Structural Change and Technology in the Manufacturing Sector

Thomas H. Klier
Federal Reserve Bank of Chicago
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Introduction

For more than a decade the ongoing changes in the manufacturing sector have captured the attention of business executives, analysts, and academics alike. It has become apparent that today's best manufacturing practices differ in many ways from the production system that came to dominate after World War II. In light of these changes it seems appropriate to review the evidence with regard to the extent of structural change as well as possible effects of technology adoption.

This paper first presents and discusses evidence on technology adoption in the manufacturing sector. Special consideration is given to regional effects of implementing best manufacturing practices. The second half attempts to conceptualize the scope and possible effects of the new manufacturing system by means of several examples.

Change in Manufacturing Technology

Evidence

Lean manufacturing refers to a production system that gained widespread attention in the early 1980s. It combines aspects of both craft production, in which skilled labor produced output that was generally very customized, and mass production, where special purpose machinery was substituted for labor to produce identical components in large numbers. The defining principles of lean manufacturing are the pull system, whereby the flow of materials and products through the various stages of production is triggered by the customer (ultimately the end-user, but within a plant this applies to an operation or a process downstream from a previous one), and the idea of continuous improvements to the production process. Implementing that production system works best with emphasis on teamwork on the shopfloor, flexible work rules, integration of skills, low inventories of finished goods and work in process, as well as delegation of quality and quantity objectives to the shopfloor (see e.g. Womack et al. 1990, Bailey and Gersbach 1995). The efforts to improve a plant's manufacturing system are often accompanied by the application of new capital equipment.

But how pervasive has been the introduction of best practice techniques for manufacturing in general? Most of the recent evidence is industry-specific and highly anecdotal. However, two large-scale studies, one for the United States and one for Canada, provide evidence that helps shed some light on this issue. Both Statistics Canada (in 1988) and the U.S. Census Bureau (1988 and 1993) administered surveys of manufacturing technologies in order to measure the extent and type of advanced manufacturing technologies used in their respective country's manufacturing plants. The Statistics Canada study covers 3,952 manufacturing establishments; the Census' data cover 8,336 manufacturing establishments, representing the 2-digit SICs 34 through 38. The information was gathered by way of questionnaire-based surveys with the objective of getting a quantitative measurement of the types of technologies used in manufacturing plants.[1] With this type of data on can ask questions like: To what extent do plants use more than one advanced technology? Are advanced manufacturing technologies implemented at the functional level? How comprehensively are advanced manufacturing technologies used in individual plants?

Both surveys showed the following: the adoption of advanced manufacturing technologies has been widespread across plants and industries, typically involving multiple technologies applied per establishment. While about half the technologies surveyed had been implemented by current users within the last 5 years, adoption varies by industry as well as technology. Figure 1 presents information on the vintage of first implementation among current users by industry for each of the 17 technologies surveyed. Some of the differences across industries reflect different degrees of applicability of a specific technology. For example, the application of robots in the transportation equipment industry (SIC 37) is much more widespread than in any of the other 4 industries studied. Similarly, the same industry leads in the implementation of computer networks between assembler and supplier plants. This is presumably driven by the establishment of closer linkages between auto assemblers and their first-tier supplier companies. In aggregating the information from Figure 1 across industries, Table 1 allows to better observe technology-specific adoption factors. First, it shows a lage variance in current application rates, ranging from about 59% for CAD / CAE and almost 47% for NC / CNC to less than 3% for Automated Storage.[2] Secondly, it also shows different peak application periods for the various subgroups. Most of the current applications of technologies in subgroups Fabrication / Machining, Automated Material Handling, and Sensor-Based Inspection / Testing were implemented more than 5 years ago, while those in subgroups Design and Engineering and Communication and Control were generally implemented most frequently 2–5 years ago.

In terms of plant characteristics, larger plants were found to adopt the technologies surveyed more rapidly than smaller plants; and, important for the Midwest, there was no evidence that younger plants are implementing these technologies at a higher rate (see Table 2; see also Dunne [1994)].[3] Rees et al. (1986) suggest as an explanation of the fact that older plants are introducing these technologies at least as quickly as plants of recent vintage that most of the new technologies are discrete units that can be introduced into a plant in an incremental fashion

These results indicate that advanced manufacturing techniques are indeed reshaping manufacturing on a broad scale. In fact, by linking the results of the survey on manufacturing technology to longitudinal Census data, researchers at Statistics Canada were able to track the technology adoption of specific establishments over time. In assessing the success of new technologies they found that plants that used advanced manufacturing technology experienced increases in market share relative to non-users (this effect was especially prominent for those plants adopting several combinations of technologies), increases in relative labor productivity, and higher relative wage rates. In short, establishments that innovate seem to do better in the market place.[4]

Regional Evidence

To what extent do application rates of best manufacturing practices differ across regions? For example, the Midwest with its concentration of manufacturing industries undoubtedly has benefited from the application of these new manufacturing practices.[5] However, recent evidence on regional differences in the implementation of advanced manufacturing techniques is scant; see for example, Knudsen et al. (1991) for a survey of Midwest plants. Little et al. (1996) try to infer regional information from the Census'

Figure 1 Implementation of Technology Among 1993 Users, by SIC

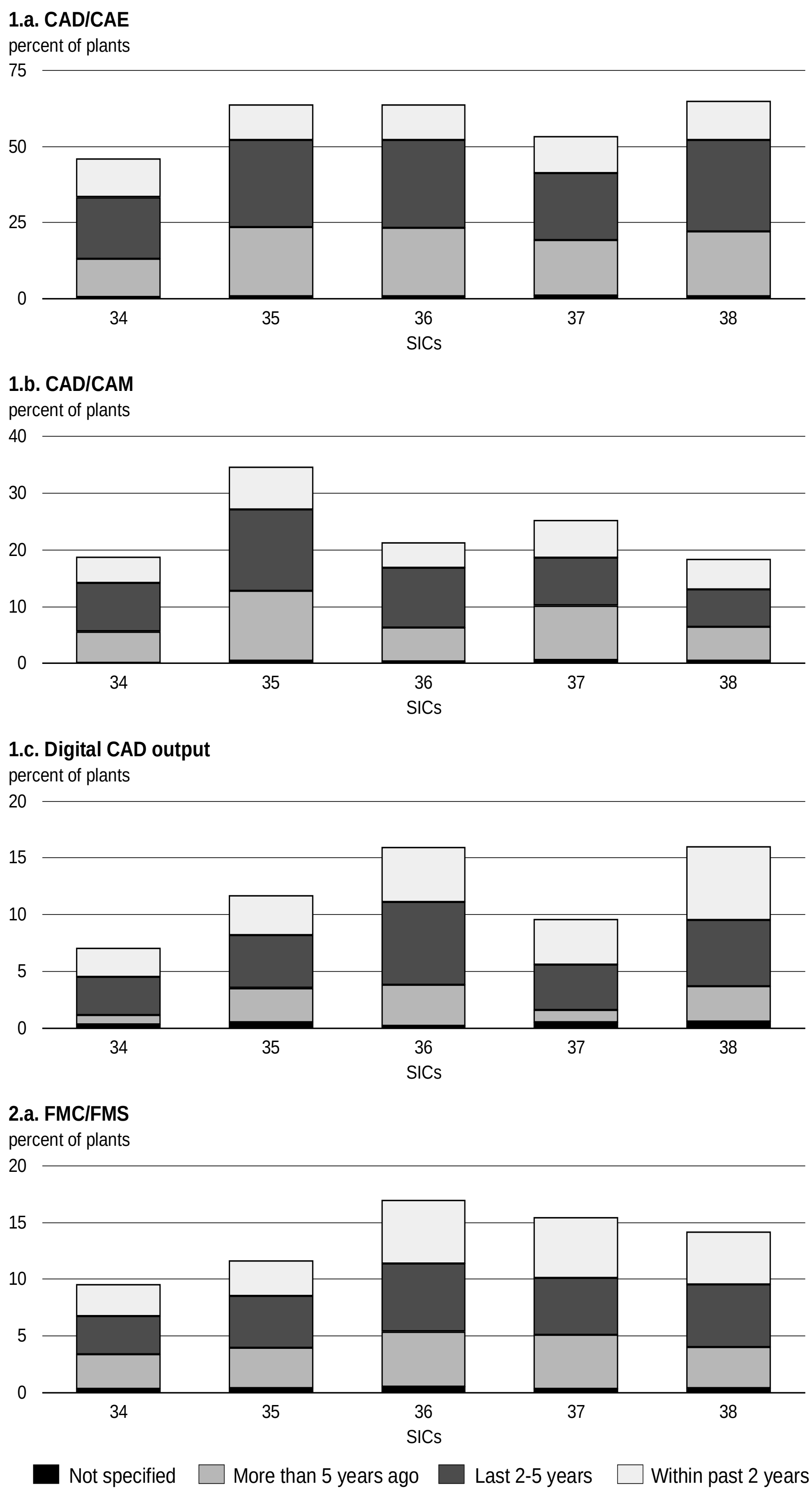
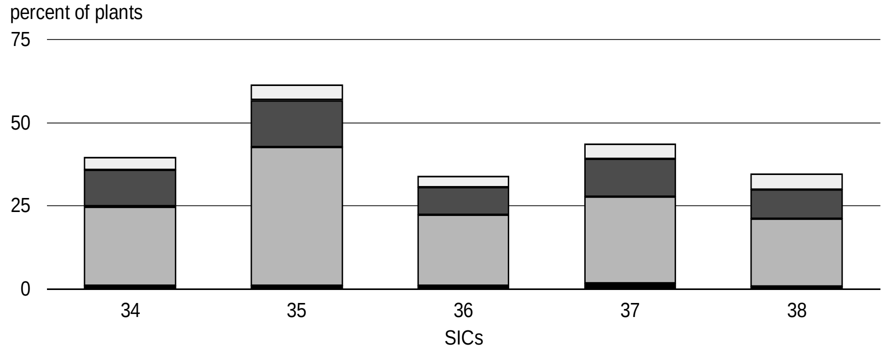
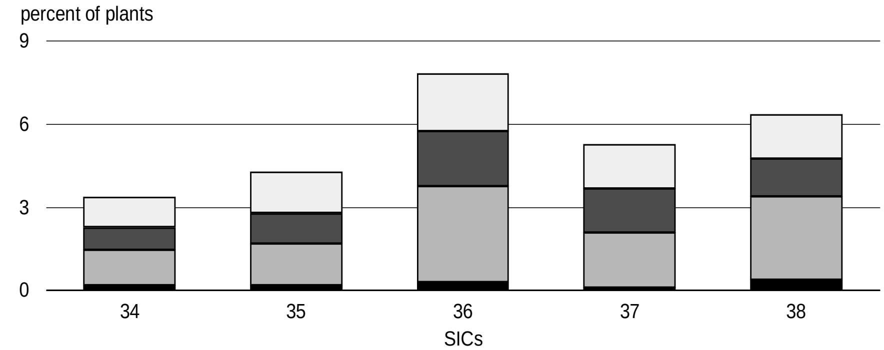


Figure 1 *(continued)* Implementation of Technology Among 1993 Users, by SIC

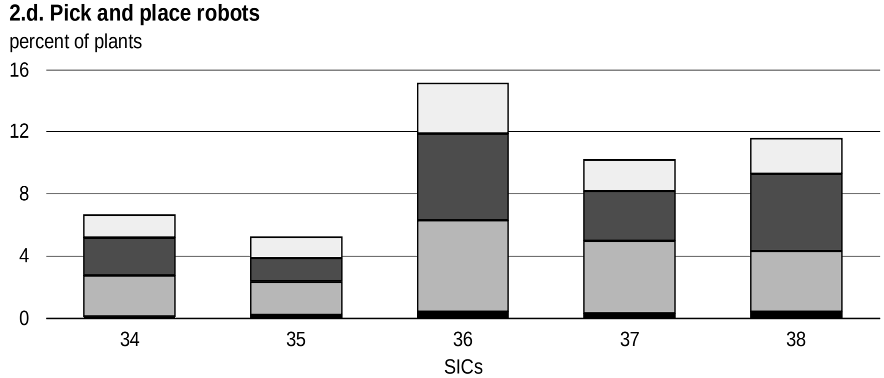
2.b. NC/CNC machines



2.c. Materials lasers



2.d. Pick and place robots



2.e. Robots

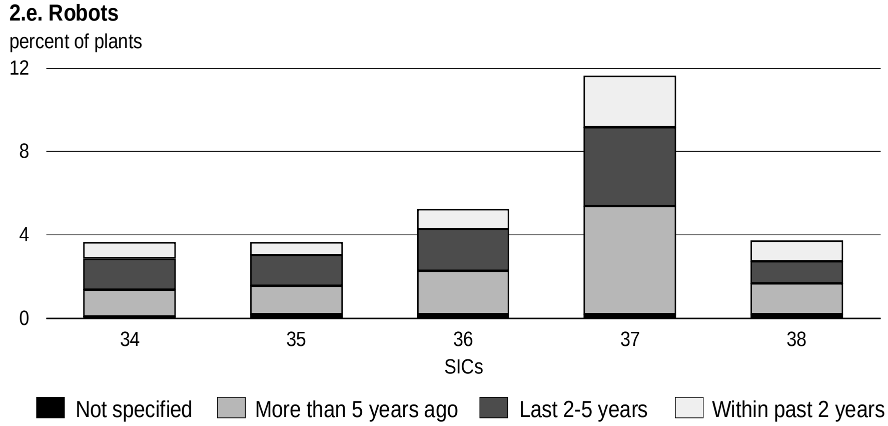
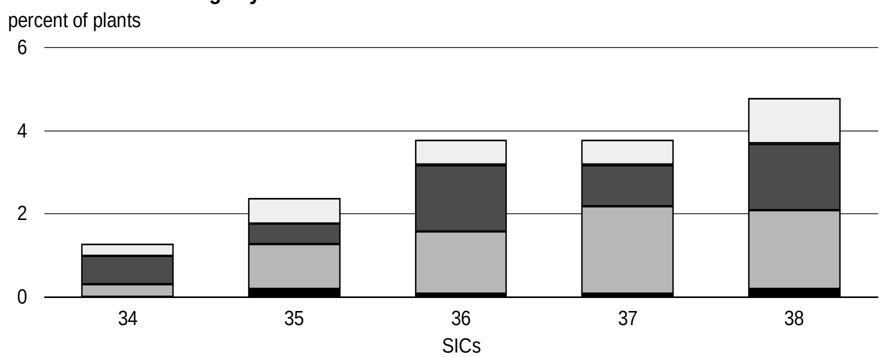
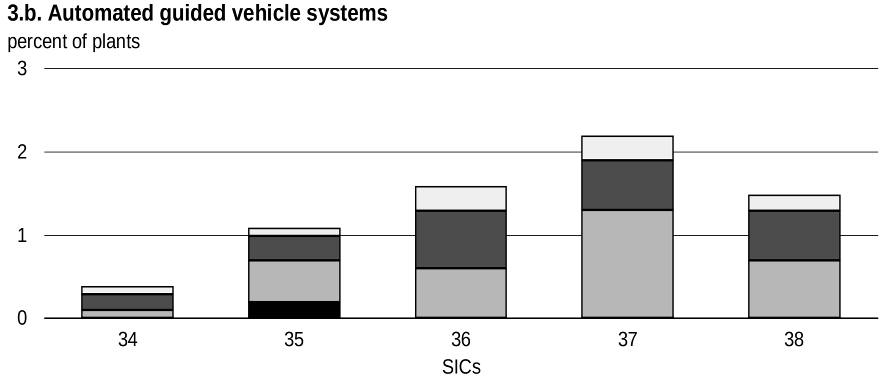


Figure 1 *(continued)* Implementation of Technology Among 1993 Users, by SIC

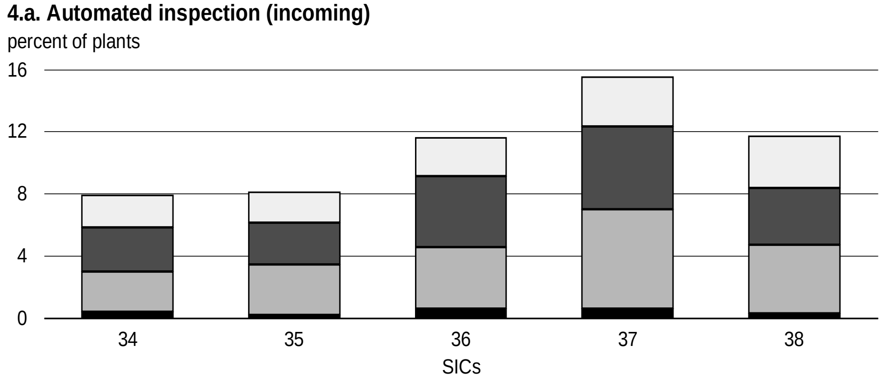
3.a. Automated storage systems



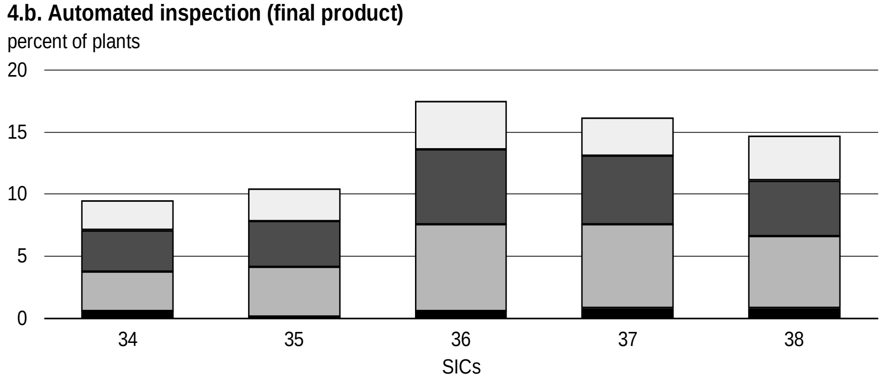
3.b. Automated guided vehicle systems



4.a. Automated inspection (incoming)



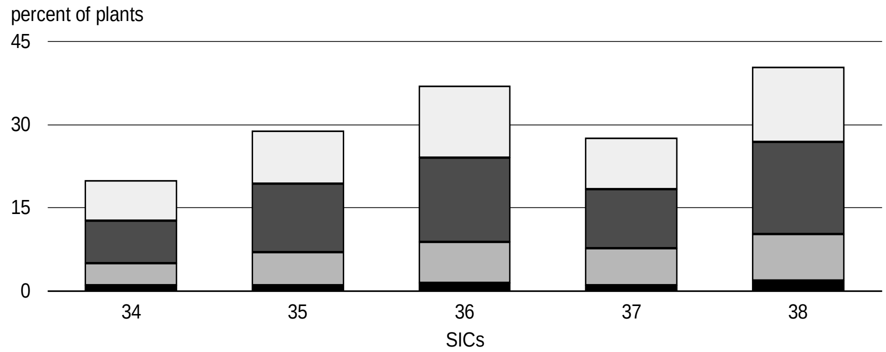
4.b. Automated inspection (final product)



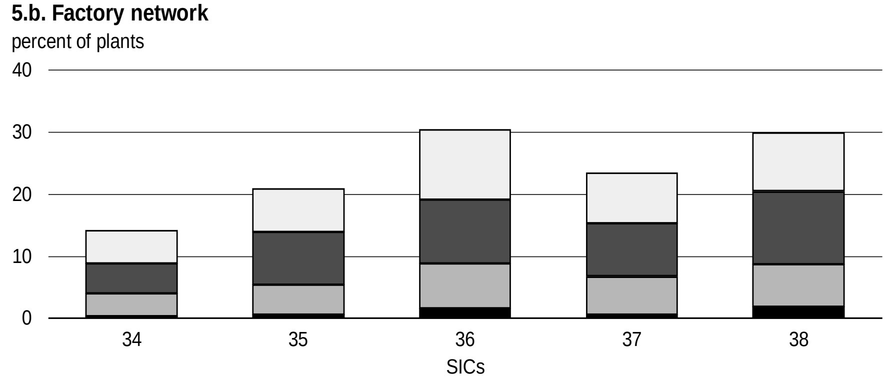
Not specified More than 5 years ago Last 2-5 years Within past 2 years

Figure 1 *(continued)* Implementation of Technology Among 1993 Users, by SIC

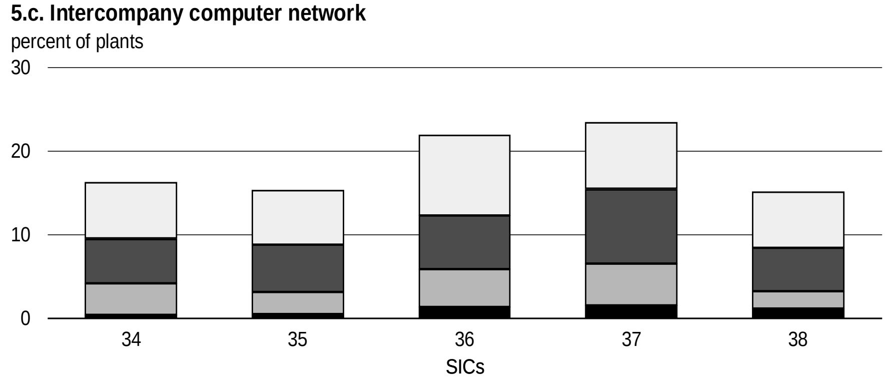
5.a. Technical data network



5.b. Factory network



5.c. Intercompany computer network



5.d. Programmable controllers

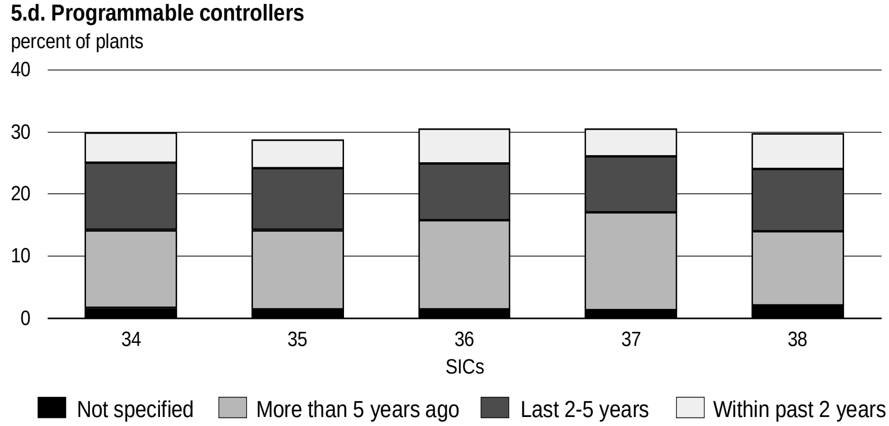
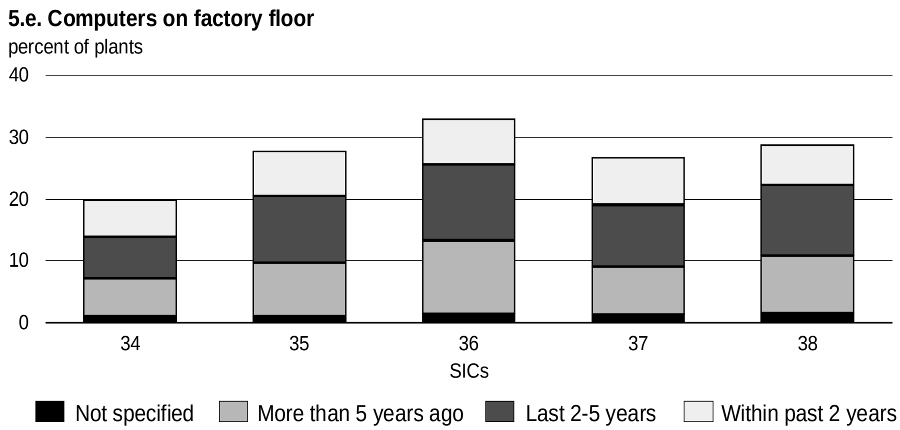


Figure 1 *(continued)* Implementation of Technology Among 1993 Users, by SIC



Note: See Appendix for definitions of technologies.
Source: U.S. Dept. of Commerce, 1994.

Survey of Manufacturing Technology data by using regionally normalized sample weights to construct geographic estimates of technology adoption. They investigate the question whether there is an effect of proximity on technology use. The authors find proximity to other users of technolgy to be associated with higher rates of technology adoption. This effect is robust to the inclusion of industry and other plant characteristics to the model specifications. Rees et al. (1986) provide some interesting regional breakdowns of the results of their own large scale survey. They find a complex pattern of regional differences in the adoption of new technologies to exist. Based on an average ranking, they show the dominance of the manufacturing belt as a user of the latest available process technology. In addition, they find the small, single plant firms in the northeast and north central Census regions to exhibit far greater adoption rates for numerically controlled and computer numerically controlled machine tools than the southern and western Census regions. That leads them to conclude that more advanced production technologies are being introduced in the higher skill, higher wage areas of the industrial Midwest, while fewer of these technologies (or less advanced versions) are being introduced to a lesser degree in the lower wage, lower skill markets of the South and West.

What Makes Lean Manufacturing Effective?

The evidence summarized above is important as a first step in gauging the size of restructuring and productivity-enhancing measures taken by businesses. However, one needs to keep in mind that surveys of the type of technology used in plants may not fully characterize the process of technical diffusion. By relying on purely quantitative measures of technologies in use in assessing the effect of lean manufacturing, we may miss

Table 1 Share of Establishments Using Selected Technologies in 1993, by Time of Adoption (Percent)

Technology	Establishments Using in 1993	Adopting in Past 2 Yrs.	Adopting in Past 2–5 Yrs.	Adopting 5+ Yrs. Ago
Design and Engineering				
CAD or CAE	58.8	12.4	26.2	19.4
CAD to Control Machines	25.6	5.9	10.9	8.4
CAD Used in Procurement	11.3	3.8	4.8	2.3
Fabrication/Machining				
Flexible Manuf. Cells/Systems	12.7	3.9	4.7	3.8
NC or CNC Machines	46.9	4.4	11.7	29.6
Materials Working Lasers	5.0	1.5	1.3	2.0
Pick and Place Robots	8.6	1.9	3.0	3.4
Other Robots	4.8	.9	1.8	1.9
Automated Material Handling				
Automatic Storage/Retrieval	2.6	.5	.9	1.1
Automatic Guided Vehicle Systems	1.1	.2	.4	.5
Sensor-Based Inspection/Testing				
For Incoming or In-Process Materials	9.9	2.4	3.5	3.6
For Final Product	12.5	3.0	4.3	4.7
Communication and Control				
LAN for Technical Data	29.3	10.0	12.0	6.0
LAN for Factory Use	22.1	7.8	8.2	5.3
Intercompany Computer Network	17.9	7.4	6.1	3.6
Programmable Controllers	30.4	5.2	10.2	13.4
Computers Used to Control Factory Floor	26.9	7.1	10.0	8.6

Note: See Appendix for definitions of technologies.
Source: U.S. Dept. of Commerce, 1994.

crucial linkages inherent in this production system.[6] Is there evidence for well-traveled technology adoption paths, along which certain seed technologies pave the way for continued and widespread application of improved manufacturing processes within the plant? For example, a recent study administered by the National Association of Manufacturers suggests computer aided design to be a precursor technology to computer numerically controlled machines and computer aided manufacturing.[7]

Table 2 Application of Advanced Manufacturing Technologies by Employment Size and Age of Plant

	Technology								
	CAD/ CAE	CAD/ CAM	Digital CAD output	FMCs FMS	NC/CNC machines	Materials lasers	Pick & place robots	Robots	Autom. storage systems
Plant Employment	(- - - - - -				% of plants using				- - - - - -)
20-99	49.5	22.0	8.9	7.6	41.4	2.8	3.6	1.3	0.6
100-499	76.4	30.5	14.1	21.4	56.5	7.5	15.9	9.5	4.1
500+	87.2	48.1	30.3	40.1	67.1	22.6	42.8	29.6	23.6
Age of Plant	(- - - - - -				% of plants using				- - - - - -)
Less than 5 years	63.5	21.1	12.5	13.4	38.4	4.0	8.1	3.1	2.5
5-15	62.0	26.4	12.9	13.3	47.9	4.9	8.7	4.2	2.5
16-30	64.4	29.0	12.7	13.4	53.7	6.2	9.4	5.2	2.5
Greater than 30	63.1	31.4	10.6	15.2	57.3	5.7	10.8	7.7	4.0

Table 2 *(cont'd)* Application of Advanced Manufacturing Technologies by Employment Size and Age of Plant

	Technology							
	Autom. guided Vehicle Syst.	**Autom. inspection (incoming)**	**Autom. inspection (final prod)**	**Tech. data network**	**Factory network**	**Interco. computer network**	**Programm. controllers**	**Comp. fact. floor**
Plant Employment	(- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	% of plants using	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -)
20-99	0.3	5.5	7.9	20.5	14.6	12.0	20.5	18.8
100-499	1.3	16.4	20.0	44.1	34.3	28.4	49.1	41.8
500+	11.8	39.1	38.8	72.5	63.4	47.1	69.8	62.8
Age of Plant	(- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	% of plants using	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -	- - - - - - - - -)
Less than 5 years	0.5	8.0	11.0	32.9	22.7	15.0	25.6	27.5
5-15	1.0	9.9	13.3	32.8	25.0	18.0	30.4	28.2
16-30	1.4	10.6	13.3	30.0	22.6	20.5	33.1	29.4
Greater than 30	1.7	13.5	15.6	30.3	24.0	22.0	39.1	30.7

Note: See Appendix for definitions of technologies.
Source: U.S. Department of Commerce, 1994.

In order to understand the returns from new technology one really needs to analyze its application in the context of the management and goals of an entire plant. The issues are complex, as one has to adequately deal with the idiosyncracies of technology application.[8] Furthermore, case studies suggest that soft innovations to improve the organization—as opposed to the degree of automation—of the production process can result in very large increases in productivity.[9] Bailey and Gersbach (1995) report on the results of comparing the productivity of nine industries in three countries: innovations, such as design for manufacturing and work place organization turned out to be more important than traditional determinants, such as capital intensity and scale, in explaining why operations in one country's industry are more productive than those in the same industry in another country. The following examples serve as illustrations of this point.

- In 1982 GM closed its auto assembly plant in Fremont, California; it had abysmal productivity and very confrontational management-labor relations. Two years later the plant reopened; this time as a Toyota-GM joint venture called NUMMI (New United Motor Manufacturing Inc.). Eighty-five percent of its hourly workers had worked in the plant before GM shut it down. However, within two years, NUMMI's productivity was higher than that at any other GM plant and the cars produced had the lowest defect rates of GM products made in North America. According to Adler (1993), the main factor in turning around that plant was not hard technology, but a management approach that combined scientific management with participatory labor-management techniques.
- A recent case study of 61 paper manufacturing plants in North America strongly suggests that people play at least as important a role as any technical factor in improving flexibility at the plant level (see Upton 1995). According to that study, in implementing best manufacturing practices, management must first decide on the goal of the implementation: improved product, production, or process flexibility. Each of these goals requires different emphases and adjustments.[10] Second, management must set rewards and incentives complementary to achieving that objective. For example, a practice of continuing to reward workers for maximum capacity utilization and output per hour may work well in a plant that is supposed to achieve economies of scale, but in the context of striving for improved flexibility, appropriate management incentives might be focusing on reducing changeover and/or lead times, and increasing process range.

  A survey of plant managers by Statistics Canada confirmed the relevance of organizational and management issues in the context of technology implementation and adoption: Difficulties related to organizational change ranked highest among impediments to technical acquisition, even above issues such as skill shortages and labor training needs.[11]
- Finally, the case of Golden State Tanning, a supplier of leather to the auto industry, documents the effects of changes in management practice and production layout.[12] The company's business, the production of leather, is highly labor-intensive as the cow hides, of which the leather is made, need to be processed individually. Before the company introduced a lean manufacturing production system it relied on a "push-system" for order scheduling. Each cutter cut complete sets (a set is the sum of all the

various pieces needed to cover an auto seat in leather). At the end of the production process a very detailed inspection of the final product was performed. The process flow on the factory floor was inefficient, and consequently, large inventories of cut leather were held (about 600,000 pieces).

After thoroughly examining the existing production system, a new approach was implemented. It features work teams to work on continuous improvements to the production system, and, to facilitate the process flow, a pull system, whereby orders are tracked downstream by means of "kanban" cards. The one change leading to the most dramatic improvements was to establish cutting teams instead of having each individual cut complete sets. Within the team each person now cuts only one piece of a set. The teams also are responsible for performing quality control functions, whereas under the old system the inspection of cut pieces used to be done separately, often with a week's delay of cutting. The work loads were leveled, which avoided "cutting ahead". These changes were achieved within existing building structures that were often very old, and, due to the existence of multiple stories within the plant, presented difficult challenges for optimizing the material flow. However, the changes to the production system were implemented without new capital expenditures—especially without building new "greenfield" plants. Table 3 summarizes the improvements to production efficiency for the case of one of the company's four plants.

To each of these examples applies the notion that restructuring with the goal of implementing best practices requires an ongoing process rather than a one-time adjustment.[13] The auto industry provides evidence of that.[14] Just recently, a follow-up study by MIT's International Vehicle Program released numbers on how the productivity of auto assembly plants has changed between 1989 and 1993/1994.[15] According to the recent data, some North American plants of U.S. auto assemblers have nearly caught up with the best Japanese plants: The best U.S. assembly plant requires 14 hours to assemble a vehicle, compared with 13 hours for the best transplant and 12 hours for the

Table 3 Change Due to Implementation of Lean Manufacturing System at a Leather Processing Plant

Plant Performance	1992	1995
Quality defects	.71%	.05%
Process inventory (pieces)	112,000	36,000
Production lead time	60 days	9 days
Cutting lead time	264 hrs	2 hrs
Cutting productivity per carton*	43 hrs	17 hrs
Lost time accidents	242	2

*A carton consists of 10 sets of cut leather pieces.
Source: Sean Traynor, presentation at the Second Annual Lean Manufacturing Conference, Ann Arbor, Michigan, May 15, 1996.

Table 4 Auto Assembly Plant Productivity

Sample	Hours per Vehicle 1989	1993/94	Percent improvement
6 Japanese plants in Japan	15.6	14.7	5.8
3 Japanese plants in N.A.	22.6	18.2	19.5
11 Big Three plants in N.A.	24.1	20.0	17.0

Note: N.A. represents North America.
Source: Diana Kurylko, "Assembly-hour gap closing," *Automotive News*, March 4, 1996, p. 1

best assembly plant in Japan. On average, the improvements are not as dramatic, yet still sizable (see Table 4). Table 4 also shows that "best practice" is a moving target; according to the study, those plants that most improved their productivity were Japanese transplants in North America.

Conclusion

Several large scale surveys of manufacturing plants document the widespread application of advanced manufacturing technologies. A set of industry studies and firm-specific analyses strongly suggests the importance of soft, that is, organizational, factors in effectively implementing the new technologies.

How does the adoption if manufacturing technology affect regional fortunes? What do we know of regional rates of adoption of the new manufacturing technologies? There is strong evidence that advanced manufacturing technologies have been widely applied. However, little is known on how the adjustment to new manufacturing techniques plays out on the regional level. An up-to-date regional breakdown of available data as well as comparisons with manufacturing centers in Europe and Japan are necessary to improve our understanding of these adjustment processes in varying geographies, cultures, and legal frameworks.

What lessons can we draw for the role of regional development policies? The evidence presented above seems to suggest a focus on the issues related to technology implementation. Since the incidence of advanced manufacturing technology usage is either independent of plant age or increases in it, there seems to be little need to focus on attracting greenfield plants in order to further the competitiveness of a region's industries. Innovation and technology networks might be more effective in transferring technology. Is the transfer of information about new technologies and management practices adequately provided through market mechanisms or is there a role for public or private-public partnership efforts? To what extent do advanced manufacturing techniques require the skills of the existing workforce to be upgraded? These issues need to be addressed in assessing the effects of implementing advanced manufacturing technology.

Appendix: Advanced Manufacturing Technologies, Definition of Terms

1. Design and Engineering

   a. *Computer Aided Design (CAD) and/or Computer Aided Engineering (CAE)*—Use of computers for drawing and designing parts or products and for analysis and testing of designed parts or products.

   b. *Computer Aided Design (CAD)/ Computer Aided Manufacturing (CAM)*—Use of CAD output for controlling machines used to manufacture the part or product.

   c. *Digital Data Representation*—Use of digital representation of CAD output for controlling machines used in procurement activities.

2. Fabrication/Machining and Assembly

   a. *Flexible Manufacturing Cells (FMCs)*—Two or more machines with automated material handling capabilities controlled by computers or programmable controllers, capable of single path acceptance of raw material and single path delivery of finished product.

   Flexible Manufacturing Systems (FMS)—Two or more machines with automated material handling capabilities controlled by computers or programmable controllers, capable of multiple path acceptance of raw material and multiple path delivery of finished product. A FMS also may be comprised of two or more FMCs linked in series or parallel.

   b. *NC/CNC Machines*—A single machine either numerically controlled (NC) or computer numerically controlled (CNC) with or without automated material handling capabilities. NC machines are controlled by numerical commands punched on paper or plastic mylar tape. CNC machines are controlled electronically through a computer residing in the machine.

   c. *Materials Working Laser(s)*—Laser technology used for welding, cutting, treating, scribing, and marking.

   d. *Pick & Place Robot(s)*—A simple robot, with one, two, or three degrees of freedom, which transfers items from place to place by means of point-to-point moves. Little or no trajectory control is available.

   e. *Robot(s)*—A reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized device through variable programmed motions for the performances of a variety of tasks.

3. Automated Material Handling

   a. *Automated Storage and Retrieval Systems (AS/RS)*—Computer controlled equipment providing for the automatic handling and storage of materials, parts, subassemblies, or finished products.

   b. *Automated Guided Vehicle Systems (AGVS)*—Vehicles equipped with automatic guidance devices programmed to follow a path that interfaces with work stations for automated or manual loading and unloading of materials.

4. Automated Sensor-Based Inspection and/or Testing Equipment

   Automated Sensor-Based Inspection and/or Testing Equipment—Includes automated sensor-based inspection and/or testing performed on incoming or in-process materials, or performed on the final product.

5. Communications and Control

   a. *Technical Data Network*—Use of local area network (LAN) technology to exchange technical data within design and engineering departments.

   b. *Factory Network*—Use of local area network (LAN) technology to exchange information between different points on the factory floor.

   c. *Inter-company computer network*—Use of network technology to link subcontractors, suppliers, and/or customers with the plant.

   d. *Programmable Controller(s)*—A solid state industrial control device that has programmable memory for storage of instructions, which performs functions equivalent to a relay panel or wired solid state logic control system.

   e. *Computer(s) Used for Control on the Factory Floor*—Exclude computers imbedded within machines, or computers used solely for data acquisitions or monitoring. Include computers that may be dedicated to control but are capable of being programmed for other functions.

Footnotes

[1] All of the advanced manufacturing technologies involve applying the computer to various facets of the production process. For definitions of the 17 technologies surveyed by the Census studies see Appendix.

[2] The *Survey of Manufacturing Technology* does not distinguish NC from CNC machines. NC machines have been widely used for a relatively long time (see Oliner 1996).

[3] These results corroborate findings of a large scale survey undertaken in 1982. Rees et al. (1986) surveyed nearly 4,000 manufacturing plants on their application of advanced production technologies in the U.S. (It turns out, that of the 8 technologies they analyzed, 7 are also included in the later Census surveys). The authors report that a) plants affiliated with multiplant corporations have much higher rates of technology adoption than single plant firms, b) larger plants show consistently higher rates of technology adoption rates than smaller plants, and c) older plants use new process technologies more frequently than newer ones.

[4] See Baldwin et al. (1994). See also McGuckin et al. (1995) who suggest that well-managed plants adopt new technologies, not that new technologies clearly improve plant performance.

[5] In a recent paper Hervey and Strauss (1996) suggest that the export success of the Midwest's manufacturers was not as much as commonly thought supported by a declining dollar. That, in turn, suggests a relatively strong contribution of restructuring efforts in the region's manufacturing plants.

[6] See Beede et al. (1996) who examine how plant performance is associated with specific technology combinations. They find a greater degree of variation in relationships between specific technology combinations and plant performance than earlier studies utilizing information on the number of technologies adopted.

[7] See Swamidass (1994).

[8] See for example, David (1990), who reports on the timing of the productivity effects of installing electricity around the turn of the century. The author reports as one of the key reasons why it took 40 years for the application of electricity to yield significant productivity gains in the country's plants and businesses that even when firms had first installed electricity, it still took them a long time to learn how to organize their factories around electric power and to take advantage of its flexibility.

[9] See Bailey and Gersbach (1995) p. 346.

[10] Product flexibility is defined as the ability to quickly change from making one product to making another; production flexibility is defined as the ability to quickly change production volumes for one product; and process flexibility is defined as the ability to increase the range of products.

[11] Remarks by John Baldwin at the Midwest Assessment workshop "The Midwest Economy: Structure and Performance," Chicago, February 13, 1996, in "The Midwest Economy: Structure and Performance," *Assessing the Midwest Economy Workshop Summary Series*, No. 2, Federal Reserve Bank of Chicago, 1996.

[12] See Traynor (1996).

[13] For a more general discussion and a thorough analysis of the process of competition over time, see Baldwin (1995). It documents the central role that mobility and turbulence play within the North American industrial structure.

[14] The auto industry frequently serves as the showcase for the implementation of best manufacturing practices and its effects on competitiveness (see for example Blumenstein et al. 1996). However, by no means is the implementation of advanced manufacturing restricted to that industry. For example, USX Corp.'s giant Gary Works, just outside Chicago, today employs only a quarter of the work force it did in 1970, yet it now produces more steel than it did then.

[15] The original study resulted in the publication of the book *The machine that changed the world*, by Womack et al. (1990).

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