAR CODING WAREHOUSING INV. CONTROL	0	0	0	0	86.5	10
CA FACILITIES PLANNING	0	0	86	8	83	6

Group Technology represents a fundamental link between automated information and part handling or data management systems and factory floor workcentres. Using common databases either stored manually or in computer-aided process planning, part families and the corresponding physical layout of work cells are formulated. Computer-aided facilities planning can be used to graphically display possible workcell configurations while Bar Coding is used to track developed part families through production.

Table 3 reveals that the order of introduction for the few advanced MW&M manufacturers that have introduced these very important AMS technologies were adopted towards the end of their present sequential application. However, a logical approach to the standardization of processes (time standards, tooling, fixtures, routings, operations) carried through to the factory in the form of plant layouts and bar code technology would introduces both informational and part handling tasks early in the sequence of integrated manufacturing.

The fragmented sequence of AMS applications by the survey's respondents makes us question the motives for each introduction. Referring back to the interviews, revealed that most of the nine producers consulted introduced each facet of new technology on a NEED basis without serious consideration given to how the application would integrate with existing, as well as future proposals. Each new technology introduced must build upon the previous one, helping develop the learning skills and education required to properly integrate areas of office information management to factory floor operations. Planning out the process of systems integration will inevitably ease the transfer of technology into the organization.

TABLE 4
NC MACHINERY

APPLICATION	COMPANY SIZE SMALL YR.	 ORDER	 MEDIUM YR.	 ORDER	 LARGE YR.	 ORDER
MILL	83	1.3	81	2.6	78	2.3
LATHE	81	1.5	79	2	79	4
DRILL	0	0	0	0	78.5	4
EDM	0	0	82	4	81	3.5
AUTOMATED TOOL CHANGING	84	4	87	6	82	4

5.4 NC/CNC Machine Centres

Machining processes are predominant in the MW&M industry sector resulting in a high usage of NC machine technology (60% of survey respondents). Due to this fact and the rise of NC machinery in the early stages of advanced manufacturing, both order and year of introductions were found to be quite early in relation with other topic areas. Milling, the most prevalent machining process (61% utilization) reveals the earliest timeframe, as well as the earliest sequence of application of all machine operations. The following relationships were found.

Because most MW&M producer's operations centre around machining, and coupled with the maturity of NC machinery easing the process of technology transfer into the factory, results show smaller manufacturers are looking at CNC/NC machinery as the initial step into flexible manufacturing.

When considering the automation of a company function to meet strategic objectives, management typically focuses on an operation that represents a large proportion of overall operating costs. Introducing numerically controlled machinery to the factory reduces machine setup costs and downtime, while increasing part production flexibility which may give the ability to produce a part at a lower cost than their competitors.

Although the corporate culture of North American businesses, particularily manufacturing are predominantly driven by finance and marketing (10), smaller firms (1-75 employees) tend to put more emphasis on production operations due to the scaled down levels of management restricting the vertical movement of innovative ideas and awareness concerning manufacturing related functions. As shown earlier, the larger organizations of the survey's respondents have introduced corporate-level management information systems before that of NC machine technology. This underscores the sales and finance orientation of Canada's larger firms.

Analyzing the survey's findings from a company-size viewpoint has helped illustrate that not only the maturity of automated part and data management technologies has played a role in the sequence of application, but that the corporate structure has an impact on how management will choose to spend up-front capital on computer-assisted hardware and software. The order of automated tool changing capabilities with relation to NC machine workcentres is quite similar. Such a result indicates an excellent integration effect between the two introductions.

5.5 Robotics

The tasks of a robot on the shop floor has grown in dimension. Industry studies have shown the origin of robotics in began the material and tool handling applications. A greater emphasis on end-product quality, coupled with the slimmed down operations of larger plants (the costs of producing products from material forming to machining, fabrication, painting and finally assembly have proven high, forcing decentralization of plants and dedicated facilities for particular production operations) has widened the scope of robotic applications.

From Table 5, material handling applications show the earliest sequence of robot use, six, by the 75 advanced manufacturers. Origins of robotics for purposes of material, part, and tool handling in the factory setting support these results (24). The higher order of implementation for both assembly and quality purposes, 8.5 and 10 respectively, is consistant with growing factory assembly operations and the push for higher quality products. The sequential order of robotic installations show important positive signs concerning the integration of more fundamental material handling tasks to processes such as as painting and welding, to assembly and quality control functions. Quality must, and no doubt will be a greater part of a manufacturer's production philosophies, thus leading to more robotic innovations. It must be kept in mind that technology transfer will only take place on a broad scale when external information sources (universities, government research centres, consultants) ease the transfer of new technologies into applicable areas of operations. This will be particularily important for the smaller organizations without readily available internal expertise and financial resources.

TABLE 5
ROBOTS ON THE MOVE

APPLICATION	COMPANY SIZE					
	SMALL		MEDIUM		LARGE	
	YR.	ORDER	YR.	ORDER	YR.	ORDER
MATERIAL HANDLING	0	0	86.5	4	84.5	6
ASSEMBLY	0	0	86	6	85	8.5
FABRICATION	0	0	85	4	85	8
PAINTING	0	0	0	0	85	8
QUALITY CONTROL	0	0	0	0	85	10

5.6 Utilization of Government and Consulting Assistance

Figure 18 shows how the respondents have utilized available government programs and consultants for transferring technology into the workplace. It is very important that companies, particularly smaller ones, recognize that financial and technical assistance is available for implementing new technologies. The survey failed to identify vendor technological support.(quite prevalent today particularly for distribution of automated information and part handling systems).

Figure 18 points out that 45% of the manufacturing group have used consultants in both system design and implementation, as well as in training. Only 34.5% of the respondents utilized government programs for training and a surprisingly low 9% accessed funding from the government. It seems thus, that manufacturers must either be made aware of available assistance, or made to put aside selfish attitudes that block outside help for system integration. Government and other external forces on the other hand, must increase the profile of available programs, and develop a wider scope of computer knowledge-based centres, coupled with closer relationships between governments, consultants, universities and vendors with the end users of automation.

5.7 Handling and Storing Material On The Factory Floor

Material handling in the factory includes storing of in-process parts and raw materials between storage and workcentres. The different modes of transportation and storage/retrieval methods outlined in the survey can play a local or plant-wide function. The following figures are representative of the survey's results showing the order and year of automated material handling applications.

TABLE 6
SHOP FLOOR MATERIAL HANDLING

APPLICATION	COMPANY SIZE SMALL YR.	 ORDER	 MEDIUM YR.	 ORDER	 LARGE YR.	 ORDER
AGV	0	0	0	0	86	10
CONVEYOR SYSTEM	0	0	0	0	78	4
RAIL SYSTEM	0	0	0	0	85	7
AS/RS	0	0	0	0	83	8

5.7.1 Automated Guided Vehicles

The AGV represents state-of-the-art material handling in the factory. In an effort to achieve flexibililty in transporting work-in-process via computer control throughout the plant, AGV technology has given the manufacturer a new means of getting parts to critical areas of production efficiently and defect-free (17). The large manufacturer group of the 75 respondents began to implement the AGV as one of their last introductions to factory automation.

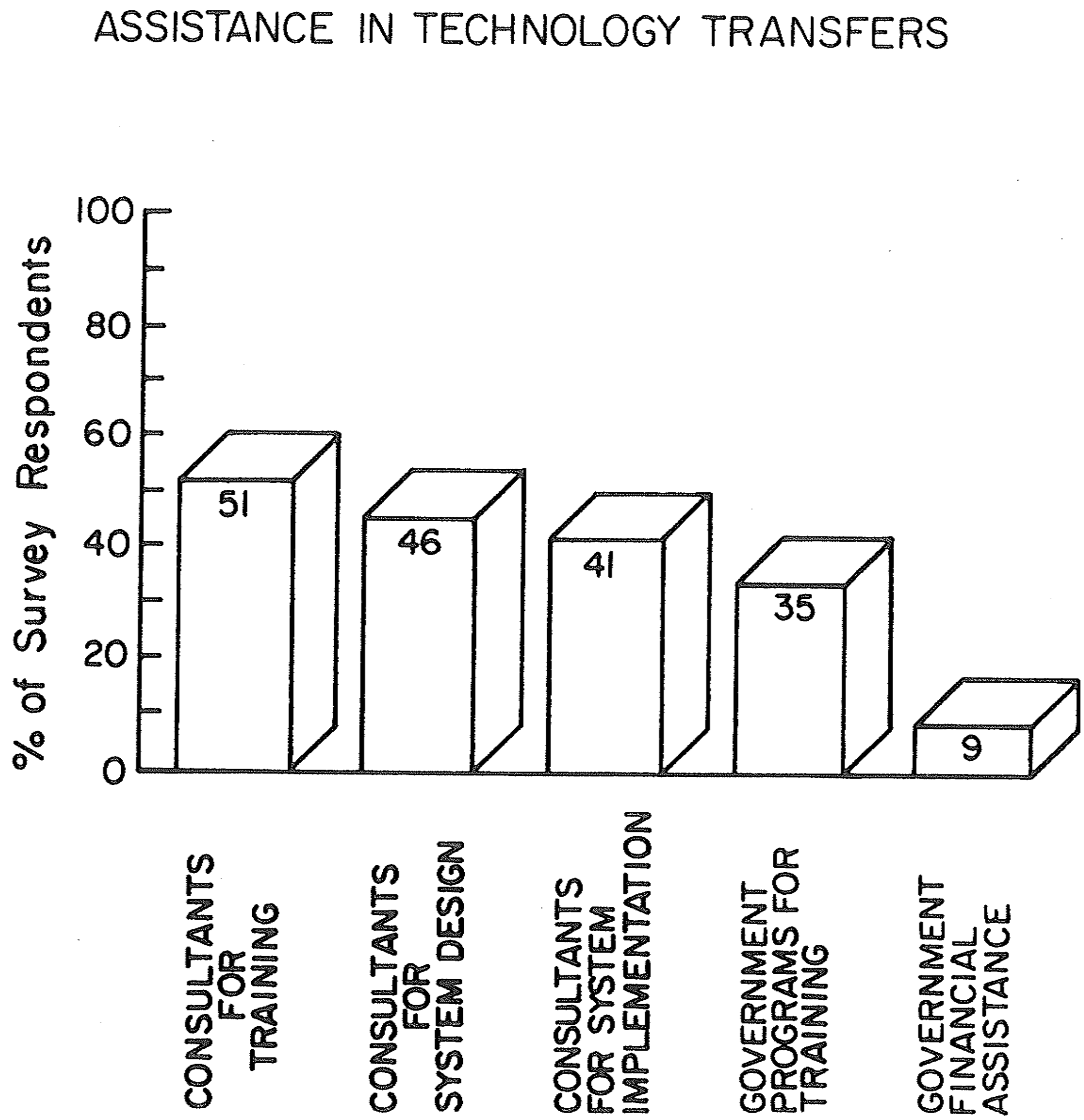
5.7.2 Conveyer Transport

A conveyor in its many forms has had a long standing in transporting materials through the manufacturing workplace. With the addition of the microcomputer and modern motor drives, conveyors can be easily integrated with local flexible manufacturing cells and other shop floor processes. Of the material handling/storage retrieval applications listed, the conveyor system gave the lowest order and year of introduction. This is a direct result of the conveyor's maturity level in the factory.

5.7.3 Overhead Rail Systems

The overhead rail system, like the conveyor, provides a traditional means of carrying materials. Primary material handling through a plant via an overhead rail

FIGURE 18


ASSISTANCE IN TECHNOLOGY TRANSFERS
% of Survey Respondents
100
80
60
40
20
0
51
46
41
35
9
CONSULTANTS FOR TRAINING
CONSULTANTS FOR SYSTEM DESIGN
CONSULTANTS FOR SYSTEM IMPLEMENTATION
GOVERNMENT PROGRAMS FOR TRAINING
GOVERNMENT FINANCIAL ASSISTANCE

system utilizes typically unused overhead space as compared to a floor-mounted conveyor or AGV system. Rails may be easily added or taken away as floor layouts change due to product and process changes. Flexibility is an excellent attribute of an overhead system. As the figures show, the application of computer-controlled rail systems ocurred in a much later time frame and sequence as compared to that of the conveyor.

5.7.4 Automated Storage/Retrieval Systems

Two considerations surround the role of AS/RS's in the manufacturing setting, the first being the reduction of inventory sufficiently so as not to require dedicated high density storage and retrieval, and the second being an inevitable volume of inventory requiring controlled management of strorage and retrieval of goods.

A conflict of interest has arisen in most recent times surrounding long term manufacturing planning to achieve JIT inventory practices. Just-In-Time theories hope to reduce the amount of on-hand materials at any one time, thus freeing up useable capital and space. The counterpart to this discussion is the reasoning regarding unavoidable inventory levels at some stage of production demanding an efficient means of controlling the input and output of stored materials. Importance must be given to information handling applications like Materials Requirements Planning (MRP) for scheduling , and expediting arrivals and departures of raw materials, work-in-process, and inventories of finished goods.

5.7.5 The Diversity of Material Handling in the Future Factory

Figure 19 shows how an AGV, conveyor, and overhead rail system may be integrated with an AS/RS and workcells. All three methods of transport are used locally and centrally to move different phases of materials into and out of a simulated factory. Whether a primary mode of plant material handling is by forklift truck or state-of-the-art AGV, all methods of transporting parts can be used at different stages of operations. The simulated factory shows a rail system being used in the warehousing facility to retrieve materials and in workcell #2 to move a robot for loading machine parts. The conveyor moves raw materials and finished parts to the shipping/receiving area as well as locally at each workcell to load and unload parts, while the central AGV system routes parts to all workcentres. This illustration shows the importance of utilizing a material handling application suitable to a specific process or area of operation.

5. 8 Quality Assurance on the Factory Floor

Tougher marketplaces are placing an increasingly growing value on product quality. A manufacturer's ability to control quality quickly and efficiently, while offering feedback of critical results can help make faster decisions in problem areas causing defective parts. An on-line defect reporting system is an important factor in taking corrective action in problem areas throughout the plant. Introduction of the microcomputer on the shop floor is an important tool for maintaining real-time defect reporting as all departments may have direct information about quality problems relating to their operation and take quick corrective action.

Application of shop floor hardware dedicated to quality control is a logical step after the introduction of automated machinery dedicated to prevalent shop floor processes. A manufacturer needs to check in-process quality at the source of initial operations to assure that part quality is carried through the plant.

5.8.1 The Coordinate Measuring Machine Backing Up NC Machine Technology

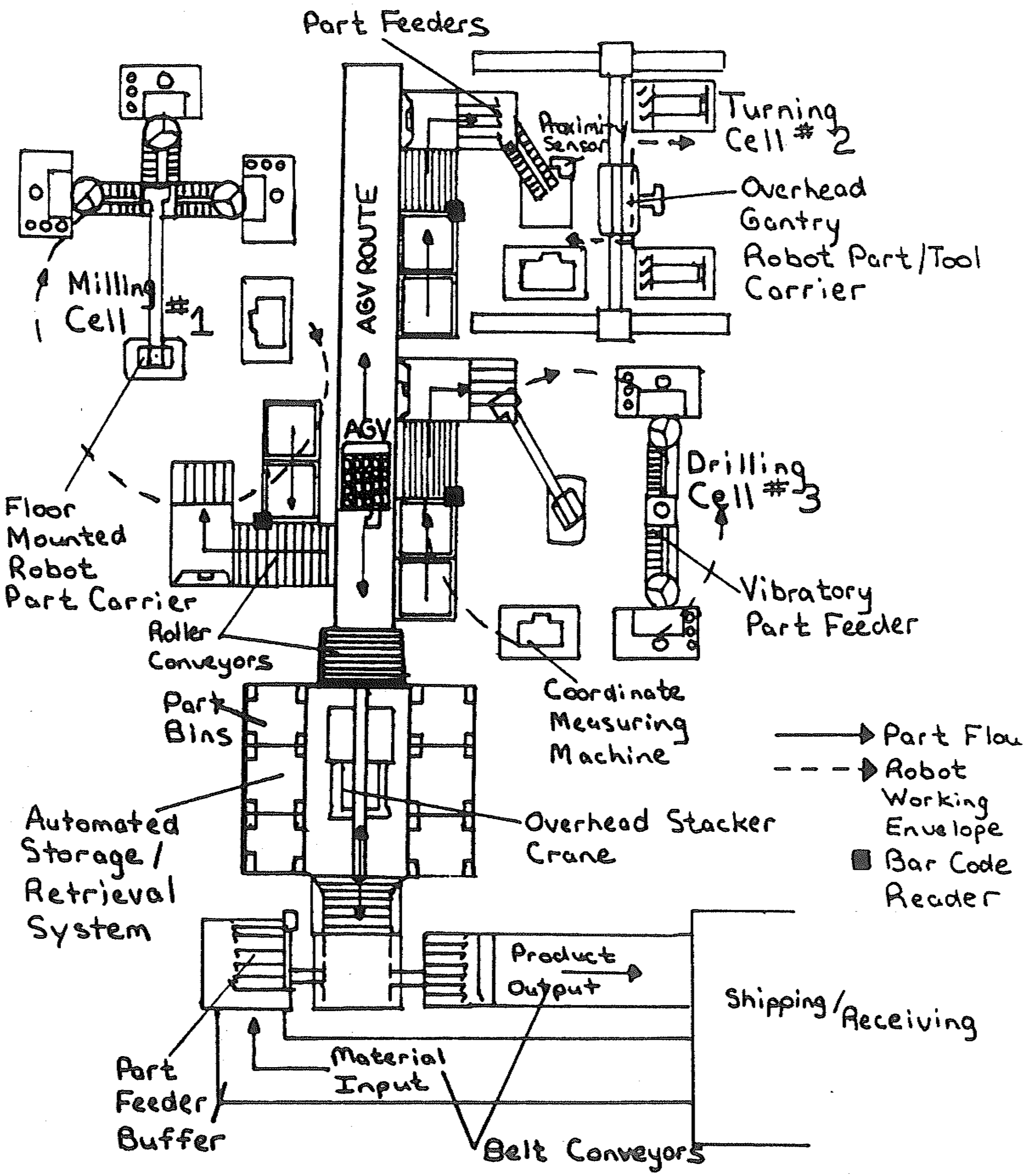
Development of the coordinate measuring machine to probe part configurations automatically evolved alongside NC. As increased part complexity and flexibility is noted at the machine centre, the awareness of part quality and benefits potentially available from automating the control of quality is brought to the forefront.

TABLE 7
QUALITY CONTROL ON THE SHOP FLOOR

APPLICATION	COMPANY SIZE					
	SMALL		MEDIUM		LARGE	
	YR.	ORDER	YR.	ORDER	YR.	ORDER
C.M.M.	86.5	3	86	5.5	84	5
VISION SYSTEM	0	0	0	0	84	9

FIGURE 19

MATERIAL HANDLING APPLICATIONS IN ADVANCED MANUFACTURING



The later timeframe (84) and sequence of introduction (5) as compared to NC machine application 80 and 2, runs counter to a logical progression between the two integral facets of AMS technologies. The lower sequence by small manufacturers indicates a closer relationship between the NC machine and the coordinate measuring machine.

5.8.2 Other Sources of Quality Control

Some applications of advanced manufacturing have shown anomalies in timeframes and sequential order of application. The vision system represents such an application indicating a timeframe identical to the CMM, but a higher sequential order. Such an anomaly can be explained by assuming it is caused by a small percentage of experienced users of automation applying new technologies at a faster rate.

Vision technology, like the coordinate measuring machine, shares a close relationship with another facet of innovative production. Robotics and vision systems are closely related in many applicable factory situations. Vision technology provides the robot with sight so as to closely verify locations in the work area of pre-programmed points. Integrating vision with robotics technology increases the ability of a robot to perform a given task (e.g. welding a seam between two metal objects).

5.9 Sensor Technology

Increasing demands from manufacturers to monitor processes, quality, and the status of work-in-process will inevitably show an increase in the application of sensor devices on the shop floor. The enormous expansion of manufacturing processes through computer and microprocessor control has given a stimulus to the development of sensing devices (7). As a logical approach to integrated manufacturing evolves in the Canadian production environment, the role of sensor technology will increase as a greater number of automated hardware applications, and demand for real-time data is warranted.

5.10 Canada's Road to Integrated Manufacturing

5.10.1 Recapitulation of Results

With changing markets driving product life cycles down, and the increasing maturity of computer-assisted hardware and software, the boundaries of advanced manufacturing are changing. Documenting the status of AMS integration in Canada's MW&M industry helps us to see first-hand the changes that can be made to suit tomorrow's manufacturer's needs. Obtaining an inside view into a manufacturer's strategies towards adoption of new technologies and how they have changed over time presents a whole new view of Canada's role in the global manufacturing battleground.

Figures 20, 21 and 22 schematically show the sequence of new technology application for large, medium and small firms within the outlined population. Critical points that have been distilled from the analysis of these survey results include:

- Decreasing rate of computer-assisted information handling application from large to small-sized respondents.
- Early introduction of NC/CNC machinery by all sizes of manufacturers.
- Later sequence order and lack of fundamental group technology (part and process groupings) and bar code technology within the sample population.
- Decreasing rate of quality control orientated hardware applications from large to small producers.
- Decreasing rate of robotic installation from large to small firms.
- Increasing time frame of AMS applications from greater to less experienced users of automation.
- Reduction in the gap between automated information and part handling application in the smaller manufacturers category.
- Lack of integration between automated information and part handling tasks.
- Decreasing utilization rate of AMS technologies from larger to smaller manufacturers.

A larger number of small firms face new levels of competition in the metal working and machinery related industries as a greater proportion of work will be subcontracted by the large assembly and fabrication plants of tomorrow. The onus will no doubt be on the smaller manufacturer to increase production flexibility and quality, while cutting costs to stay abreast of competitors. The survey has indicated that smaller manufacturers are undeniably less experienced users of new technologies. However, both small and large manufacturing firms can learn from a logical approach to system integration which may force a new focus on otherwise unapproached technologies.

5.10.2 Further Points to Be Addressed

Like the evolution of computer-based manufacturing technologies, researching the integration of these systems requires scrutiny of many factors. Attention needs to be directed to additional points so as to achieve the integration of many facets of the Advanced Manufacturing System.

The following remarks highlight questions that future studies of the problem of AMS system integration should address:

- Why were steps of AMS technology taken which would have revealed the awareness of systems integration?
- How successful have the steps already taken been in achieving companies proposed goals detailing Canadian success stories to date?
- What alternate route of technological application would the manufacturer take to help establish a future model of integration?
- Annual sales of manufacturer to determine the financial capability of those companies that are introducing different levels of new technologies.
- A breakdown of particular industries within metal working and machinery sector that are implementing a greater proportion of integrated manufacturing systems.
- Addressing the problem of systems integration in other Canadian industries (i.e. Garment, Furniture, Chemical, Steel, etc.).

FIGURE 20

PRESENT DAY MODEL OF CANADA'S SMALL MW & M SECTOR ADVANCED MANUFACTURERS

1 NC MACHINERY
25% 1983

↓

2 MANAGEMENT INFORMATION SYSTEM
73% 1983

↓

3 CAD / CAPP / MRP / DEPT. MICROS
FACTORY / OFFICE NETWORKING
29% 1986

↓

4 QUALITY CONTROL
C.M.M.
AUTOMATED TOOL CHANGING
3% 1987

FIGURE 21

PRESENT DAY MODEL OF CANADA'S MEDIUM
MW & M SECTOR ADVANCED MANUFACTURERS

1 MANAGEMENT INFORMATION SYSTEM

90% ↓ 1980

2 NC MACHINERY

38% ↓ 1981

3 DEPARTMENTAL MICROCOMPUTERS

60% ↓ 1985

4 CAD / CAPP / MRP / FACTORY / OFFICE NETWORKING

44% ↓ 1985

5 AUTOMATED TOOL CHANGING

8% ↓ 1985

6 ROBOTICS PART HANDLING
WELDING
ASSEMBLY

5% ↓ 1986

7 QUALITY CONTROL C.M.M. / VISION SYSTEM

7% ↓ 1986

8 PART FAMILIES

10 % 1987

FIGURE 22

PRESENT DAY MODEL OF CANADA'S LARGE MW & M SECTOR ADVANCED MANUFACTURERS

1	MIS	100%	1976
2	NC MACHINERY (MILLING)	80%	1978
3	NC MACHINERY (TURNING/LATHE)	75%	1979
4	AUTOMATED TOOL CHANGING	25%	1981
5	MATERIAL REQUIREMENTS PLANNING	58%	1981
6	CAD / CAPP / DEPT. MICROCOMPUTER	82%	1983
	QUALITY CONTROL / C.M.M.	67%	1984
7	FACTORY / OFFICE NETWORKING	31%	1984
8	ROBOTICS / VISION SYSTEM	26%	1985
9	DATA ACQUISITION / BAR CODING	19%	1986
10	WORKCELL GROUPINGS	18%	1986
11	MATERIAL HANDLING / STORAGE RETRIEVAL	10%	1986

5.10.3 Additional AMS Technologies to Study

Further to the important points noted above, some AMS applications that will no doubt have a future impact on integrated manufacturing have been missed:

- Preventative Maintenance Programs (computer-assisted) playing a large role in maintaining a high level of operations regarding automated hardware at regular intervals without affecting production downtime too severely.
- Artificial Intelligence Software having potential positive effect on real-time computer-based monitoring systems of factory floor operations.
- The number of axes of NC/CNC machinery affecting machining flexibility, part complexity, and machine setup costs.
- Computer simulation modelling for phasing in successful technology implementations.

5.11 Future Plans of AMS Applications

Stepping into a world of computer-integrated manufacturing is a corporate decision. Confronting the up-front costs of automation and deciding what application to start with, manufacturers are faced with the potential benefits of new technology (i.e. flexibility, quality, customer service, and productivity increases, with lower costs per unit) weighed against the corporate objectives. Illustration of the survey's advanced manufacturer's six year outlook on adoption of computer-assisted manufacturing technologies will shed some light on the proposed order of applications being considered.

5.11.1 Plans of the Small Manufacturer

5.11.1.1 Planning For CAD and NC First

Figures 23 through 25 detail our proposed sequential order of technology introductions by the small, medium and large manufacturers of the sample population. Dominating the future plans of the small manufacturer (like in the present model) are NC machinery and computer-aided design. Due to the often strong presence of design engineering in a small organization's infrastructure, coupled with the low cost of user-friendly CAD software and microcomputer hardware, computer-aided design represents an excellent application for the smaller firm stepping into automated information handling tasks.

5.11.1.2 Robots and Quality Control

It is very encouraging to note new technologies in the areas of robotic assembly and quality control, together with vision system technology. The two technologies (i.e. Robotics and Vision) logically integrate to attain maximum gains in both assembly and quality applications. A strong emphasis on quality through the use of the coordinate measuring machine also indicates the smaller manufacturer is beginning to stress quality in his production operations.

5.11.1.3 MRP Is Sought to Manage Production Information

Introductory proposals for Material Requirements Planning systems, third in order, show that small organizations are recognizing the need to manage the flow of information between finance, engineering, production, and purchasing departments more efficiently through MRP. Using the computer to assist in managing information flow reduces bottlenecks in traditional paper generating systems that often slow down people and information travelling through a company.

5.11.2 Plans of the Medium-Sized Manufacturer

5.11.2.1 Domination of Computer-Aided Information Handling

Modelling the future plans of the medium-sized advanced MW&M manufacturers shows a strong underscoring of computer-assisted information handling tasks. Both MRP and CAD dominate the initial steps of future technological plans. Both MRP and CAD systems play a large role in an oraganization's ability to quickly and efficiently retrieve, manipulate and transmit new information within the company. Bar Code technology in both warehousing/inventory control and tracking work-in-process should receive much attention by the medium-sized manufacturer.

FIGURE 23

FUTURE MODEL OF CANADA'S SMALL MW & M SECTOR ADVANCED MANUFACTURERS

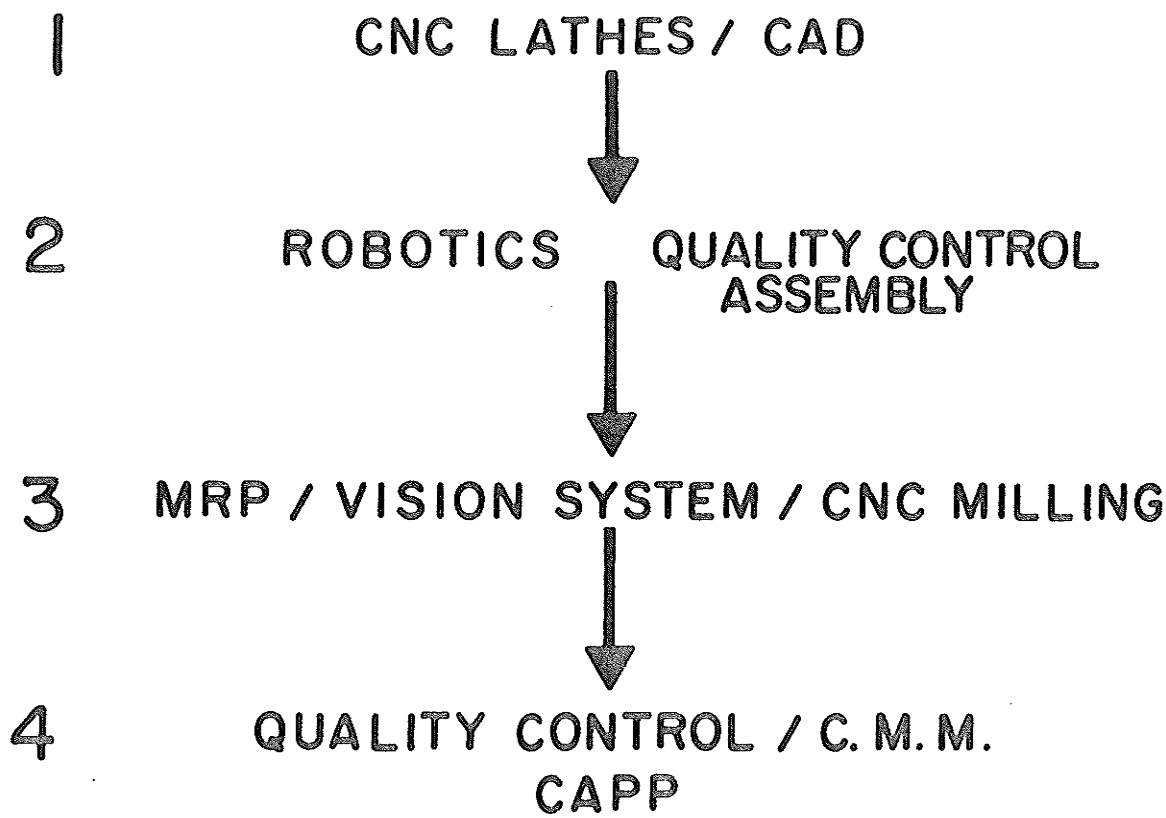


FIGURE 24

FUTURE MODEL OF CANADA'S MEDIUM MW & M SECTOR ADVANCED MANUFACTURERS

1 DEPT. MICROCOMPUTER / MRP

↓

2 CAD / CNC MILLING

↓

3 DATA ACQUISITION / BAR CODING
WAREHOUSING

↓

4 CNC LATHES / ROBOTICS
PART HANDLING

↓

5 DATA ACQUISITION / BAR CODING
IN - PROCESS
AUTOMATED TOOL CHANGING
QUALITY CONTROL / C.M.M.

↓

6 FACTORY NETWORKING
MATERIAL HANDLING (AGV)

FIGURE 25

FUTURE MODEL OF CANADA'S LARGE MW & M SECTOR ADVANCED MANUFACTURERS

1 CAD

↓

2 ROBOTICS PAINTING / CAPP / BAR CODING IN - PROCESS

↓

3 ROBOTICS PART HANDLING
ASSEMBLY
QUALITY CONTROL
WELDING

CELL TECHNOLOGY / GROUP TECHNOLOGY / PART FAMILIES OFFICE NETWORKING

↓

4 VISION SYSTEMS

↓

5 FACTORY NETWORKING / MATERIAL HANDLING
AGV RAIL CONVEYOR

↓

6 COORDINATE MEASURING MACHINE

↓

7 AUTOMATED TOOL CHANGING SENSORS

NOTE : Due to the small percentage of manufacturers proposing future introductions and wide timeframe, several technologies are grouped together.

5.11.2.2 Group Technology Needs Greater Attention

Group technology providing the fundamental link between information management systems such as MRP, CAPP, and Bar Code technology on the shop floor is not being considered at this time. It is not logical to apply bar coding to the shop floor without integration of group technology. Bar Code Technology builds upon the part groupings (or classifications) established by Group Technology to link the shop floor with the office.

5.11.3 Plans of the Large Manufacturer

5.11.3.1 Information Handling Comes First

The large manufacturer's future AMS introductions are initially governed by information handling applications. CAD, CAPP and bar code technology being used to acquire factory data reveal a continuing trend of all manufacturers' strong emphasis on data management systems before that of automated hardware on the shop floor. The present day model of Advanced Canadian MW&M firms did show a similar trend from large to small manufacturers.

5.11.3.2 Group Technology Takes Shape

A very small percentage of large manufacturers have introduced group technology to date as the survey has indicated. It is now up to these manufacutrers to introduce the proper framework of conceptual and physical distribution of part grouping and processes on the shop floor. This process, however, must now take place with a variety of highly automated equipment already in place (e.g. CNC equipment, robotics, C.M.M).

5.11.3.3 Communications Networking

Factory networking indicated by both the medium and large groups towards the end of their future AMS proposals signifies firms are not tackling the problem of data communications early in either present or future plans of technology. Communications networking must be an on-going project running parallel with further inroads into computer-assisted information and part handling, and the introduction of shop floor microcomputer workstations.

5.11.3.4 Material Handling

A variety of material handling applications are being considered. AGV's, conveyors, and overhead rails emphasize the predicament larger factories face as efficient movement of parts and materials becomes a vital function of production dynamics.

5.11.4 The Future Model of Today's Advanced Manufacturers

Analysis of the future plans of AMS introductions by the 75 survey respondents has shown a shift in primary considerations. Applications focusing on the management of information bases via the computer have moved further up the ladder to the forefront of new technology introduction. Computer-Aided design, process planning, material requirements planning, and group technology have all been allocated in the initial stages representing future proposals for meeting objectives inherent to automation (i.e. increased quality and productivity of worker and information flow). The present model of AMS introduction previously outlined (refer to Figures 23, 24 and 25) showed a initial emphasis on NC/CNC machinery. Small and medium sized respondents still indicate an emphasis on numerically controlled equipment, although not as early, and the larger group excludes NC technology altogether in future plans.

More advanced technologies such as vision systems, AGV's and communications networking are being examined for potential factory introduction by the smaller firms. Penetration of newer AMS applications to the smaller MW&M sector clearly highlights the evolution of the state-of-the-art manufacturing organization. How well these future proposals are integrated with one another will determine success or failure.

Similar to the model established for present-day usage and order of application, future plans do not seem to suggest any particular strategy for systems integration. Projects dependent on each other, such as NC machinery and tool changing are far apart, while bar code technology is being proposed before standard data management systems are established.

For the manufacturer of tomorrow, success depends on top management's willingness and ability to learn and support proposals that effectively build upon one another leading slowly to the new world of computer-integrated manufacturing.

CHAPTER 6: A LOGICAL MODEL TO INTEGRATED MANUFACTURING: PAST AND PRESENT

By analyzing the results of our survey as outlined in the previous sections of the thesis, an excellent cross-section of AMT usage and sequential order of introduction is obtained. It is clear that large manufacturers have dominated the applications of more advanced technologies. The question is whether this group of companies may be looked upon as a practical role model for the smaller, less experienced users of new systems technologies searching for ways to maintain long term competitiveness through product and process flexibility and total quality.

6.1 Origins of Factory Automation

Numerically controlled machinery surfaced in the manufacturing plants of the early 1960's introducing automation to a variety of labour intensive production tasks. Emphasis in the late 1970's turned to the development of robotic installations for handling and later process tasks (27). Islands of Automation formed on the shop floor causing a breakdown in the ability to transfer critical information to work centres. Realizing the need to build bridges between vital areas of the organization, and shop floor islands, the origin of direct automated information handling and communications was born. The need for greater communications between the islands of automation has assisted the improvements in computer hardware and support software capabilities.

6.2 The Computer Takes Shape Managing Information

The need to link organizational areas, particularly design, production control, manufacturing and finance to the factory gave way to new technologies and computer-aided applications. Armed with a computer, former manual tasks of drafting, design, process planning, inventory control, scheduling and financial planning experienced new methods of accessing, manipulating and transmitting information. With the formation of large databases in various areas of the plant and controls over automated hardware and work-in-process from the factory, communications technology evolved.

At present, management of information systems have reached maturity levels that offer practicality to the new users in manufacturing businesses. Terms such as CAD/CAM, MRP, GT and JIT now dominate the Advanced Manufacturing System. Due to the ability of the computer and its support software to efficiently manage data at a low cost, today's smaller firms face new dimensions of what's been called "factory automation". It may be best understood by focusing on a conceptual versus execution stage of system integration. The conceptual stage centres on the development of databases that best reflects the operations of management, as well as the factory while the presence of machine groups, labour and processes (e.g. painting, welding, assembly) are taken on at the execution stage on the factory floor based on information developed at management levels (i.e. design, finance, production control and manufacturing). The long term goal is to achieve total system integration at all levels of the business from the factory operator monitoring a machine's performance to the manager evaluating the producibility of a product's design.

The following sections of this chapter follow the steps outlined in Fig. 34 based on the author's viewpoints regarding the development of a "Logical Model of Integrated Manufacturing".

6.3 Entering the Computer Age

6.3.1 The Ability to Manage Information

Establishing long term manufacturing strategies with respect to new technologies demands top management support and understanding. The capital outlay required for AMS investments will fall short without proper understanding how technologies will affect product/process flexibility, quality, productivity, costs and market competitiveness. The method of cost justification considers both tangible and intangible benefits. Finance departments clinging to traditional payback and rate of return cost analysis lose sight of the long-term corporate strategies and benefits that integrated manufacturing offers. Figure 26 points out the breakdown of cost justification methods used by the survey's respondents. The results show that 73% of the manufacturers are using traditional accounting methods while 58% are using an organizational strategy for new technology justifications. From these numbers, it is clear that a significant proportion of the manufacturers are using a combination of both, indicating that the maturity of computer-based hardware and software applications are reaching cost levels where they can be both financially and strategically justified.

6.3.2 Taking on Administration Functions

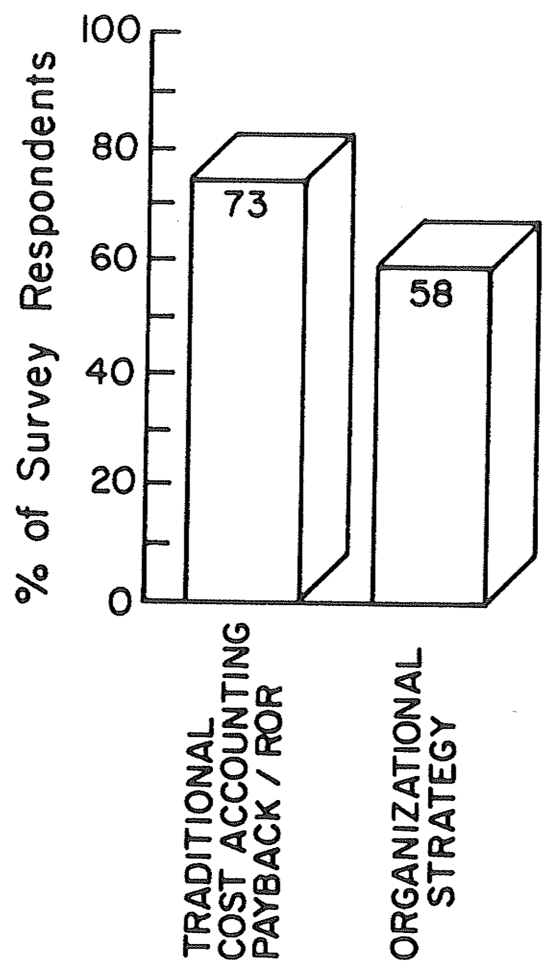
Ushering in new computer-aided tasks to the corporate level of the manufacturing firm represents a logical approach to technology initiation. Administrative functions including finance, sales, marketing and personnel play a large role in the corporate culture of today's businesses. When speaking of manufacturers, it must be understood that the manufacturing function represents only one entity of the overall company structure.

Management Information Systems (MIS) incorporate the automation of financial accounting procedures, sales and marketing forecasts, job costing, staffing, and payroll calculation. The MIS may be mini- or micro-computer based depending on the size of company and amount of information being managed. MIS brings the manufacturer into the realms of the computer age, and its ability to access and analyze data quickly and efficiently. Supporting communications between departments of the organization increases employee productivity through more effective handling of information and tasks at hand.

The survey has shown that advanced Canadian MW&M manufacturers of all sizes have indeed followed a logical approach to adoption of the AMS initially, having introduced the management information system first. Management Information Systems may take on different meanings in the introduction to different levels of the organization. Industrial experiences have shown that MIS's can be found at the factory level where the management of data between various automated hardware applications is performed (22). Such factory MIS's will only be realized on a large scale in years to

FIGURE 26

COST JUSTIFICATIONS



come when smaller manufacturers tackle the integration of such devices as bar code readers, NC machinery, robotics, material handling and sensing devices.

6.3.3 Using the Microcomputer

For the small manufacturer today, the costs of computers continue to fall in relation to their performance capabilities as Fig. 17 showed. Memory, processing speed, resolution, software programs, and operating systems are all on the increase (21). Modularity is a key aspect in all applications of comptuer-assisted technologies including the MIS. A small producer may utilize a microcomputer or grouping of them at a low cost to serve as a training ground for initial data management requirements. As new applications are found for the computer and the amount of data increases, a micro will give way to a mini-computer. The same relationship holds true for mini- and mainframe computers being used in larger sized firms. Modularity also spreads the costs of automation over a longer time frame, while accounting for the technology learning curve.

6.4 The Business Entity

6.4.1 Opening the Lines of Communication

The smallest firms are generally structured in such a way that design and manufacturing engineering operate independently of one another. Production is typically confined to the day to day fire fighting of shop floor activities. Distinction between design and manufacturing departments should be confined only to tasks carried out, and not on the communicative level, or by organizational priority. The walls that often go up between departments of a company only lead to the demise of that business. It is important that design and manufacturing work hand in hand with respect to producibility. High production costs will be witnessed if part designs aren't within the abilities of shop floor equipment, processes, and labour. Introducing the computer to both departments will help initiate the flow of communications as one database depends on the other. Management must play the key role in making sure all areas of the company get involved in new inter-departmental technologies provoking the exchange of innovative ideas and long term productivity. In addition, the future factory should be an open communication network accessible to all departments, encouraging ideas from all employees to ensure on-going innovation of intellectual and technological assets. Execution of new tasks may still be segregated to project groups, but they must ensure all affected areas of the organization are aware of the job at hand, and provide their full support.

6.5 Design Engineering

6.5.1 Computer-Aided Design

Entering the initial stages of computer-assisted information handling in design engineering is represented by computer-aided design, or CAD. Manually performed drafting and design tasks are labour-intensive often slowing down the path of a new job being processed through "the system" of an organization. The "system" as most firms refer to it is the route a new sales order or request for changes must take before a job or part/process change is actually activated for production. Automating the drafting and design phase of the "system" helps reduce the number of hands and copies a sales order/engineering change must go through, i.e. the time a product takes from the acquisition of a job to delivery to the customer's doorstep. Automating the management of information at this level has a enormous impact on overall customer service and market competitiveness.

CAD enables the engineering department to store all existing drawings in a computer database that a draftsman/designer can access quickly at any time for purposes of in-process deviations or modification for a new job. The structure of a CAD's database, based on groupings of similar part configurations, is important to ensure efficient retrieval of drawings is performed when needed. CAD, like other new manufacturing technologies demands a certain level of manual input before implementaton to help reduce the learning curve, or transfer of technology, and maintain a user-friendly environment.

Like any new product, CAD has positives and negatives that the manufacturer must be aware of so that expected gains don't fall short, and that potential problems are reduced, or corrected. The following points should be considered when proposing the introduction of computer-aided design:

- 2 times overall productivity level of drafting over manual tasks.
- creating new drawings on CAD can take a considerable length of time over manual drafting.
- introducing CAD into an environment where completely new drawings are required frequently questions the applicability of CAD. These manufacturers may operate on a contract basis involving different product designs.
- increased quality of drawings positively affecting:
  i) Shop Floor/Operator Interpretation
  ii) Customer Service/Who Requests Drawings
  iii) Improved Clarity for Engineers and Management
- affording too much detail in drawings having negative effects on the previous three points outlined.
- workstation ergonomics (i.e. furniture, lighting, noise) affecting productivity of CAD operator(s).
- integration of CAD with product Bill of Materials to aid both design and manufacturing functions
- nesting of part components with relation to raw material sheet sizes to maximize material utilization.
- development of computer programs for purposes of accessing blocks of drawings quickly, as well as drawing of more complex parts. This is a direct analogy to macro development in such programs as LOTUS 1-2-3 for spreadsheet calculations.
- modularity of initial computer hardware to ensure sufficient computer memory for existing library of drawings, while making sure too large of a system is not obtained at too high an initial cost.
- integration of computer-aided engineering tasks at CAD workstation.
- future consideration of integrating with NC machinery and tooling programs.

Computer-aided-design is a key application to a manufacturer's strategical stand on modelling long term integrated manufacturing. As indicated, tackling a project like CAD requires many critical areas of consideration. Applicability, modularity, and integratability, all keys to the logical model of advanced manufacturing, are important to the successful implementation of CAD.

6.5.2 Computer-Aided Engineering

The term referred to today as computer-aided engineering, or CAE, centres around the analysis of part designs from a structural standpoint. Computer software packages have automated the number crunching involved in analyzing the effect of stresses, forces and other external factors that may act on a part causing possible deformation. While not as all-encompassing as design and drafting tasks in the engineering department, the ability to reduce times associated with stress and force analysis will increase the productivity of an engineer. CAE can be easily integrated into the CAD workstation(s) already established making use of available computer memory space and keeping system hardware costs at a minimum. Due to the 1.5-2 year learning curve associated with CAD proposals, CAE may be phased in during the final part of the curve so as to ensure CAD system integrity before building upon present introductions.

6.5.3 CAD: A Starting Point to Integration

The integration process of advanced manufacturing bases itself on a building block learning format. As employees learn from hands on use with one system, the groundwork is laid for adopting the next project thus reducing subsequent learning curve effects.

An analogy of a comparison between CAD and the first operation of a part's production is that CAD designates an important starting point to future AMS applications, and the first operation of a part determines the success of the next series of process operations, to ensure either successful systems integration or end product quality.

It is encouraging to see that CAD enjoys a high application rate (63% of the 75 advanced manufacturers responding), but the order of introduction was done approximately halfway or more through the present path of advanced manufacturing applications for all three sizes of firms. Bringing CAD on-line after NC/CNC machinery introduction by all sizes of manufacturers opposes the logical integration path between the two facets of the AMS. It is encouraging, however, that one notes the continuing drop in order of application from large to small producers.

6.6 Manufacturing Engineering Developing Process Standards

6.6.1 Computer-Aided-Process Planning

An organization's manufacturing and production areas are critical to new jobs entering the "system". Paralleling CAD, the origins of computer-aided process planning help standardize historical processes in a common computer database that can be accessed quickly by engineers and planners for critical production related information. Process planning occupies a specific place within a three tiered hierarchy (5). The first level, production planning, consists of management, coordination, scheduling, sequencing and routing of parts through the plant. This level of CAPP will afford direct integration with future MRP and group technology systems. Process planning represents the second tier of CAPP. How is a part made? Determination of the proper factory processes, the sequencing and routing of operations and the workstations involved describe the boundaries of process planning. A further breakdown to the operation level details information about tooling, fixtures, operational parameters and standard labour rates required to produce a part.

The wide scope of process planning indicates the importance to the manufacturing organization and throughput time of jobs undergoing "system" processing. A key consideration in the adoption of computer-aided process planning as like other innovations in the manufacturing setting, is that the computer does not replace the planner or scheduler, or designer, but provides them with a new tool to increase efficiency of retrieving, modifying and transmitting information. New systems like CAD, CAPP and MRP are not unmanned turn-key systems, but require human interaction to make knowledgeable decisions (16).

Important points to consider when one's manufacturing department is proposing a new CAPP system include:

- a manual investigation into historical process plans to help simplify input of information into the new sytem.
- improved efficiency of product and process planning.
- increased throughput of new jobs from engineering to the shop floor via production control.
- reduction in effects of new tooling and operational requirements due to increased ease of modification.
- integration with future MRP system working hand in hand to ensure tooling/fixtures/part components and manpower are at the right workcentre on time according to production schedules.
- integration with future group technology concepts providing a common database of similarities in part processes, tooling, workcentres and other critical operational parameters.
- integration with CAD system so that part design takes operations into consideration with respect to producibility.
- increased throughput of manufacturing changes to tooling, standards, raw materials so that variances are reduced in final output of part using changes processed.
- clearer documentation of factory workorders helping standardize flow of operations on the shop floor.
- providing a communication link between manufacturing and design engineering.

Computer-aided-process-planning establishes a feasible informational medium that is critical to the design, scheduling, sequencing, routing and operational phases of a product. It is essential that an inexperienced user of computer-assisted manufacturing applications push towards CAPP from the initial stages of integrated management and production.

Survey findings showed very little adoption of CAPP has taken place by smaller manufacturers. The small and medium producers that have adopted CAPP do show a steady drop in the rate of application from that of the larger firms generally introducing automated information handling tasks at a later stage than that of automated part handling.

6.7 Materials Requirements Planning

MRP, or materials requirements planning forms the groundwork for the control of three very important facets of production:

1) Inventory Control
2) Bills of Materials
3) Master Production Schedule

System integration plays an important role in the operation of MRP. Bringing together the three areas of production determines a manufacturer's ability to produce according to schedule with minimum work-in process inventory. Not an easy proposition! The logical model of integration utilizes both CAD and CAPP databases to ease the development of MRP, because of the many organizational departments affected by the system's performance.

6.7.1 Bill of Material Development

The origins of production control and MRP starts at the BILL OF MATERIAL level. Without a structured BOM, different component levels of parts cannot be costed, scheduled and monitored through the manufacturing environment. Standardizing the BOM function increases the ability of all areas of the company to manage costs, manpower and material resources as well as shop floor operations. All too often, the smaller manufacturer finds himself working to more than one "system". Engineering, manufacturing and finance/sales all work to a different tune regarding BOM structuring which produces adverse effects on the above mentioned parameters.

The Bill of Material has an impact on the rudimentary stages of part families due to similarities in part components leading to group technology. Integration of CAD, CAPP, MRP, and GT examplifies the logical approach to development of system integration from company top to bottom.

6.7.2 The Master Production Schedule

The MPS, or Master Production Schedule, represents the main drive to the manufacturing function. Based on sales and marketing figures regarding forecasted markets, coupled with labour standards dictating manhours required to produce a product, a manufacturer's products are scheduled so that raw materials, labour and equipment are available when needed. Purchasing comes into play making sure vendors supply materials according to schedule, while raw material and in-process lead times are built into the MPS.

6.7.3 Inventory Control

Effective control of inventory has a twofold influence on production. The first is the insurance that the right materials are on hand to meet the Master Schedule, while not carrying too much stock tying up capital that could be devoted to new process/part developments. The ability of an MRP system to have the correct quantity of materials at correct times carrying minimum inventory with as little manual expediting as possible is expressed as the "class" of system being operated. The higher the class of an MRP system (e.g. "A") the greater control a manufacturer has over important aspects of production operations.

6.7.4 Quality Control

Quality control plays a role in the cast of MRP participants. Manual communication, and eventual integraton with Q.C. computer databases with an MRP system represents an invaluable area of information management (1). Quality control procedures performed on incoming vendor raw materials and semi-finished goods form a statistical database on percentages of rejects and acceptances for part producibility. These figures, transmitted to purchasing and inventory control, establishe on-line knowledge of the quality of raw materials needed for production. Statistics on scrap and rework rates from quality control help production control get a handle on production problems arising from particular in-process parts, and take corrective action. The survey did not address conceptual quality control techniques such as statistical process control and on-line documentation of defect and scrap rates, but does represent a very important function in monitoring and refining finished product quality.

6.7.5 MRP: Bringing It Together

MRP is a vast undertaking and team members from all company departments must take part to see system integration achieved. Focusing on a modular approach to MRP helps a manufacturer spread out computer hardware and software costs, while learning each module (BOM, Inventory Control and MPS). Following other informational management tasks, survey results show MRP increasing in order of application and decreasing in utilization from large to small producers. It is clear that small firms will have to look hard at the personnel makeup of various departments if they hope to achieve material requirements planning success through a modular approach.

6.8 Group Technology

Building upon the database of process planning and the bill of material MRP module, group technology (GT) extends the managment of part information to the physical layout of equipment and part handling on the shop floor. Group Technology carries the logical progression of computer-assisted information handling to the factory and workcentre operations. Based on commonalities between part configurations, tooling, processes, equipment and handling devices, group technology uses coding classifications to formulate families of parts (32). Extension of this concept to the factory comes in the form of grouping equipment, dedicated to production of part families, together while optimizing the flow of in-process parts and manpower.

6.8.1 Conceptual Group Technology

GT is best understood by dividing the concept into two stages: conceptual and execution. The conceptual phase consists of establishing part family codes based on present part and production operating conditions, coupled with simulation of plant layouts based on new workcell development. Through the conceptual stage of GT, code classifications unlocks the door of CAPP to allow easy access to historical data of similar parts (5). As markets change and manufacturing flexibility becomes more important, arrival of new products will force engineering and manufacturing departments to utilize existing part data as efficiently as possible.

At the conceptual stage, it is important to consider the repercussions future automated devices in the factory will have on the flexibility of present plant layout proposals. It is essential that dedicated workcentres do not become too fixed in operating capabilities leading to future production inflexibility. To illustrate, consider a company producing a variety of industrial and commercial fans sets up its factory layout in such a way that manually operated machinery, forming, fabrication and paint stations are fixed far apart from one another in the plant. Based on the present product line, production is able to carry on at low levels of profitability. As the market shifts and new fan products appear, no solid groundwork is performed regarding revision or formation of part families, or layouts based on new designs, future machines and process equipment additions. Without modifications to factory layouts, inefficient part production will continue.

6.8.2 Shop Floor Material Handling

By standardizing material handling, racking, fixtures and tote boxes, built-in flexibility can be achieved by grouping a number of products together requiring similar modes of transportation. Extending group technology to material handling saves money in constructing a variety of racks..., while maintaining a high level of part quality through safe storage of work-in-process. A manufacturer may produce a variety of part components that fall into different surface classes. Varying surface classes depend on the visual profile of that component with respect to the final product.

While increasing the awareness of operators manually handling materials is important, proper protection of higher class surfaces (A) from scratches, dents and other material blemishes affects the amount of rework and scrap of in-process components.

6.8.3 Execution of Group Technology

Group technology solidifies the link between product design and processes, and factory workcentre layouts. As application of AMS technologies like CNC machinery, robotics, AGV's, sensors, pallet transfer stations, vision systems and storage/retrieval systems is undertaken, flexibility of workcentres will increase. The execution of GT takes place on the factory floor where new layouts of machinery, handling devices, manpower, and processes are orchestrated into a functioning system. Integrating these production attributes will inevitably reduce setup costs, and lower the amount of material handling, leading to higher quality, and improve overall plant flow.

For smaller manufacturers not considering highly advanced hardware applications in the near future, eventual execution of Group Technology will translate into significant savings. For those considering computer and microprocessor controlled equipment, new workcells and shop floor layouts can lead to proper steps of factory automation. Redefining current plant layouts to maximize in-process flow based on existing equipment and processes will also issue benefits. By utilizing data management performed at the conceptual stage, the physical distribution of current facilities can be optimized with future AMS hardware integration taken into consideration.

6.8.4 Appropriateness of GT to All Manufacturers

One must consider that group technology is not for all, at least on a plant-wide basis. Canadian manufacturers operating on a contract-to-contract basis find themselves producing a variety of products varying in some degree or another. This makes it difficult to pin down a family of parts. However, creating logical plant layouts helps build in an excellent flow of operations from incoming raw material to finished painting and assembly.

From the survey, all indicators point to an extremely low rate of group technology application. Unfortunately manufacturers, particularly smaller ones, are not adopting such a fundamental concept that can lead to potentially high reductions in manufacturing costs. Group Technology must attain a higher profile in the Canadian manufacturing scene enabling present conditions to change. Reaching a higher recognition can be done via industry publications, seminars, government and university sponsored learning programs. Tackling GT manually through organization of process plans, bills of materials and traditional industrial engineering plant layout techniques can serve as initial steps, but to ignore the age of the computer with its low costs and high capabilities runs counter to the logical route to greater competitiveness. A manufacturer must weigh the costs of not entering the era of computer-assisted technologies versus application of the new manufacturing tools.

6.8.5 Computer-Assisted Facilities Planning

Computer-aided-design workstations offer a new application to the manufacturer, facilitating simulation of plant layouts through graphical display. Using CAD, the manufacturing department may simulate visually what effect new groupings of machines and movement of primary process areas will have on optimizing material and worker flow based on new GT classifications.

6.9 Data Acquisition Through Bar Coding

6.9.1 Bar Code Technology: Linking Information Systems to the Shop Floor

Acquistion of data from the factory floor drives many of the computer-assisted information systems outlined so far. Quick and responsive decision-making relies on real-time knowledge of production operations. Bar Code Technology designates a medium of data acquisition that integrates quite closely with group technology acting as a support mechanism. Either pen-like wands, laser scanners, or recently introduced credit-card bar code readers are used to identify GT part family codes establishing a new medium for in-process production monitoring.

Tracking work-in-process helps drive the MRP system indicating the status of parts through the factory (13). Corrective action can be taken quickly via a bar code reader and a factory floor microcomputer on those parts bottlenecked in the information system. Such real-time response to production problems helps maintain schedules, customer service and isolates bottleneck operations that slow down production throughput time. For those manufacturers operating in a labour intensive environment, bar coding can give a real-time indicator of worker performance.

Applications of bar coding can also be introduced in areas of warehousing assisting inventory control. Policing the status of materials and work-in-process assists MRP's inventory control module. The efficiency of storage and retrieval of stored parts and materials is greatly affected by quick, accurate identification of products.

Other applications of bar code technology in the production environment include routing and recognition of parts to dependent pockets of automation on the shop floor. To illustrate this point, the following situations are considered:

i) Signalling the arrival of parts at the workcentre and supplying part information for robotic handling, NC machine programs and machine tool clamping devices.
ii) Recognizing a part's configuration for a manipulating arm or robotic paint system.
iii) Routing an automated guided vehicle or rail system to a part('s) next destination for processing.
iv) Identifying a part to load a robotic welding workcell with proper fixturing and part programming.
v) Establishing the proper storage location/bin for automated retrieval devices (i.e. stacker crane, robot, forklift).

The role of bar coding in these and similar applications will only be recognized as more advanced automated hardware is introduced to the factory. Revealing this side of bar code use clearly shows the two fold capacity the technology possesses with respect to both automated information and part handling. Group Technology shares a common link between both facets of automation. Introducing both bar code and group technology first to the small factory establishes a solid foundation which later hardware developments can utilize to ensure proper communications and operations.

Although survey results highlighted a low utiliziation of GT, bar coding used for in-process purposes received a higher rate of application, 33.3%, by large manufacturers. Such anomalies illustrate the lack of integration carried out to-date by advanced manufacturers in the Canadian MW&M sector.

Bar Code Technology is readily accessible to the small producer with various cost-effective readers, and computer software available ($1000 for a standard bar code wand). Like many new technologies, it is the performance of software used to process and communicate part codes set up by the user that ultimately spells success. The ability to identify integrative relationships between bar coding and other fundamental manufacturing concepts is invaluable.

6.10 Computer-Aided Manufacturing

6.10.1 CAD/CAM: Two Different Technologies

The long used term CAD/CAM seemed to first alienate companies and then confuse them over its true meaning. CAD/CAM is not a single technology, but two distinct applications of manufacturing. As discussed, CAD is used to establish a common database of drawings increasing the capabilities and productivity of the designer/draftsperson. CAM, or computer-aided manufacturing is defined as the computer control of numerically controlled machinery through machine tool language programming. In simplistic terms, this is what happens: a part's design configuration, stored in CAD, is transferred via computer networking or manually to CAM where the part data is converted into NC machine tool language. Simple language codes represent movements of the tool according to the dimensions of material removal required for the production of the part. CAM takes the design engineering department to the final stage of automated information handling.

CNC machining refers to programming part data on a computer instead of traditional NC punch tape. Total integration of CAD/CAM is represented by DNC operations. Distributed Numerical Control transmits computer-based part data files stored either locally at the floor workcell or from the engineering department to the NC machine (30). CNC and DNC provide an easy method for programming changes compared to the slow turnaround time associated with correcting and preparing new punch tape. Reducing the level of downtime in the dynamic production environment results into successful management. With continuing developments in such projects as MAP (General Motor's Manufacturing Automation Protocol), standardizing communications technology to a variety of shop floor devices will become increasingly easier. This will assist smaller firms in their quest for more competitive manufacturing.

Numerically controlled machinery has witnessed an evolution from the days of tape generated programs running at low speeds and limited part complexity. NC or CNC operations now have the ability to produce a wider variety of precision parts more flexibly and quicker. Computer-aided manufacturing involves the input of both design engineering and manufacturing departments to integrate first CAD to CAM and then the selected NC machinery. Application of CAM must run parallel with that of NC machinery selection so as to ensure a faster startup time of new machinery operations while utilizing existing CAD databases. The survey did not classify CAM as an independent AMS application, although results generated from usage of microcomputer-based factory floor CNC programming shows penetration of CAM technology into the Canadian MW&M sector (See Fig. 32).

Introducing aspects of computer-assisted information handling to management stresses the importance of human interaction between an organization's departments. The logical approach to new management technologies outlined in Fig.

34 reduces the intensive labour content of manual accounting, drafting, and process planning, while increasing the level of communication between management. A company is able to pursue more long-term innovative ideas with the availability of new found time computer-assistance offers. Afterall, innovation leads to greater competitiveness. Whether it be management, product or process oriented.

Today's small manufacturers are feeling the brunt of a new competitive level caused by larger firms moving towards an "assembly oriented" factor increasing the level of subcontracting out machining and fabrication operations to the smaller factories.. Interviews with small and large companies supported this claim as smaller shops try to increase operational flexibility and quality, and larger ones reduce the number of production operations. A key to the small factories of Canada will be central focus on a logical approach to integrated manufacturing helping meet the new demands of product quality and process flexibility being a part of today's manufacturing era.

6.11 NC Machinery Meets Bar Coding on the Shop Floor

With structured computer databases existing at the organizational level, factory automation represents the next phase to integrated manufacturing. Figure 34 shows how the logical approach to integrated manufacturing introduces NC machinery and bar code technology first on the factory floor. Both applications build upon CAM and Group Technologies linking important aspects of factory floor data with information management levels at the office level.

6.11.1 Automation of the Plant's Primary Operations

Production operations most prevalent to the MW&M sector as survey results supported is machining or material removal tasks. It is, therefore, only logical that a manufacturer focuses his attention first to automating a primary function of production operations. In particular, small manufacturers tend to concentrate more on machining tasks as managers are often former machine operators, as well as a closer relationship held between management in general and the shop floor (29). This is due to the lower levels of management in a smaller manufacturer allowing managers greater first-hand knowledge of production operations.

A mature NC/CNC machine technology allows for quick adoption of this hardware application initially to the plant while bar coding is phased into a data acquisition role. Group Technology utilizes shop floor data from bar codes to update process planning and sets up workcell layouts to optimize process flow and setup costs around new machinery (32).

Adopting a cellular plant layout, eases the management of shop floor control and reduces future hardware and software costs. As growth in production takes place and new aspects of factory automation are added, a workcell configuration limits the number of operating parameters (operators, NC workstations, bar code readers and support software, pallet transfer stations, robots, tooling, quality devices, microcomputer stations and communications network related hardware and software) necessary to produce parts. Opposing a cellular layout is a decentralized approach to workcentres which increases the costs and downtime of production. Integrating three AMS technologies together at the outset of factory automation (Group Technology, Bar Code Technology, and NC Machine Technology) supports long-term system success.

Factors affecting NC machine implementation include:

- type of machine operation to be performed by new hardware (i.e. milling, drilling, boring, turning) or combination of them based on largest proportion of parts requiring specific material removal tasks.
- number of axis of NC machine or the different movements of table and tool head determined by complexity of parts being produced, capital available, and market gain potential through more efficient machining of competitive products.
- feedback and adaptive control capabilities used to monitor process in real-time (i.e. tool-wear, tool positioning, coolant-flow, program execution) reducing dependence on operator and affecting machine downtime due to

tool breakage, coolant stoppage, and part quality due to tool and program problems.

- automated tool changing capabilities reducing setup costs and tool magazine capacity based on the number of tools required to produce family of parts.
- ease of future integraton with robotic part/tool loading, pallet transfer stations, quality devices (i.e. coordinate measuring machine), tool carousels and computer-aided clamping devices.
- automatic removal of machine coolants and material chippings (health and safety/clean working environment).
- material handling between parts/materials, tooling and machine.

Tool magazines located on machines complete with toolhead rotation for transferring tools are an important attribute of the NC machine. Opting for a NC machine without automated tool changing capabilities denies the cost savings possible from reduced machine downtime as tools are changed during machining processes.

The survey has shown that all sizes of Canadian MW&M manufacturers are introducing NC machinery first on the shop floor, before introducing formal information management systems. This is counter to a logical progression to advanced manufacturing that suggests first the establishment of information databases that can later be manipulated efficiently for job processing.

6.12 Quality Evolves Throughout The Factory

6.12.1 Monitoring Product Components Quality

One objective of industrial automation is to increase product quality. As the public and private sectors have demanded more from a product, manufacturers have attempted to reply with new concepts and technologies that will help achieve top quality. Bringing numerically controlled machinery on-line in the plant does not correspond to problem-free machining. The interaction between operator and machine still exists, and difficulties arising from coolant, and tool feedrates, mis-clamping of parts, tool-breakage, and internal malfunctions an operator may ignore or fail to detect can spell disaster for precision machining.

Quality control programs instituted in one's plant possess both machine hardware and human-related attributes. The hardware approach to Q.C. starts with the coordinate measuring machine (C.M.M.) where precision parts are checked based on programmed part data after NC machining. Until further practical developments in machine sensing technologies is achieved, reducing operator-dependency, the C.M.M. will always play a significant role in part quality monitoring. Forming a quality control cell containing a C.M.M. located centrally to all machining operations takes GT workcell configurations into consideration. Such a design will lower equipment costs (one coordinated measuring machine for a number of NC machining stations) and reduce the distance of part travel, or non-production time.

6.12.2 Quality Control Programs: Getting Everyone Involved

The human approach to Q.C. on the shop floor including self-inspection, statistical process control and greater manufacturer/vendor relationships represents an on-going process that must start early in the advanced manufacturing system. Achieving a sound relationship between employee and part quality awareness is essential. Worker participation and managing psychological characteristics towards change (in this case technology) is the starting point to any successful system development (24). Future quality control hardware applications include vision systems integrating robotics with part quality, along with sensing and other monitoring devices.

6.13 Material Handling Moving to the Forefront

A global problem facing both large and small plants is the efficient transport of work-in process. Todays manufacturer must also address the movement of materials without defects caused from extensive labour/input, (such as dents, scratches, etc.) unprotective carriers, and forklift contact.

Automation of material handling and storage/retrieval functions have to a large extent been left out of the manufacturing picture as indicated by survey findings and recent industry figures. In a typical factory environment, material is handled or stored 90-95% of the time, while the remaining time is being used to produce the end product (11). Efficient material handling today is of paramount importance for a cost-effective plant operation, but is often overlooked. With manufacturers of all sizes attempting to reduce lot sizes and carry less work-in-process inventory, the ability of a M/H system to efficiently and effectively deliver smaller quantities of parts to production areas is vital to the drive for low cost, quality production.

6.13.1 Material Handling Before the Robot

Because of the greater volume of work that larger manufacturers generally process in welding, painting and assembly tasks, it is only logical to address a universal problem of material handling before that of robotic processing for the small MW&M sector firm. Smaller manufacturers tend to look upon the robot not as just another machine, or tool, but as a device beyond their technical skills. They must, however, be made aware that a robot is simply a handler of material that with the addition of a tool can be used in process or part handling applications. We will discuss integrating robotics into the logical model in the next section of the thesis.

6.13.2 Shop Floor Integration

Material handling systems must integrate with NC and manually operated machinery, process areas, and storage centres to increase production up-time and help cut factory costs (11). Future considerations of robotic installations must be kept in mind when developing a central M/H system. A robot may be introduced into a machining cell to handle part and tools locally, but must work with existing external material handling devices. Integration stands on the premise that one introduction cannot operate to its potential without regard to support systems previous to and following that introduction. From a simple hand cart and forklift to a comptuer controlled rail or conveyor system, and automated guided vehicles, managing the transport of parts and materials is key to the advanced manufacturing system.

One must consider the different phases of work-in-process that have an impact on mediums of material transport. From raw materials coming into the plant (sheets of steel, bar stock and semi-finished goods) through size reduction of sheared/formed and machined parts to transport through welding, painting and assembly lines, material handling takes on many faces. Figure 27 shows how the utilization of available transportation methods may be applicable on a local or plant-wide basis.

Material handling systems should start with the establishment of standardized carrying devices (racks, carts, boxes, stands). This has an effect on:

- material/part defect reduction through greater protection
- increased carrying flexibility
- driving up plant throughput time by optimizing the number of parts handled per square foot of plant
- greater consideration of material surface classes by designated transport fixtures
- reduced setup times by having right materials/parts and tooling at workstation on-time
- more organized shop floor.

The relationship between proposed material management methods and group technology cannot be neglected. GT establishes the basic framework for which a plant will be laid out based on similarities in parts and processes. These similarities generate the formation of workcells and process centres (16). Coordinating material handling with the GT framework will ensure optimum in-process flow integrating materials with production equipment at point of use.

Introduction of the computer offers a whole new means of monitoring and scheduling the movement of product components. Real-time production and material control becomes a greater reality. Depending on the size of a plant, and volume of product flow, different methods of material movement can be used. Highly flexible overhead rails utilizing unused space above the factory floor and automated guided vehicles require computer assistance. But, the small manufacturer may focus initially on simpler methods. Careful control over forklifts carrying standard carriers along structured paths integrated with semi or automated conveyors at points of operation introduce greater material handling effectiveness.

As a company grows and experiences greater work volumes, the required steps into higher level computer-based systems can be made easier if the groundwork is already established. Examples of integration between information and part handling are:

1) GT/NC Machinery/Material Handling/Storage and Retrieval
2) CAPP/GT/Bar Coding/MRP
3) GT/NC Machinery/Robotics
4) CAD/CAM/NC Machinery
5) CAD/CAM/CAPP/GT/Bar Coding/ MRP, Microcomputer-Based Communications Network
6) MRP/Warehousing

These relationships can be better understood by studying Figure 34 displaying the logical model of integrated manufacturing step by step.

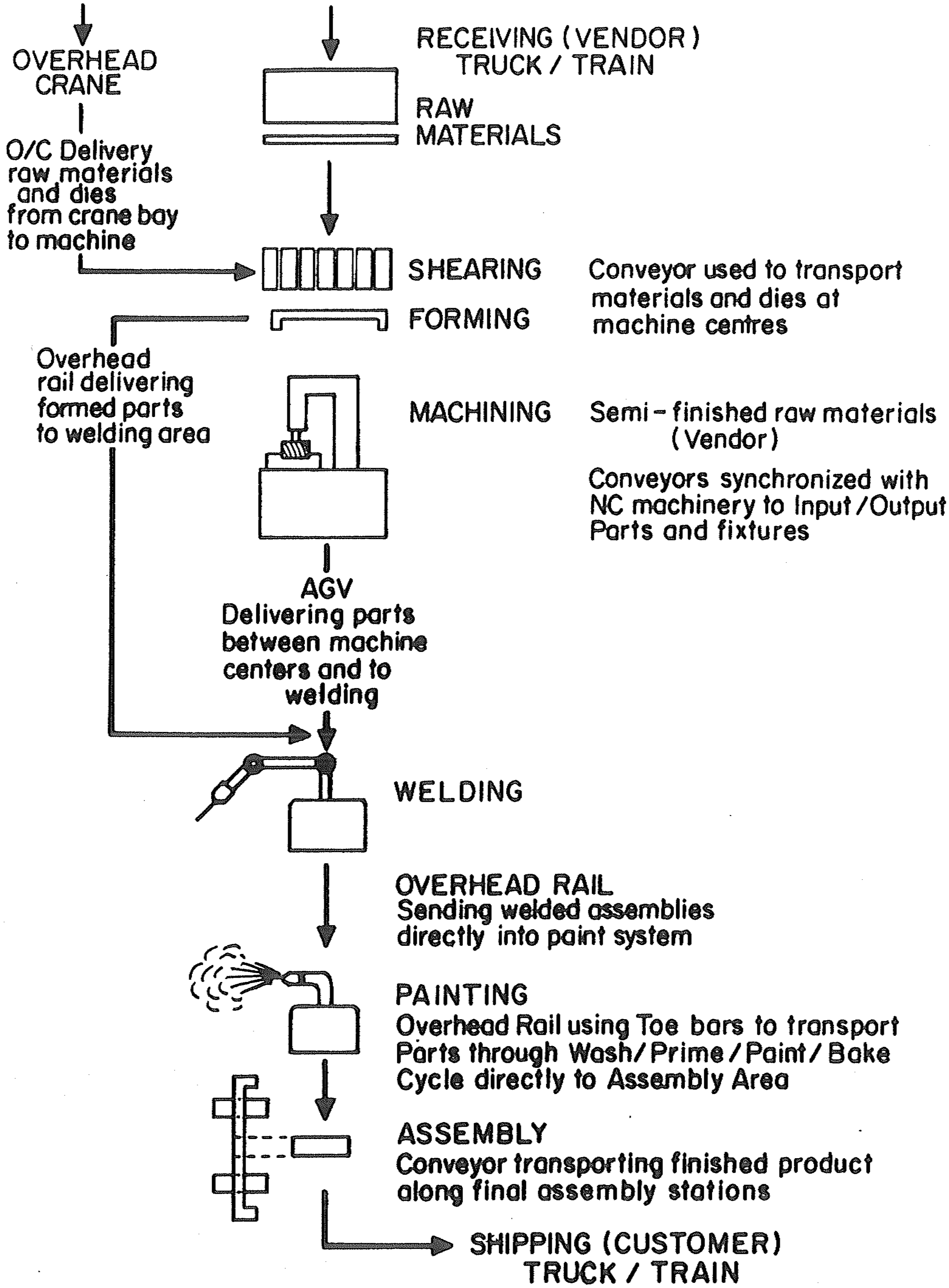
6.14 Entering Robot Practicality

The main thrust behind AMS technologies at the information and part handling levels is the informational and process flexibility a computer and support software, coupled with shop floor hardware such as industrial robots offer to the user. As changing markets result in greater frequency of changes driving down the product life cycle, no longer does a manufacturer have the luxury of producing one part repeatedly, year after year (36). Robotics offer a whole new level of flexibility and consistant quality to a variety of production operations. With little more than re-programming and change of the gripper (hand), new products can be accommodated.

The term "industrial robot" can be defined as a simulator of human upper body motion designed to move and process parts through programmable instructions via a computer or local microprocessor (27).

FIGURE 27

FLOW OF MATERIAL THROUGH FACTORY



6.14.1 Large Manufacturers Leading Robotic Application

The large MW&M producers with high volumes of machining, part handling and process orientated tasks can justify similar reasoning between NC machinery and robotic application. The stronger emphasis being placed on welding, painting and assembly operations by today's larger factories changes the logical order of introduction for our plants. Trends led by the automaker's consolidation of fabrication, painting and assembly operations has had a tremendous impact on robotic application in these areas. Survey figures of 25%, 23% and 21% in robotic welding, painting and assembly respectively testifies to these new industry directions.

6.14.2 Robots: Just Another Machine

The robot represents a giant step to the small factory. Attitudes are still frozen in the "that technology is beyond my means" syndrome. Today's ease of progammrability right down to the worker level, coupled with fundamental tasks of part and tool handling at a workcentre allows the robot to prove itself. Although the robot is simply another automated machine, it's usually humanoid connotations cause it to be considered differently from other machines.

Robots don't necessarily replace workers, but integrate with them in either a monitoring, programming, part loading/unloading and operating capacity. An illustration of this is a welding cell made up of three workcentres fixturing automotive axles in place. The robot's working envelope or base rotation gives access to all three fixtures. By having the operator first tackweld and then load each fixture with parts, begin the robot's cycle and unload finished parts, while robotic welding is taking place alternately at all three stations increases workcell productivity and consistent welding quality. The introduction of a robot into a small factory as a simple material handler by an external consultant, or advisor would provide the manufacturer with a first-hand opportunity to witness the potential benefits available. Although a fundamental mover of parts and tools, the versatility of a robot can be increased dramatically through the addition of production tools to the robot's gripper or hand.

6.14.3 Robotics: Building New Technologies Step by Step

Research and development into vision systems gives the robot a new dimension of sight improving upon the spectrum of applications available to the factory (38). Sensor technology also provides the robot with the ability to sense part size and local distances around its periphery of operation. As the learning process unfolds and a greater spectrum of robotic performances and controls are achieved, a manufacturer may choose to add systems such as vision and sensors to his robot's capabilities.

Our survey shows that the introduction of robotics into the Canadian metalworking and machinery related industries occurred two steps before that of material handling applications by the larger firms. Both steps were taken towards the end of their present introduction of new technologies. Survey results supported industry experiences stating a lack of robot installation by smaller factories. New manufacturing technologies are available to the small companies of Canada, but it is the method by which they are introduced that will ultimately prove success. Treating each new step of technological innovation the same as total system integration through a building block approach helps:

- spread capital costs out over a period of time
- reduce the learning effects of each step into new technologies
- allow for system requirements to arise logically instead of forcing new technologies upon the organization (i.e. introduction of new technology will bring dependent applications to the surface as time and knowledge progresses)
- control and monitor the performance of new applications over period of time documenting impact on personnel, market, quality, productivity and overall operating costs
- allows for further developments into automation to occur before application takes place
- slowly changing worker mentality toward new ways of doing things.

6.14.4 Net Effects of New Systems on Business

Figure 28 shows graphically the net effects of new systems on the population sample surveyed. Our survey shows that productivity improvements registered the highest percentage, 85%, while customer service, reduced manufacturing costs, and increased quality all shared equal representation of 75%. From these numbers it is quite evident that new system technologies are indeed having positive affects on the entire company structure.

6.15 Optimizing Warehouse Control

Storage and retrieval functions within warehousing areas share an importance with central and local material handling. Previously storage/retrieval and material handling were put on the backburner of a manufacturer's production strategies. Today's emphasis on tight control over inventory levels and integration of materials/parts storage with the dynamics of small batch production demands a careful look at quick and responsive warehouse management.

6.15.1 Efficient Storage/Retrieval

The full-blown automated storage/retrieval systems of the warehousing environment that have received such high acclaim by the manufacturing industry in the early 1980's are not necessarily viable for all sizes of producers. Volume of stored materials in smaller factories demands a slightly modified version of automated stacker-crane hardware employed to access stored goods. As the Japanese success stories with Just-In-Time Inventory concepts filter into the Canadian corporate culture, greater emphasis is now being put on the role that efficient storage/retrieval of work-in-process and raw materials has on low cost production (28).

All of the manufacturers interviewed in preparation for this paper stressed high priority on reducing lot sizes in an effort to cut work-in-process inventory levels. In order to achieve this, production flexibility must be attained. Integration of the storage and retrieval of product components with material handling systems plays a significant role in gaining that flexibility.

6.15.2 Semi-Automated Storage/Retrieval

For the smaller manufacturer, a semi-automated storage/retrieval system (S/AS/RS) represents the most practical step towards greater inventory control and faster throughput times of products. Construction of modular racking flexible enough to store all parts and materials brings standardization to the warehouse area. The microcomputer can be introduced as a local data manager keeping track of structured storage locations and the corresponding parts and materials. Setting up the database of stock locations can be networked to the company's MRP system to give planners on-line knowledge of what components are available and when stock levels reach re-order points.

6.15.3 The Warehouse Database Manager

The computer gives the operator a graphical display of storage locations to increase the efficiency of retrieval upon the request of shop floor workcentres. Management of in-plant warehousing via a S/AS/RS system gives the small factory the following positive features:

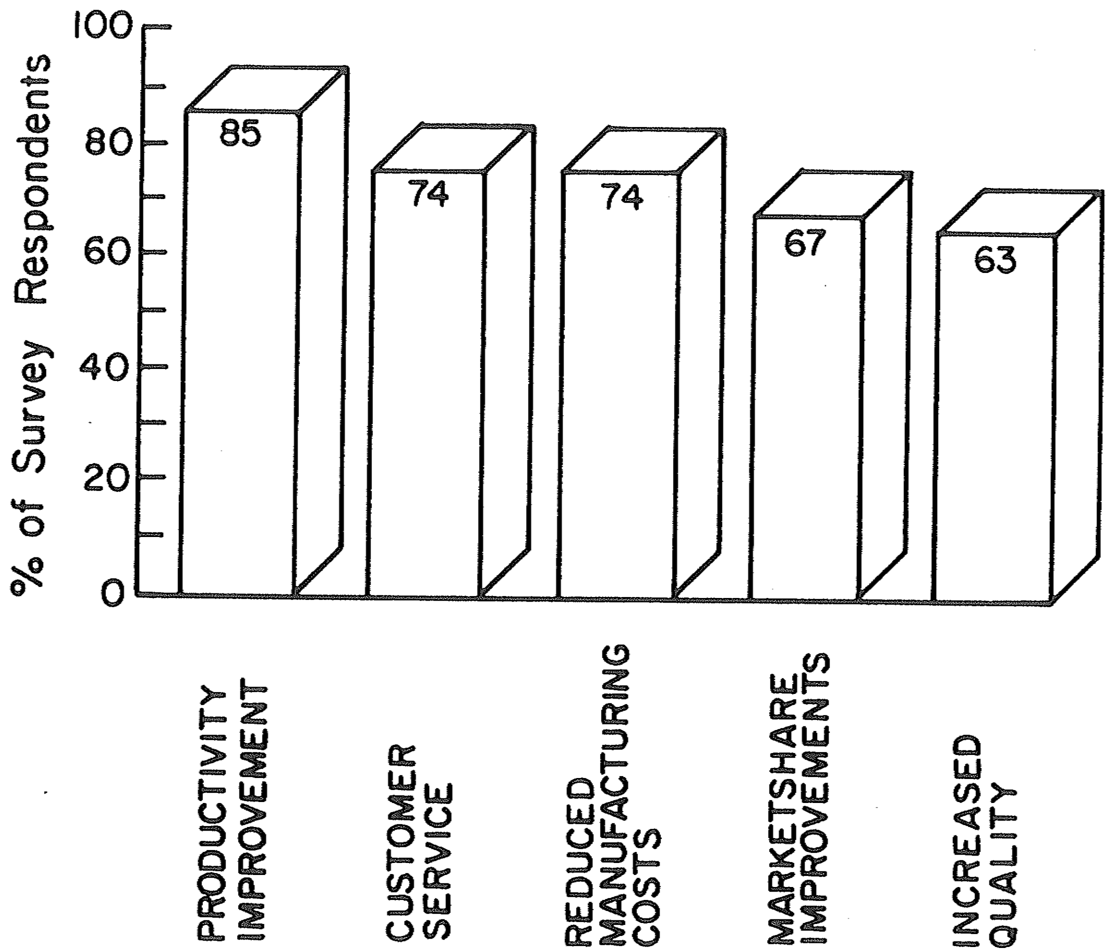
1) a shop floor tool aiding the operation of MRP system's management and purchasing functions
2) reduce the chance of production slowdowns due to part shortages
3) getting materials and parts into production faster
4) aiding finance in up-to-date information on inventory levels and transactions
5) increasing overall throughput time of product effecting customer service.

6.15.4 Maximizing Storage/Retrieval of Toolage

Efficient storage and retrieval of fixtures and tools is also very important to the flexible production environment. The time it takes a fixture or tooling to be located, handled and transported to a workcentre effects the downtime of production. The same factors considered in a semi-automated storage/retrieval system for the warehouse stand true for fixture and tooling storage and retrieval.

FIGURE 28

EFFECTS OF NEW SYSTEMS ON MANUFACTURER



Workcentre setup costs can be reduced by consolidating the location of fixtures and tooling both physically on the floor and in a common computer database combined with work packages being released to shop floor workcentres.. Through CAPP, GT and MRP, greater control over storage and retrieval of fixtures/toolage will reduce the time taken from process planning down to the shop floor workstation.

6.16 The Evolution of Communications Networking

Unlike individual applications of AMS discussed up to this point, factory floor communications networking is a step by step process that must run parallel with each new introduction of computer-assisted technology. The path of logical integration from the organization to the factory floor cannot take place without a structured communications link between top level computer databases, and shop floor devices and microcomputers.

6.16.1 Two Different Cases of Communications Flow

Two distinct areas of data communications exist that must be understood as a company surges ahead into unchartered technological waters.

1) Global Communications Networking linking all operating hardware, and computers on the shop floor with various data management systems located in the offices above
2) Local-Area-Networking between groups of computer databases, automated hardware, and other computer-assisted tools either at the office and/or factory levels.

To best illustrate the two phases of communications technology from a practical standpoint, the following cases are presented:

1) In the first example, a factory producing industrial fans has introduced two NC machining cells, robotic welding and painting areas, semi-automated storage/retrieval system, and bar coding used to track in-process and signal workcentre operations. The Material Requirements Planning system must

communicate with the warehouse computer to update inventory control, and with bar code readers to update location of parts and production schedules. A local NC machine computer must access tool programs via CAD workstations in engineering to run both machining cells. Part recognition by bar code readers at each factory workstation utilize group technology codes to link with robots on the floor and information management tasks in the office (i.e. MRP and Process Planning). The central computer database of robotic programming located in the manufacturing department must communicate with the controllers of the robots to ensure proper part handling and processing. Factory floor microcomputers situated in the foremen's offices used for word processing and real-time status of work-in-process also must communicate actively with both engineering and manufacturing departments to monitor the status of design and process changes helping to ensure the right parts and processes are used.

Critical information between factory workstations and data management systems in the office is communicated verticially between them. Utilizing the microcomputer on the floor as a middleman between upper level computer and automated hardware helps ease the process of communications through direct integration between two computers, and acting as an information buffer for operators, and local NC and robotic controllers.

2) In the second example, an automated workcell consisting of a 6 axis handling robot, a 3 axis NC mill, a 3 axis NC lathe, coupled with a bar code reader are linked with an incoming plant conveyor. For all components of the cell to communicate in real-time between each other, the following communications must be considered:

- conveyors must signal the bar code reader of incoming parts
- bar code readers must signal robot controller via cell microcomputer of

what parts have arrived using GT codes to make sure the robot's gripper opens a maximum distance for the part's shape

- NC part programs must be accessed based on part identification
- the different proprietary processors of mills and lathes (i.e. difference machine vendors) must be communicated with via the cell's microcomputer to ensure proper operation is executed.

Because of the wide spectrum of technology vendors, and their types of proprietary controls (bar code reader, robot, mill, lathe are all from different vendors), communications via computer software between each device is quite difficult. In order for the workcell's devices to integrate physically together, data must be transferred to one another to achieve outlined production. Information is passed horizontally as opposed to the vertical flow of data illustrated in the previous example. Figure 29 displays a flexible manufacturing cell containing a variety of automated devices requiring a real-time local-area communications network as depicted in Case 2. A global communications network as outlined in Case 1 is schematically shown in Fig. 31.

6.16.2 Local Area Networking At The Factory Floor Level

As the logical model of integrated manufacturing progresses through information handling systems and into factory automation, open looped vertical communications will have to be instituted first to ensure each step into the advanced manufacturing system is supported by dependent databases. The emphasis on application of factory automation (NC, Robotics, AGV's) by larger manufacturers to-date as supported by our survey has caused considerable development in standard factory communications networking. As the number of automation vendors grow, increasing problems with attempting to link a variety of proprietary rules used by each vendor in their machine controls has arisen. General Motors, a large investor in factory automation found themselves facing this communication problem (2). Over the past six years, GM has made inroads into factory communications networking through a standard system called Manufacturing Automation Protocol, or MAP. What MAP has done is raise the awareness of equipment vendors about the communications problem and establish an open forum for all industry to participate in trying to achieve a standard networking system for all.

6.16.3 The Logical Model Changing the Emphasis of Standardizing Factory Communication

The logical order to integrated manufacturing being presented changes the emphasis on initial factory communications networking. Introductions into computer-assisted applications such as MIS, CAD, MRP, CAPP and GT first puts the onus on communications between computers, and not a variety of proprietory automated hardware devices. Establishing an office local-area-network between the databases of finance, engineering and manufacturing departments need to be addressed early in the integration process. Innovations into computer networking software eases this phase of the communications process as opposed to various proprietary hardware devices. Adopting factory automation after information management tasks are transferred into the organization, gives the manufacturer time to take advantage of the ever-growing developments into standardizing factory local area-networking making the eventual task much easier.

Survey figures showed a surprisingly equal applications of factory and office networking by the large manufacturing group, while a greater emphasis on office level communications is being adopted by smaller companies because of the earlier introduction of computer-assisted information management systems.

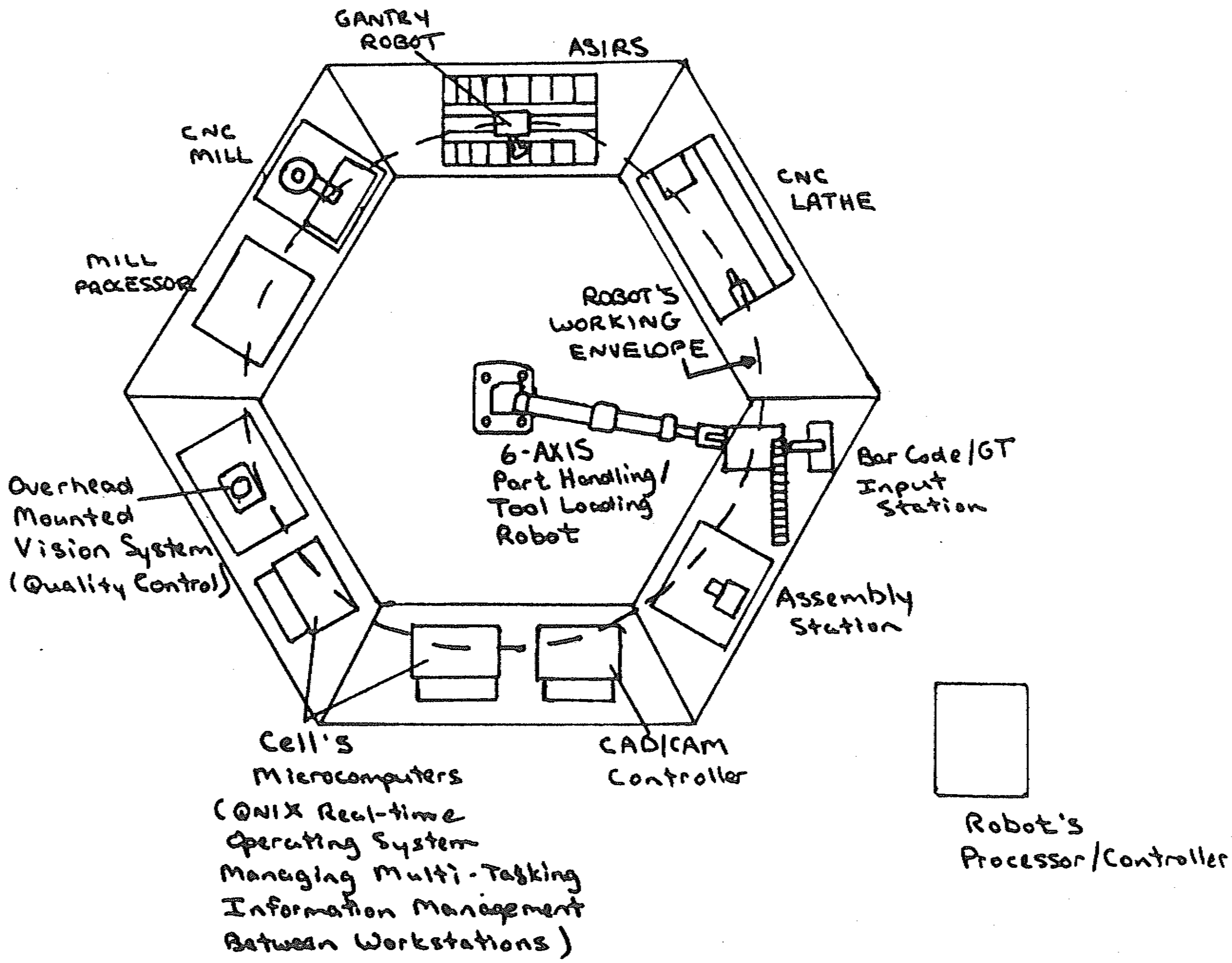
6.16.4 Attributes of a Communications Network

The attributes of a communications network are presented to better understand the applicability of a network to the office and factory environments. A structured communications network relies on three important factors:

1) Communications Medium
2) Method of Transmission
3) Physical Configuration

FIGURE 29

COMPUTER INTEGRATED MANUFACTURING CELL:



NOTE: BOTH CYLINDRICAL AND RECTANGULAR PARTS UNDERGO CELL INPUT VIA CONVEYOR/BAR CODE READER TO STORAGE... MACHINING... QUALITY ANALYSIS... ASSEMBLY OPERATIONS ALL INTEGRATED INTO ONE CELL.

6.16.4.1 The Medium

Mediums used for communications networking are baseband, broadband and fibre optics. The choice of which medium depends on the operating environment. Baseband systems employ a single channel for all users. A broadband system, on the other hand, has multiple channels over the same cable. Fibreoptics is a broadband system which can travel over greater distances and withstand worse operating conditions, but is still in the development stages from a practical usage viewpoint.

6.16.4.2 Method of Transmission

The methods of transmission represent how rapidly messages are sent to various computer databases or factory floor workcentres. Token passing and carrier sense multiple access/collision (CSMA/C) designate the two methods of transporting information. Token passing can handle a heavy communications traffic, while the CSMA/C method cannot (4).

6.16.4.3 The Physical Layout

The physical configuration of a communication network should try and reproduce the network of computers or automated equipment being employed. Ring, Star and Bus configurations designate patterns by which data can be transmitted. In a ring network, as signals must be passed sequentially to each station on the network, this slows down the time it takes to get a station requiring access to the network, but situated towards the end of the ring. A star configuration depends on a central station for all information to pass through before moving to the designed receiver slowing down informational flow. The bus network is designated similar to a fish diagram as shown in Figure 30 where each station is a branch off the main line connecting all areas to the network. Such a layout allows for each station to quickly access or transmit information along the network.

6.16.5 Choosing The Right Network For The Working Environment

The drive for real-time communications in the factory, heavy traffic flow, and the number of short, quick messages on the network demands a broadband token-bus network to be used in the dynamic production environment of the factory. Local-area-networks in the office depend less on real-time information flow and a reduced frequency of messages being transmitted means a baseband CSMA/CD networking scheme can be used. Figure 30 shows three possible configurations of a network layout, while Figure 31 graphically details a practical communications network integrating information handling systems in the office with factory floor microcomputers and automated devices.

6.17 The Microcomputer Evolution

As the evolution of communications technology progresses with each step into the logical model to integrated manufacturing, so does the microcomputer. The hardworking members of the computer world provide a powerful information management tool for the factory. From coordinating NC machine cells to bar coding, and warehousing, as well as robotic installations, the microcomputer introduces a whole new medium to real-time monitoring, processing, and feedback of machines, personnel and in-process parts in the plant.

Due to the low cost of micros, (a complete system costs between $4000 to $10000), high performance capabilities and flexibility, tomorrow's world of factory automation cannot be envisioned without this new breed of personal equipment (21). Our survey addresses the areas of potential microcomputer applications on the shop floor in an effort to document their influx into the Canadian MW&M industry. Figures 32 and 33 detail the differences between today's presence of the microcomputer in Canadian industry to that of the logical model of integrated manufacturing proposed in this thesis.

6.17.1 Results of Factory Floor Use

From an analysis of the model shown in Exhibit 37, the following important points are presented:

- equal representation of CNC microcomputer programming and NC/CNC machinery application on behalf of large manufacturers, although a 5 year gap exists between the two. This reveals the maturity of NC machinery versus the microcomputer

- large proportion of respondents claiming application of word processing using the microcomputer as an excellent timesaver for production supervisors generating documentation of daily problems, etc.
- earlier introduction of microcomputer usage for quality control applications than that of automated Q.C. hardware showing the computer is an excellent medium for running on-line defect/scrap reporting to enable quicker correction to problem parts/processes
- equal representation of factory communications networking, and employment of the microcomputer for this purpose. Tomorrow's communications technology in the plant requires the microcomputer's assistance to quickly and effectively transmit and acquire important data
- smaller percentage of large manufacturers utilizing the micro as a cell controller for NC machines, robots, C.M.M., etc. as compared to that of actual application of these machines. This supports the observation that there is a lack of group technology being utilized on the shop floor.
- clear domination of microcomputer use on factory floor by larger manufacturers supporting previous factory hardware results.

The growth in personal or microcomputer has brought a whole new perspective to a small manufacturer's ability to cost-effectively manage future factory installations, as well as information systems in their engineering and management departments (CAD/CAM, CAPP, CAE, GT, Finance and Sales). It is important that the application of an AMS technology in the factory be supported by a microcomputer with multi-user capabilities, meaning that more than one factory automation function may be managed using just one microcomputer workstation.

FIGURE 30

LOCAL AREA NETWORK CONFIGURATIONS:

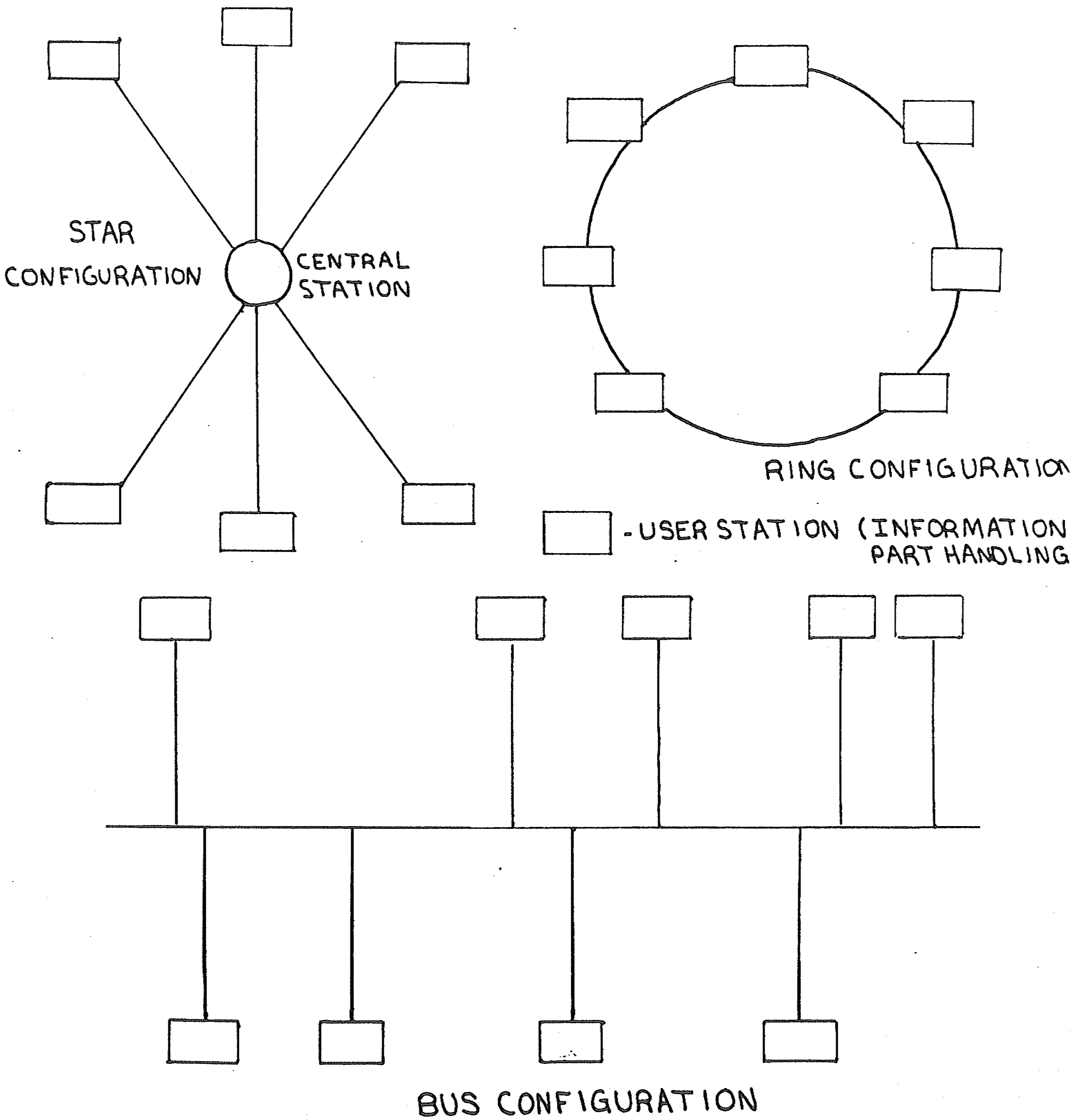


FIGURE 31

LOGICAL INTEGRATED COMPUTER NETWORK

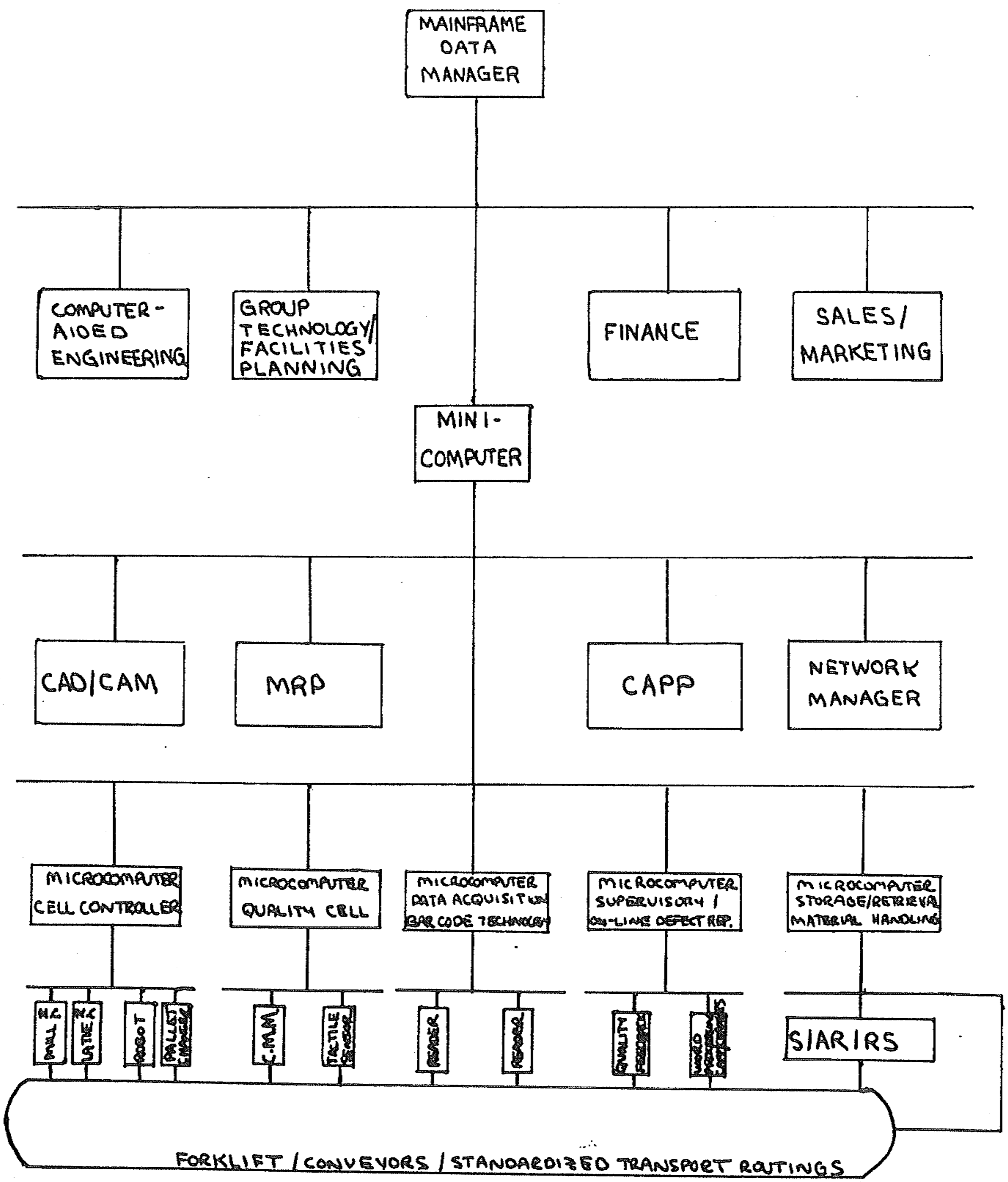


FIGURE 32

PRESENT DAY FACTORY FLOOR MICROCOMPUTER MODEL OF APPLICATION

LARGE MANUFACTURER

USAGE	APPLICAITON	YEAR	ORDER
88%	CNC PROGRAMMING	1982	1
65%	WORD PROCESSING	1983	2
38%	QUALITY CONTROL SPC (DEFECT REPORTING / C.M.M. / VISION)	1984	2.5
28%	PART ROUTING / SCHEDULING ORDER PROCESSING / TRACKING BILL OF MATERIAL / INVENTORY CONTROL	1984	3
24%	FACTORY COMMUNICATIONS DATA ACQUISITION	1984	4
20%	CELL CONTROLLER (NC MACHINE, ROBOTICS, C.M.M.)	1985	5
15%	MATERIAL HANDLING STORAGE / RETRIEVAL	1986	6

MEDIUM MANUFACTURER

USAGE	APPLICAITON	YEAR	ORDER
23%	WORD PROCESSING	1983	1
37%	CNC PROCESSING	1984	1.5
32%	QUALITY CONTROL	1985	2
18%	INVENTORY CONTROL BILL OF MATERIAL	1986	3
15%	PART ROUTING / SCHEDULING ORDER PROCESSING / TRACKING	1987	4
8%	CELL CONTROLLER	1987	5

SMALL MANUFACTURER

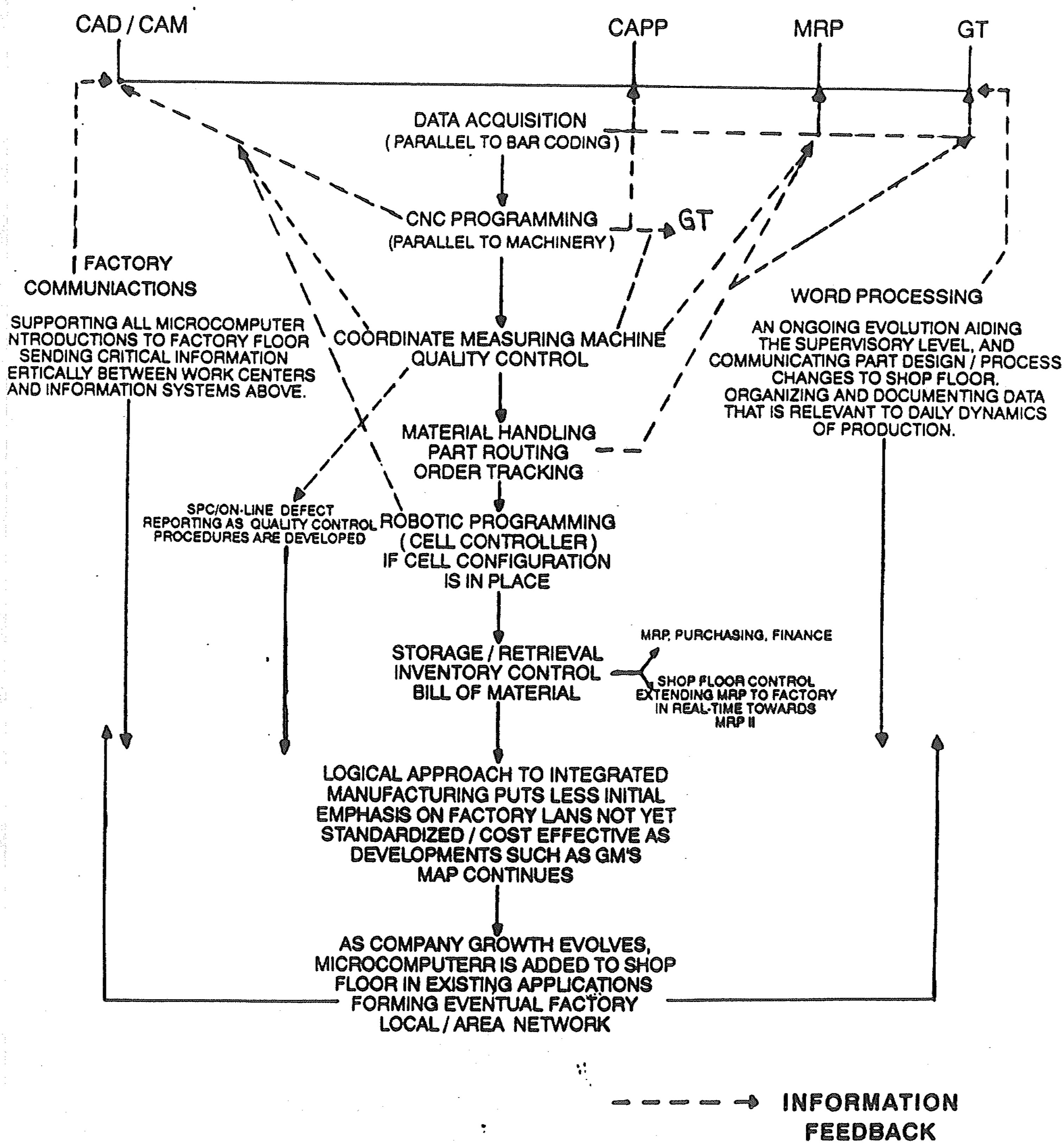
USAGE	APPLICAITON	YEAR	ORDER
42%	CNC PROGRAMMING	1984	1
35%	WORD PROCESSING	1984	1.5
25%	INVENTROY CONTROL BILL OF MATERIAL	1985	2
15%	QUALITY CONTROL	1985	3
10%	PART ROUTING / SCHEDULING ORDER PROCESSING / TRACKING	1986	4

NOTE: POSITIVE SIGNS REVEALED BY CLOSE RELATION BETWEEN BOM / INVENTORY SHARING MRP FUNCTIONS, AND SIMILARITIES BETWEEN ORDER TRACKING AND PART ROUTING.

FIGURE 33

LOGICAL INTEGRATED MICROCOMPUTER MODEL ON THE FACTORY FLOOR

INFORMATION MANAGEMENT SYSTEMS



6.18 Sensors Meet The Production Environment

Sensors parallel communications networking on the shop floor by assisting the transfer of vital information between workcentres..

Sensors form an in-process middle ground for monitoring, diagnosing, and identifying, parts and processes in the factory. With the aid of a microcomputer, sensors can drive a wide spectrum of factory applications. Information gained from such applications can be used to drive shop floor and office data management systems. Tactile sensors used in checking the dimension of machined holes can feedback data on the accuracy of NC machine programs. Strain gauges attached to a robot's gripper sense the speed of the robot's arm with respect to its peripheral operating environment allowing for robotic programming changes. Optical sensors used on pallet transfer stations can signal the arrival or departure of parts updating production control functions relating to the status of work-in-process. Even simple force-torque sensors can have an effect on such applications as the placement of fasteners and torquing of gears. The list goes on, but the important fact is that applicable sensory tasks be integrated with in factory automation to attain positive feedback results. Whether it be for supporting the company's MRP system, quality control procedures or preventative maintenance programs, reliable sensor technology can be very useful even for the small manufacturer to use (31).

6.19 The Logical Route to Integrated Manufacturing

Moving into the unknown world of new technologies is a difficult step for Canada's small manufacturers. Where to start first is often the question asked. Presenting a logical model to follow towards integrated manufacturing may help guide the small company through the quagmire of technological buzzwords, (FMS, CIM) and the diverse scope of computer-assisted information and part handling systems available to them.

Most important to the manufacturer is that the proper planning steps be taken when considering new technologies. The logical model presented in this paper has not only followed a specified sequence of steps towards the advanced manufacturing system, but laid out the groundwork involved in implementing a new application.

6.19.1 Bring On Information Handling First

Adapting automated information handling first before factory automation presents a new sequence of applications for tomorrow's manufacturing organization. Top management support and awareness is critical to any new application of technology. Introducing the computer to this level first not only automates the heavy paper pushing typically done, but opens the eyes of managers to the powerful tool a computer represents.

Establishing a framework of structured data for use by engineering and manufacturing related departments using the computer, transfers technology into the workplace in a step by step fashion. Building upon each introduction strengthens the learning process of each employee as systems integration progresses through the office into the factory. From a corporate standpoint, introducing office automation through management information systems, computer-aided design and process planning to material requirements planning and group technology has a significant impact on company profitability and competitiveness. (See Figure 34 for Illustration of Logical Model to Integrated Manufacturing).

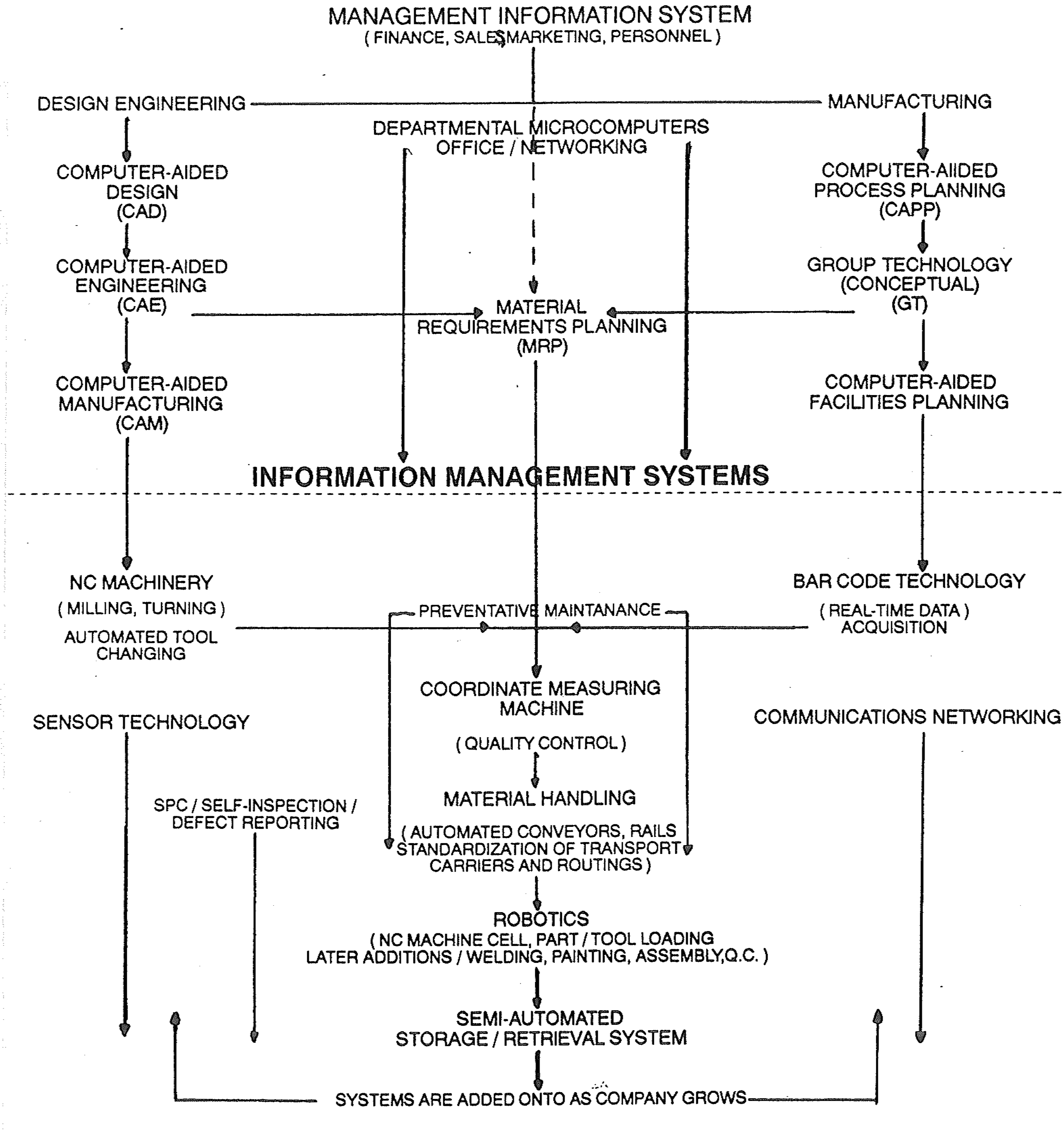
6.19.2 Factory Automation Building Upon Information Systems

Factory automation introduces machinery and other hardware devices to a manufacturer's system growth. Utilizing available information management systems introduces bar code and NC machine technology to the production environment. Tackling common problem areas of material handling breaks open plant-wide efficiency, while phasing in robotics to process orientated tasks gives the small manufacturer a whole new outlook on fundamental technological capabilities. Microcomputer-based communications networking weaves a web through the new factory making sure real-time production becomes a reality.

Advanced manufacturing technologies are not for everyone, but proper planning for them in a logical sequence will inevitably determine the difference between Canadian success or failure on the global manufacturing front.

FIGURE 34

LOGICAL MODEL OF INTEGRATED MANUFACTURING



PART HANDLING MANAGEMENT SYSTEMS

CHAPTER 7: CONCLUSION

The Advanced Manufacturing Systems survey sampled Canada's largest user base of automation, the machine and metalworking industry. Results of the survey have helped develop an original snapshot of our nation's sequential adaptation of new manufacturing technologies. Industry has stated that the proper sequence to systems integration is what holds back Canada's application of new technologies. Using the survey's results of Canada's adaptation of new technologies as a benchmark, a logical model to integrated manufacturing is proposed that will assist manufacturer's transfer of technology into their organizations.

7.1 Summary of Survey Results

Larger manufacturers were found to be the more experienced users of Advanced Manufacturing Technologies averaging 11 introductions, while medium and small firms indicated 7 and 4 technological applications respectively. From the three models established, it is clear that computer-assisted information handling tasks (CAD, CAPP, MRP) have been employed at an earlier rate by the smaller less experienced users of available technology. This result can be contributed to the current developments of computer hardware and software's performance capabilities and user-friendliness. The survey has shown us that the smaller manufacturer has introduced information handling tasks more recently, taking advantage of the computer evolution. Management Information Systems and NC machine technology share the number one and two position of each present group's sequential model. The application of NC/CNC machine technology initially by all sizes of the survey respondents can be contributed to two reasons. The first being the emphasis that all machinery and metalworking industries put on machining operations. The second being the early and on-going development of NC technology, (1960's), having an effect on the ease of application for the user. Interestingly enough, the fundamental concept of group technology for moving information management systems from the office into the factory, has been all but neglected by everyone of the 75 out of 1000 survey respondents. It is difficult to reason why Canadian manufacturers have not adopted group technology into their production facilities. One proposal is possibly the lack of emphasis industry media has put on group technology. The fundamental concept which utilizes plant layout practices and process planning is an important link between initial computer-assisted information management tasks, and factory automation.

Future AMS proposals include an initial push into computer-aided-design by both small and medium firms, coupled with new emphasis on robotics and vision systems. Group Technology only registered in future proposals by the larger industrial group of respondents.

Flexibility, a main attribute of new technologies plays a major role in adapting to market changes, increasing throughput time of new jobs, providing greater total quality, faster setup times, and improved customer service while enhancing the abilities of personnel. Management must appreciate the significance of flexibility in acquiring future growth and competitive market levels, while shedding historical concerns dedicated strictly to reduction in labour costs. The decentralization trend of individual production operations by larger manufacturers emphasizing final preparation and assembly of end-products will continue to put more pressure on Canada's smaller factories. A practical model to technology application is needed to help the small manufacturer to attain a long-term manufacturing success.

7.2 The Author's Proposal For Aiding System Integration

The model proposed by the author focuses initially on organization and standardization of information handling tasks at the management level. Company departments often find themselves using different systems (finance, engineering and manufacturing) regarding crucial areas such as costing, bills of materials and product/process correlation leading to bottlenecks in the arrival of new jobs in the organization. Introducing the computer into these company functions establishes a common language between them and increases the productivity and quality of information management. Many of today's manufacturing technologies and techniques are simply a logical progression of fundamental concepts. One example is group technology which expands upon traditional plant layout techniques linking similarities in process plans with the physical layout of the factory. A second example is Material Requirements Planning, or MRP, combining scheduling, inventory control, and bills of materials functions in a common computer database. The above two examples illustrate that technologies are available to even the smallest of firms, but human interaction is essential to new systems.

Once logical steps of information systems are under control, one may plan for factory automation. The rules are the same, but a variety of automated devices enter the picture. Building upon data management programs such as group technology and computer-aided design, hardware applications of bar code readers and NC machinery designate the logical progression. Rules of organization and standardization hold true for the plant environment as like the office, as attempts to optimize production flow and quality are striven for similar to that of information flow at management levels.

7.3 The Microcomputer's Role in Tomorrow's Advanced Manufacturing System

The realm of the microcomputer's use on the factory floor is diverse, and without considerable planning into its application paralling other new production technologies A slow growth in Canada's manufacturing competitiveness will result. Survey results reveal that domination of large manufacturer's application of NC programming, word processing, quality control and shop floor control functions (order tracking, inventory control, and bills of materials). The microcomputer will in the future act as a communications medium of programming, quality information, design and process changes, part routings, equipment diagnostics and parts availability that shop floor personnel can act on and managers can react to responsively.

7.4 The Future of Canadian Manufacturing

In conclusion, Canadian manufacturers of all sizes are making a dent in technology's armour as the survey results have indicated but without a well-documented framework of system integration into our many in-experienced manufacturing facilities defined by the Logical Model of Integrated Manufacturing, our nation's economy may fall closer towards a service-driven economy. Manufacturing is important to jobs, our intellectual assets including the area of academia, and an entire business entity. It is hoped that the proposals put forward here would assist Canadian industries in better adopting and introducing new technologies for their insured success in the world marketplace.

REFERENCES

1. Alessi, Patrick., Operational MRP vs. Integrated MRP, Production and Inventory Control Management Review, June, 1986, pp. 50-54.

2. Bairstow, Jeffrey., GM's Automation Protocol Helping Machines Communicate, High Technology, November, 1986, pp. 50-59.

3. Berenger, Catherine., Seeking A Route With MRP, Manufacturing Engineering, September, 1986, pp. 49-54.

4. Brown, Allen., Using Communications Standards to Link Factory Automation Systems, Machine Design, August, 1984, pp. 123-126.

5. Burgam, Patrick., Will CAPP Technology Replace the Planner, CIM Technology, Winter, 1984, pp. 25-31.

6. Canadian CAD/CAM Council., Management In Crisis - Implementing CIM in Canada, July, 1986.

7. Cholakis, Peter., Sensors, Robotics Today, April, 1986, pp. 39-43.

8. Devor, Elmer., The Barriers to Acceptance of Change, 1988 ASEE Conference on Engineering Education and Economic Development.

9. Famili, A., Integrated Software Provides Workcell Autonomy, Robotics Today, February, 1987, pp. 62-64.

10. Hagerdon, Homer., Adopting Factory Automation, American Machinist, December, 1985, pp. 54-67.

11. Halligan, Thomas., Integrating Material Handling on the Factory Floor, Production, October, 1986, pp. 62-74.

12. Jaikumar, Ramchandran., Post-Industrial Manufacturing, Harvard Business Review, November, 1986, pp. 69-74.

13. Klopper, Gunter., Using Bar Coding in Shop Floor Management Systems, Manufacturing Engineer, November, 1984, pp. 71-73.

14. Kochen, Anna., The World Scene of AMT, The Industrial Robot, December, 1984, pp. 230-238.

15. Koeller, Richard., Successful Factory Automation Projects Heed Effects on Cultural Systems, Control Engineering, November, 1982, pp. 84-89.

16. Kusiak, Andrew., Interactive Grouping of Machines and Parts, University of Manitoba Industrial Engineering Department, July, 1986.

17. Lasecki,. Robert., Automated Guided Vehicles, CIM Technology, Winter, 1986, pp. 90-94.

18. Majchazak, Ann., A Quantitative Assessment of Changes In Work Activities Resulting From Computer-Assisted-Design, Krannert Graduate School of Management - Purdue, November, 1984.

19. Majchazak, Ann., The Human Side of Factory Automation, Jossey-Bass Publishers; London, 1988.

20. Manitoba Industry, Trade and Technology, The Management of Technological Change in Manitoba, Vol. 4, Automation, Robotics and Information Systems.

21. Mazur, Frank., Personal Computer Series - PC's on the Factory Floor, Electronic Design, August, 1984, pp. 95-107.

22. Myers, Charles., Choosing the best MRP II System, Production Engineering, February, 1986, pp. 62-64.

23. Nelson, Craig., How to Develop a Competitive Manufacturing Strategy, Production,. March, 1986, pp. 37-46.

24. Ontario Ministry of Trade and Technology., The Market for Flexible Automation in Ontario, November, 1985.

25. Petzold, Charles., OS/2 A New Beginning, PC Magazine, April, 1988, pp. 276-280.

26. Richardson, John., Design In the Factory Floor of the Future, Ontario CAD/CAM Centre Report/1986.

27. Robertson, Nickerson Ltd., Utilization of AMT's in the Machinery and Electrical Equipment Sector, Toronto, Ontario, March 1986.

28. Sanford, Brian., Material Handling Systems, Smarter and Faster, Production Engineering, August, 1986, pp. 32-37.

29. Shweinsberg, Hans., The Pace of Automation Picks Up, Canadian Consulting Engineer, February, 1987, pp. 22-25.

30. SME Technical Papers Series.
Data Acquisition on the Factory Floor
Group Technology Gains New Exposure
Distributed Numerical Control

31. Stauffer, Robert., Sensors Control Robot Speed, Production, June, 1987, pp. 36-37.

32. Surtees, Lawrence. ,Dramatic Changes in CAD/CAM Business, The Globe and Mail, March, 1987, pp. C15.

33. Urban, Peter., GT - One Step Closer to Integration - Production, October, 1986, pp. 16-20.

34. Western Opinion Research Inc., Manitoba Manufacturing and Processing Technology, Winnipeg, Manitoba, March, 1985.

35. Waite, Ralph., Planning for Factory Automation, The Industrial and Process Control Magazine, October, 1983, pp. 33-38.

36. Warndorf, Paul., Development and Future Trends in CIM in the U.S.A., International Journal of Technology Management, Vol. 1, November, 1986.

37. Zeidenberg, Jerry., Huge Mainframes Designed to Meet New Demands, The Globe and Mail, March, 1987, pp. C9.

38. Zuech, Nello., Machine Vision, Robotics Today, April, 1986, pp. 35-37.

39. Zymart, Jeffrey., FMS: Curing the Cure All, High Technology, November, 1986, pp. 45-49.

40. 87 Census, Canadian Machinery and Metalworking, May, 1987.