Science, Innovation and Electronic Information Division

RESEARCH PAPER

PATTERNS OF ADVANCED MANUFACTURING TECHNOLOGY (AMT) USE IN CANADIAN MANUFACTURING: 1998 AMT Survey Results

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Patterns of Advanced Manufacturing Technology (AMT) Use in Canadian Manufacturing:
1998 AMT Survey Results

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The Science and Innovation Information Program

The purpose of this program is to develop **useful indicators of science and technology activity** in Canada based on a framework that ties them together into a coherent picture. To achieve the purpose, statistical indicators are being developed in five key entities:

- **Actors**: are persons and institutions engaged in S&T activities. Measures include distinguishing R&D performers, identifying universities that license their technologies, and determining the field of study of graduates.
- **Activities**: include the creation, transmission or use of S&T knowledge including research and development, innovation, and use of technologies.
- **Linkages**: are the means by which S&T knowledge is transferred among actors. Measures include the flow of graduates to industries, the licensing of a university's technology to a company, co-authorship of scientific papers, the source of ideas for innovation in industry.
- **Outcomes**: are the medium-term consequences of activities. An outcome of an innovation in a firm may be more highly skilled jobs. An outcome of a firm adopting a new technology may be a greater market share for that firm.
- **Impacts**: are the longer-term consequences of activities, linkages and outcomes. Wireless telephony is the result of many activities, linkages and outcomes. It has wide-ranging economic and social impacts such as increased connectedness.

The development of these indicators and their further elaboration is being done at Statistics Canada, in collaboration with other government departments and agencies, and a network of contractors. Prior to the start of this work, the ongoing measurements of S&T activities were limited to the investment of money and human resources in research and development (R&D). For governments, there were also measures of related scientific activity (RSA) such as surveys and routine testing. These measures presented a limited picture of science and technology in Canada. More measures were needed to improve the picture.

Innovation makes firms competitive and we are continuing with our efforts to understand the characteristics of innovative and non-innovative firms, especially in the service sector that dominates the Canadian Economy. The capacity to innovate resides in people and measures are being developed of the characteristics of people in those industries that lead science and technology activity. In these same industries, measures are being made of the creation and the loss of jobs as part of understanding the impact of technological change.

The federal government is a principal player in science and technology in which it invests over five billion dollars each year. In the past, it has been possible to say only *how much* the federal government spends and *where* it spends it. Our report **Federal Scientific Activities, 1998 (Cat. No. 88-204)** first published socio-economic objectives indicators to show *what* the S&T money is spent on. As well as offering a basis for a public debate on the priorities of government spending, all of this information has been used to provide a context for performance reports of individual departments and agencies.

As of April 1999, the Program has been established as a part of Statistics Canada's Science, Innovation and Electronic Information Division.

The final version of the framework that guides the future elaboration of indicators was published in December, 1998 (**Science and Technology Activities and Impacts: A Framework for a Statistical Information System,** Cat. No. 88-522). The framework has given rise to **A Five-Year Strategic Plan for the Development of an Information System for Science and Technology** (Cat. No. 88-523).

It is now possible to report on the Canadian system on science and technology and show the role of the federal government in that system.

Our working papers and research papers are available at no cost on the Statistics Canada Internet site at http://www.statcan.ca/cgi-bin/downpub/research.cgi?subject=193.

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Executive Summary

The *1998 AMT Survey of Advanced Technologies in Canadian Manufacturing*, conducted by Statistics Canada, covers the use and planned use of 26 Advanced Manufacturing Technologies (AMT) at the establishment level. Additional information was obtained on a wide range of factors that could influence AMT use. The questionnaires were sent to a sample of 3,757 manufacturing plants with more than 10 employees. Responses were obtained from 3,702 plants for a response rate of 99.5%. The results given below are weighted to represent the distribution of manufacturing plants across Canada.

76% of manufacturing plants used at least one AMT in 1998, compared to a third in 1993. The percentage of plants that use five or more AMTs has increased from 14% in 1989 to 46%.

Most of the expected growth in AMT use over the next two years is due to the adoption of new types of AMTs by plants that currently use AMTs. Very little growth in AMT use is expected from the adoption of AMTs by plants that currently do not use any AMTs.

The average number of different AMTs in use increases with plant employment from 3.8 AMTs for plants with 10 to 49 employees to 12.8 AMTs for plants with over 250 employees. The percentage of plants that plan to adopt a new type of AMT within two years also increases with plant size, from 69% of current AMT users with 10-49 employees to 81% of current users with over 250 employees.

The type of production system used by the plant has a significant influence on the number of AMTs in use and the results of AMT use. AMT use rates are highest among plants in the high value-added discrete parts engineering sectors, such as machinery and transport equipment.

Of the 26 AMTs covered in the survey, 9 are 'mature'. These AMTs have above average adoption rates and applications in most manufacturing sectors. They are also relatively simple to implement. Of note, 17% of the plants only use mature AMTs.

Foreign-owned plants use an average of 7.9 AMTs compared to 4.9 AMTs in Canadian-owned plants. However, part of the higher use rates among foreign plants is due to the fact that they are larger and more likely to be part of a multi-plant firm than domestically-owned plants.
There is a significant and positive correlation between the number of information sources cited and AMT use, suggesting that a diversity of information sources plays an important role in adoption. The use of information sources varies by plant size, but small plants do not use different information sources – they are simply less likely to cite each one of them.

The internal capabilities of a plant are an important factor in its patterns of AMT use. AMT adoption rates increase with the R&D capabilities of the controlling firm. Firms that only perform product R&D adopt fewer AMTs than firms with process R&D capability. Similarly, the methods that plants use to introduce AMTs have a strong effect on the rate of AMT adoption. AMT adoption rates are lower among plants that can only purchase AMTs off-the-shelf or license AMTs than plants that are capable of customizing or developing AMTs. Almost three times as many plants that only obtain AMTs off-the-shelf or via licensing only use mature AMTs.

More small plants than large plants report that small markets, high equipment costs, and skills shortages are obstacles to AMT use.

Two measures of AMT use were analysed using multivariate regression: the percentage of total investment in machinery and equipment in the previous three years that was spent on AMTs (the investment share) and plans to adopt one or more new types of AMTs within the next two years. These regressions provide an evaluation of the determinants of AMT use. The main results are as follows.

- Investment in the previous three years has the most pronounced influence of all variables on planned use by current AMT users. Plants with high levels of investment are over five times more likely to adopt another AMT than plants that have zero investment in AMTs. This result indicates the importance of learning-by-using and learning-by-doing in developing internal capabilities to adopt, implement, and manage AMTs.
- Compared to firms with no R&D capabilities, in-house R&D capabilities at the level of the firm decreases AMT investment shares while the use of contract or occasional R&D increases investment shares. Similarly, for small plants, in-house development capabilities at the plant level decrease investment shares. One explanation is that in-house capabilities reduce costs, thereby decreasing the share of investment in AMTs.
- Skill shortages increase AMT investment shares and the probability of adopting a new type of AMT. This suggests that skill shortages increase costs, but they do not prevent plants from acquiring new AMTs. A lack of technical support from vendors decreases the probability that a plant will adopt a new AMT and it also increases investment shares. These results indicate that a lack of technical support is a more serious obstacle than skill shortages.
- The regression analyses for planned adoption of a new type of AMT show that several factors that correlate with both the incidence and intensity of AMT use are also determinants of future AMT adoption. These factors include plant size, production system, and foreign ownership.
- Indicators of internal capabilities, such as past investment, R&D performance at the firm level, and the ability at the plant level to develop AMTs, all increase the probability of adoption.
- The role of competition is complex. Competition, measured by the number of competitors, consistently increases AMT investment shares, but too much competition decreases the probability of future adoption for current users of AMTs, although it increases the probability that non-users will adopt.
- There is very little difference between small plants and all plants in the factors that affect the probability of adopting a new AMT.

Environmental factors such as several obstacles to AMT use, shortages of skilled labour, and the number of competitors, appear to play less of a role in AMT adoption than internal capabilities within the plant or firm. As AMT adoption becomes more prevalent, the plant’s internal capabilities could play an increasingly pivotal role in the successful use of AMTs.

The past decade has seen a major technological transition in Canadian manufacturing, from conventional production to computer- and microelectronics-based manufacturing. This study has found that many of the factors correlated with AMTs are similar to those reported in other studies.

Yet, some of the results suggest that the relative importance of some factors could be changing over time. As AMT adoption becomes more prevalent, plant size could be a less important determinant of use. Skills shortages also seem to figure less prominently than in earlier surveys. On the other hand, the plant's internal capabilities could be playing an increasingly pivotal role as the use of multiple AMTs becomes more prevalent.

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Acronyms

AI: Artificial intelligence
AGV: Automatically guided vehicle
AS/RS: Automated storage and retrieval systems
ATC: Automatic tool changer
CAD: Computer-aided design
CAE: Computer-aided engineering
CAM: Computer-aided manufacturing
CAPP: Computer-aided process planning
CM: Cellular manufacturing
CMM: Coordinate measurement machine
CNC: Computerized numerical control
DfMA: Design for Manufacturing and Assembly
DRP: Distribution resource planning
EDI: Electronic data interchange
EDM: Electrical discharge machining
EIS: Executive information system
EOQ: Economic order quality
ERP: Enterprise resource planning
FEA: Finite element analysis
FMC: Flexible manufacturing cells
FMS: Flexible manufacturing system
HSM: High speed machining
ISO: International Standards Organization
JIT: Just-in-time
KBS: Knowledge-based systems
MES: Manufacturing execution system
MHS: Material handling system
MRP I: Materials requirements planning
MRP II: Manufacturing resources planning
NC: Numerical control
PDM: Product data management
QFD: Quality function deployment
RPS: Rapid prototyping system
SCADA: Supervisory control and data acquisition
SPC: Statistical process control
SQC: Statistical quality control
TOC: Theory of constraints
VP: Virtual prototyping
WIP: Work in progress

1 Introduction

The use of advanced manufacturing technology has become a critical measure of technological capability in modern industrial economies. By increasing manufacturing productivity and opening new market opportunities, the diffusion of advanced manufacturing technologies (AMTs) generates economy-wide benefits. Knowledge of what influences AMT use can thus help to build a stronger economy.

This report presents the results of an analysis of the *1998 AMT Survey of Advanced Technologies in Canadian Manufacturing*, conducted by Statistics Canada. The survey covers the use and planned use of 26 AMTs at the establishment level. Additional information was obtained on skill requirements, technology development and implementation practices, the results of technology adoption, barriers to adoption, and the firm's R&D activities.

The analysis focuses on identifying the patterns of technology use by manufacturing plants. It builds on previous AMT research in Canada[1] and abroad. Research on the factors correlated with technology use serves to improve the effectiveness of economic development and industrial modernization programs by providing an understanding of why plants vary in their technology use. Firm managers can also benefit from learning more about the factors contributing to successful AMT adoption and implementation.

The 1998 AMT Survey follows similar surveys conducted in 1989 and 1993 by Statistics Canada. Since the first 1989 survey, Canadian manufacturing has made the transition from conventional machinery to computer and microelectronics-based manufacturing technologies. This means that Canadian manufacturers face different challenges today than they did ten years ago, when the majority of Canadian plants had not yet adopted their first AMT. The 1998 AMT Survey results point to the growing importance of the development of internal capabilities for adopting, implementing and managing AMTs as a critical success factor.

1.1 Report Organization

This report analyses the factors correlated with technology use and compares the results to the findings from previous research. The report's organization reflects the categorization of these factors into five categories as follows:

- *Technology-related factors*, such as technological maturity and the type of production system.
- *Plant-level factors*, such as plant size and ownership.
- *Management-related factors*, such as business strategies and R&D capabilities, that reflect management policy and practices.
- E*nvironmental factors*, that is, influences external to the plant, such as the availability of skilled workers.

Each of these categories is discussed in a separate chapter, (Chapters 4 through 7). Chapter 9 examines the effects of selected factors in relation to AMT invest over the previous three years and

1 See Baldwin and Diverty, 1995; Baldwin, Diverty and Sabourin,1995; Baldwin and Sabourin, 1995; Baldwin, Sabourin, and Rafiquzzaman, 1996; Baldwin and Sabourin, 1999; Baldwin and Lin, 1999; Baldwin, Rama and Sabourin, 1999.

plans for AMT adoption in the coming two years. Other chapters discuss the analysis methodology, the basic indicators of AMT use, and the reported benefits of AMT use.

1.2 Summary of Previous AMT Research

Complex social, economic and structural conditions shape the decision to adopt new manufacturing technologies. Table 1.1 summarizes the literature on the effects of several factors that have been found to influence AMT use.

Table 1.1 Summary of Previous Research on Factors Linked to AMT Use

Factor	Description of Effect
Plant Size	Smaller plants are slower to adopt and use fewer AMTs than larger plants.
Multi-Plant Status	Plants in multi-plant firms are more likely to use AMTs than stand-alone plants.
Ownership Location	Foreign-owned plants have higher AMT use rates than domestic plants.
Export Status	Plants that export use more AMTs than plants selling to domestic markets.
Industry	The rate of AMT use varies by industry.
Prior AMT Experience	Prior AMT use increases the likelihood of further adoptions.
Internal Expertise	Production-related expertise facilitates the adoption of AMTs.
Organizational Practices	Advanced organizational practices are important complements to AMT use.
External Network	Linkages with external technical resources increase the rate of adoption.
Urban Proximity	Urban plants have a higher propensity to adopt than rural plants.
Maturity of Technology	After an initial slow diffusion stage, the adoption rates for individual AMTs first accelerate, then slow as markets reach saturation.
Cost of AMTs	The high cost of AMT equipment is a significant barrier to adoption.

In all previous empirical studies, plant size is the dominant variable in predicting technology adoption[2] Smaller firms, hampered by a lack of both technical and financial resources, lag behind larger firms in the adoption of AMTs. The influence of industry and market structure is reflected in several other plant characteristics besides plan size. Exports, branch plant status, foreign ownership, and urban proximity also increase AMT use, although plant size appears to moderate the influence of these variables. AMT use also varies by a plant's sector of activity but there is no widely accepted explanation for the pattern of variation.

Researchers have evaluated a wide range of barriers to technology adoption.[3] Survey respondents cite the lack of skilled workers and AMT expertise as principle obstacles, though in recent North American studies, the availability of skilled workers is becoming less of an issue, while the need for

[2] See Fortier et al., 1993; Northcott and Vickery, Shapira and Rephann, 1996; Kelley and Helper, 1997; Baldwin and Sabourin, 1999.

[3] See Northcott and Vickery, 1993; Baldwin et al., 1996; OECD, 1997; McGranahan, 1998; Millen and Sohal, 1998; Baldwin and Lin, 1999.

AMT-related production experience, especially during the project implementation phase, is becoming more significant. Furthermore, as the growth in AMT use is principally among firms that have already adopted at least one AMT, AMT implementation issues are receiving more attention from researchers and are now viewed as critical factors in the intensity of AMT use. Another barrier is the cost of AMTs, including the costs to evaluate and integrate the new technology. High AMT costs have been found to slow adoption.

Other resource-related factors can influence AMT use. The organization of internal technical resources can hinder or promote the use of AMTs. Practices that promote integration of different organizational functions, such as concurrent engineering and cross-functional teams, complement AMT use. Likewise, the development of linkages to external resources and sources of information favours AMT adoption.

The maturity of AMTs also influence their adoption. This is implicitly recognized in the construction of survey questionnaires, which include emerging AMTs and drop older, widely-used AMTs.

2 Analytical Framework

The 1998 AMT Survey questionnaires were sent to a random sample of 3,757 manufacturing plants with more than 10 employees. Responses were obtained from 3,702 plants for a response rate of 99.5%.[4] The results provide cross-sectional data on AMT use and plant characteristics in 1998 or over a three-year period before 1998.

This report presents both descriptive and multivariate regression results. All results are weighted by the inverse of the sampling fractions to estimate conditions among all manufacturing plants in Canada with more than 10 employees. Statistical differences in AMT use rates are calculated after normalizing the weighted results to the original sample size.

2.1 Statistical Methods

The 1998 AMT questionnaire uses two main response categories: a nominal 'yes' or 'no' response and an ordinal importance scale ranging from 1 (low importance) to 5 (high importance). Ordinal categories are used in three main question groups: business strategies, the results (or outcomes) of adopting AMTs, and obstacles to adoption.

There are two options for determining the frequency of responses to ordinal questions. One is to calculate the extreme score, or the percentage of respondents that give a score of 4 or 5, where '5' represents the highest importance level. The other option is to present the 'most important' frequencies. This gives the percentage of respondents that gave their highest score to a specific sub-question. Both methods can be biased by two problems.

First, smaller plants tend to give lower average scores to all sub-questions. This problem can be avoided by using the 'most important' score. Second, some respondents give the same score to every sub-question in a question group. Some of these will be valid, but an unknown percentage will be due to a lack of interest in carefully evaluating each sub-question. Unfortunately, the latter responses can seriously distort the results of both the extreme scores and the most important scores.

Preliminary analyses showed that the least biased results were obtained from the extreme scores to the questions on the results and obstacles to AMT adoption and the most important scores for business strategies. Where relevant, an indicator of the robustness of the results is provided. We assume that the results are robust if they are statistically significant and follow the same direction in four analyses: the most important score both including and excluding same-score respondents, and the extreme scores both including and excluding same-score respondents.

Previous studies of AMT use in Canada used logistic models to evaluate the factors that are correlated with the use of one or more AMTs.[5] These analyses are not repeated in this report because the majority of plants in 1998 use at least one AMT. The widespread adoption of at least one AMT reduces the policy interest in the factors linked to this measure of AMT use.

[4] Sabourin and Beckstead (1999) provide further details on the survey methodology and a summary of the descriptive statistics.

[5] See Baldwin and Sabourin, 1999.

Alternatively, multivariate techniques might be used to explore the effect of several factors on the number of AMTs in use. However, the interpretation of these models is severely constrained by the fact that the 1998 AMT survey does not collect data on when the AMT was introduced - it could have occurred three months or ten years before the survey. This means that conditions in the plant, such as ownership status or the number of employees, could have changed substantially after adoption. Therefore, we do not know if a factor such as current plant size could have influenced the number of AMTs in use.

The 1998 AMT survey includes two questions that present fewer problems for multivariate regression, although both have their limitations. The first concerns the percentage of the plant's investment in machinery and equipment that was spent on advanced equipment, while the second concerns planned adoption within two years. In all regressions, independent variables based on ordinal questions are coded as 1 when the respondent gives the variable a rating of 4 or 5 on a five-point importance scale and zero otherwise.

2.2 Basic Indicators of AMT Use

The five basic indicators of AMT used in this study are shown in Table 2.1. The indicators were chosen to facilitate comparisons with previous work and to expand the interpretation of AMT use patterns.

The indicator for the percentage of plants that only use mature AMTs (described in Chapter 4) has not been used in previous studies. A mature AMT is one which has achieved a relatively high level of penetration across most industrial sectors. A lower level of technological capability is likely required of firms only using mature AMTs.

Table 2.1 Basic Indicators of AMT Use

Indicator of plant use	Previous use
Percent using one or more AMTs[1]	Most widely used indicator.
Percent using 5 or more AMTs	Widely used as an indicator of more intensive AMT use.
Percent only using mature AMTs[2]	New
Percent with AMT investment greater than 25% in previous 3 years	Similar to intensity measure used in 1993 survey (Baldwin and Sabourin, 1995).
Mean number of AMTs in Use	Widely used. Results depend on the number and type of AMTs included in the survey.

1. Includes 26 AMTs listed in the 1998 AMT Survey. See Appendix A for survey definitions.
2. Includes 9 of 26 AMTs: CAD/CAE, CAD/CAM, electronic exchange of CAD files, PLCs, LANs, WANs, inter-company computer networks, computers used for control on the factory floor, and use of inspection data in manufacturing control.

There are several limitations with the basic AMT use indicators:

- They do not tell us about the extent or intensity of use. We do not know how frequently each AMT is used or whether a plant has only one unit or multiple units of the same AMT.
- They measure penetration as opposed to diffusion rates (Fortier et al., 1993). Penetration rates do not account for the applicability of the technologies across the survey population, whereas diffusion rates indicate the number of users only in relation to those companies where the technology has potential applications.
- The indicators do not account for one type of AMT replacing another over time or substituting for each other.

3 1998 Prevalence of AMT Use in Canada

Table3.1 gives the prevalence of AMT use for the entire population of Canadian manufacturing plants in 1998. In addition, the table gives estimates weighted by 1995 manufacturing value-added, employment, and shipments.[6]

Table 3.1 Prevalence of AMT Use for All Manufacturing Plants in 1998

AMT Use indicator	Plants	Mnfg. Employment[2]	Mnfg. Value-added[2]	Mnfg. Shipments[2]
Use any AMT	76%	92%	96%	97%
Use 5 or more AMTs	46%	76%	87%	88%
Only use mature AMTs	17%	10%	7%	6%
AMT investment > 25%[1]	27%	33%	31%	33%
Mean number of AMTs in use	5.2	—	—	—

1: Over 25% of total investment in machinery and equipment in the previous 3 years is for AMTs.
2: Based on 1995 data for 2,950 plants.[7] The results maintain establishment weighting and are calculated as the share, for example, of total employment for all plants that use at least one AMT over total employment for all plants.

76% of the plants used at least one AMT in 1998, compared to one-third in1993 (Baldwin and Sabourin, 1995). The percentage of plants that use five or more technologies has increased from 14% in 1989 to the current use rate of 46%. Of note, 17% of the plants only use mature AMTs.

Plants that use at least one AMT account for over 90% of manufacturing employment, value-added, and shipments. The difference between the percentage of plants that use AMTs and the percentage of employment, value-added, and shipments from these plants can be explained by the size distribution of manufacturing plants in Canada and the positive correlation between plant size and AMT use. An estimated 68% of manufacturing plants have between 10 and 49 employees. These small plants have the lowest use rate for AMTs and contribute to a much smaller fraction of value-added and shipments than larger manufacturing plants.

Two major conclusions can be drawn from Table 3.1. First, plant-based estimates of AMT use underestimate the actual role of AMTs in production. This creates problems for comparisons of AMT use between countries or regions with different plant size distributions. These should either use employment-weighting or evaluate differences within specific size classes. The second conclusion is that the use of at least one AMT is reaching saturation. This means that the focus of analysis must shift from the determinants of any AMT use to an analysis of the intensity of AMT use —or what factors influence plants to use multiple AMTs.

[6] Manufacturing shipments is the total shipment price of all goods produced by the plant in 1995. Value-added is equal to the difference between shipment prices minus the cost of all inputs other than labour costs and is a measure of the extra value added by the plant. More recent data on employment, value-added and shipments were not available at the time of this study. Since manufacturing employment has grown between 1995 and 1998, this will create errors in these estimates.

[7] AMT use is slightly lower among the 2,950 plants for which data is available.

3.1 Use Rates for Individual AMTs

Table 3.2 gives the use rates for each of the 26 AMTs and the percentage of plants planning to adopt each AMT within the next two years. The 26 AMTs are ranked in descending order by their percentage of users.

Table 3.2 Percent of Plants That Currently Use or Plan to Use Each AMT

Rank	AMT	In Use	Plan to Use	In Use or Plan to Use
1	Computer-aided Design/Engineering (CAD/CAE)	44	10	54
2	Programmable Logic Controllers (PLCs)	37	9	46
3	Computer-aided Design/Manufacturing (CAD/CAM)	36	14	50
4	Local Area Networks (LANs)	36	13	49
5	Company-wide computer networks (including Intranet and Wide Area Networks (WANs))	35	19	54
6	Electronic exchange of CAD files	34	13	47
7	Computers used for control on the factory floor	31	21	51
8	Inter-company computer networks (including Extranet and Electronic Data Interchange (EDI))	29	21	50
9	Use of inspection data in manufacturing control	26	16	42
10	Manufacturing Resource Planning II (MRP II) or Enterprise Resource Planning (ERP)	21	19	40
11	Automated parts identification devices (e.g. bar coding)	18	21	39
12	Knowledge-based software	18	15	33
13	Computer Integrated Manufacturing (CIM)	18	15	33
14	Modeling or simulation technologies	17	13	30
15	High speed machining	17	12	29
16	Supervisory Control and Data Acquisition (SCADA)	16	16	32
17	Flexible Manufacturing Cells or Systems (FMC/FMS)	15	11	26
18	Other automated sensor-based inspection/testing systems	13	8	21
19	Automated vision-based inspection/testing systems	11	8	19
20	Lasers used in materials processing	9	8	17
21	Robots with sensing capabilities	8	7	15
22	Near net shape technologies	7	6	13
23	Robots without sensing capabilities	7	5	12
24	Automated Storage and Retrieval Systems (AS/RS)	5	9	14
25	Distributed Control Systems (DCS) (Digital, remote controlled process plant control, e.g. fieldbuses)	5	8	13
26	Rapid Prototyping Systems (RPS)	5	7	12

The five most commonly used technologies in 1998 were CAD/CAE, PLCs, CAD/CAM, LANs, and company-wide computer networks with use rates ranging from 44% to 35%. LANs and company-wide computer networks are communications infrastructure technologies, PLCs and CAD/CAM are principally used in manufacturing process control, and CAD/CAE is used in design. In comparison, the highest use rate for an AMT in Canada in 1993 was 21%, for CAD/CAE (Baldwin et al., 1996).

The first nine technologies in Table 3.2 are mature AMTs. (See section 5.1 for a definition of mature AMTs.) All nine have current use rates that exceed planned use.

The top three AMTs that Canadian plants plan to acquire within the next two years are automated parts identification devices, computers used for control on the factory floor, and inter-company computer networks. Planned use exceeds current use for four AMTs: data collection devices, AS/RS, DCS, and RPS. The latter three technologies are the least used AMTs, but electronic parts identification devices currently rank eleventh.

3.2 Conclusions

The principal findings on the prevalence of AMT use by Canadian manufacturing plants in 1998 are as follows:

- 76% of manufacturing plants used at least one AMT. These plants account for over 90% of manufacturing employment and value-added.
- On average, plants use approximately five different types of AMTs. Plants that use five or more AMTs account for 76% of manufacturing employment and 87% of value-added.
- Mature AMTs with applications across all manufacturing sectors and with above average penetration rates account for the nine most widely used AMTs. 17% of plants only use mature AMTs.
- The top three technologies that Canadian plants plan to acquire within the next two years are automated parts identification devices, computers used for control on the factory floor, and inter-company computer networks.

4 Technology-Related Factors

The 1998 AMT survey includes a variety of AMTs that differ by their function in the manufacturing process and in their applicability to different sectors. In this chapter, we develop two indicators to address this diversity. The first indicator, the percentage of firms that only use mature AMTs, is used throughout the report as a basic indicator of AMT use. The second indicator is an alternative to classifying plants by their industrial sector. It is based on the dominant type of production system found in an industry.

4.1 Maturity of the Technology

The maturity of each AMT is linked to the diffusion process. The characteristic s-shaped diffusion curve applies to the adoption of AMTs (Edquist and Jacobsson, 1988; Northcott and Vickery, 1993). At the start of the diffusion process, few potential users are aware of a new technology and there are few applications for it. At this stage, the technological capabilities required to successfully adopt the technology could be considerable. As the technology matures, more potential users hear of it and the number of proven applications increases. Also, performance improves through accumulated experience, both during its manufacture and its use (Rosenberg, 1982; Sahal, 1985). These conditions tend to accelerate adoption. In the final stage of diffusion, the number of users far exceeds the number of potential users, the range of potential new applications narrows, and the rate of adoption declines.

4.1.2 Maturity Indicator

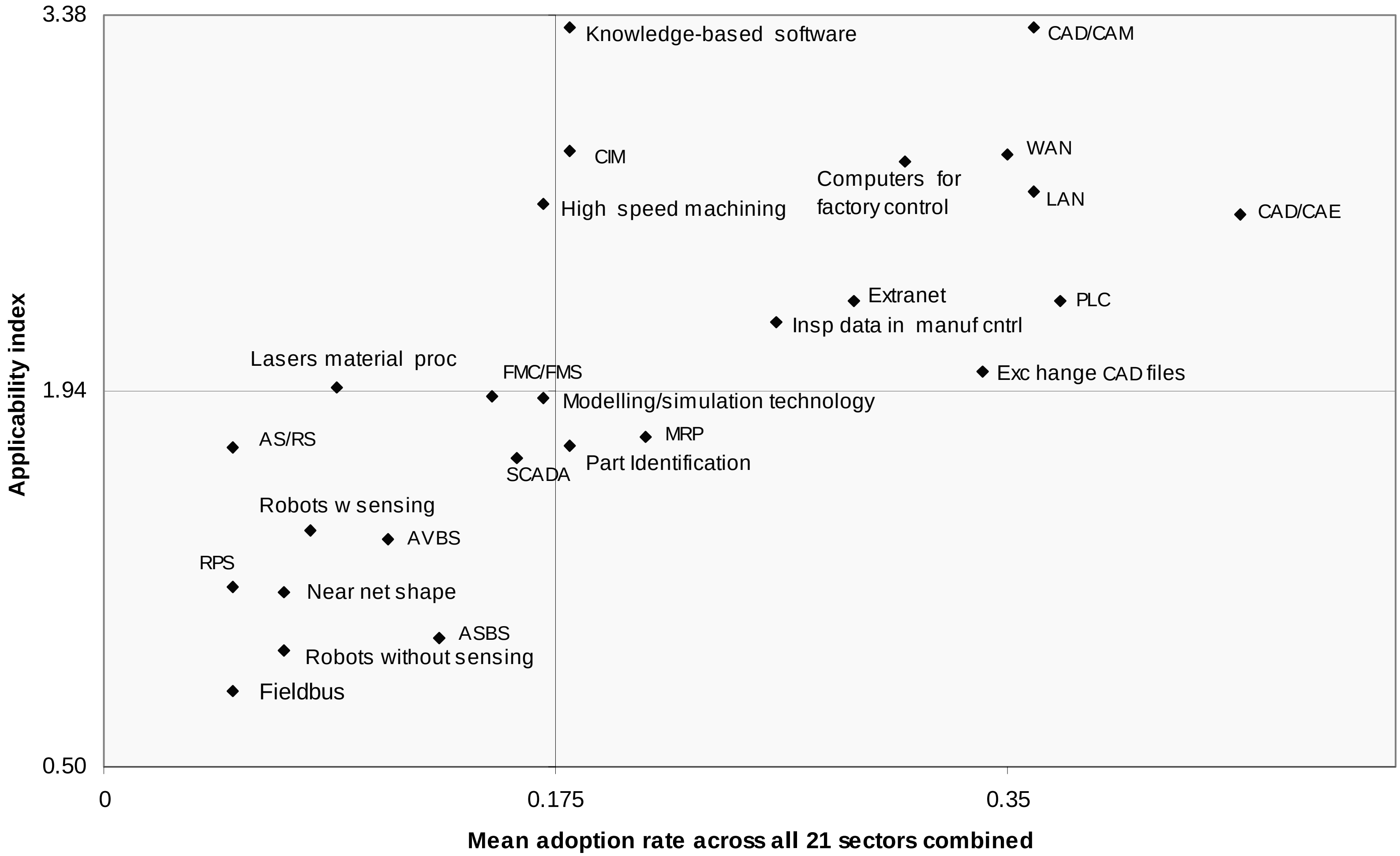
This study develops an index for AMT maturity. The index is based on the penetration rate (the percentage of all plants in the survey sample that have adopted a specific technology) and an index for the applicability of the technology across all manufacturing sectors.

The applicability index is equal to the mean adoption rate divided by the standard deviation for the mean adoption rate across all sectors. This indicates how generic or cross-cutting the AMT is. A high applicability index shows that there is little difference in the adoption rate across sectors. This can occur when the average percentage of firms that have adopted the AMT is either very high *or* very low. Conversely, a low applicability index shows that there are large differences in the penetration rate by sector.

Figure 1 graphs the applicability index by mean penetration rate for each of the 26 AMTs. The median applicability index is 1.94, while the median penetration rate is 17.5%. These two medians divide the graph into four quadrants:

- Quadrant 1 (upper left corner) includes AMTs with below average penetration rates but above average applicability rates.
- Quadrant 2 (upper right corner) includes AMTs with a high applicability index and a high penetration rate.
- Quadrant 3 (lower left corner) includes AMTs with a low applicability index and a low penetration rate.
- Quadrant 4 (lower right corner) includes AMTs with a low applicability index but a high penetration rate.

FIGURE 1. AMT Applicability by Mean Adoption rate in 21 Manufacturing Sectors



A striking result is that almost all of the AMTs lie in either quadrant 2 or quadrant 3: they are either high applicability and high penetration AMTs (mature) or low applicability and low penetration AMTs. This suggests that AMT penetration rates are strongly influenced by applicability. AMTs with a wide range of applications across manufacturing sectors will be in wider use than AMTs with a limited number of applications. This is a logical result, but also highlights the arbitrary nature of many of the widely used indicators for AMT use. One possibility is that low observed penetration rates for AMTs in specific firm size and sector combinations could simply be due to a lack of applicable AMTs.

The few AMTs that fall outside of these two quadrants lie very close to the median boundaries. Only two AMTs fall in the low penetration/high applicability quadrant: high-speed machining and lasers for material processing, although knowledge-based software and computer-integrated manufacturing are very close to the median boundary for the penetration rate and lie a long way away from the other AMTs in this quadrant. For the purposes of this study, these two AMTs are not defined as quadrant 2 AMTs. Two AMTs, manufacturing resource planning (MRP) and automated parts identification devices, lie in the low applicability/high penetration portion of the graph (quadrant 4).

For simplicity, we refer to the nine AMTs that fall clearly in quadrant 2 (high penetration and high applicability) as “mature”. This excludes knowledge-based software and CIM. All other AMTs are defined as “developing” AMTs. It is important to note that the maturity index is <u>not</u> a measure of the number of years that an AMT has been available on the market, although the median decade of commercialization for the nine mature AMTs is the 1960s, compared to the 1970s for the 17 developing AMTs.

The distribution of AMTs in Figure 1 suggests a new basic indicator of AMT use. This is the percentage of firms that *only* use a mature AMT from the upper right quadrant. We would expect that these AMTs pose the fewest difficulties for adoption, particularly for smaller firms with limited access to highly specialized skills.

4.2 Industry and Production System

Previous surveys have observed industry variations in the level of technology use and the mix of particular technologies in use (Northcott and Vickery, 1993; Fortier et al., 1993). However, industry classifications based on product categories, such as the Canadian and the U.S. Standard Industrial Code (SIC) classification systems, do not readily explain AMT adoption (Young, 1993; Shapira and Rephann, 1996). The exception is the high incidence of AMT use in the electronics industry, which is attributed to greater familiarity with microelectronics-based technologies. By contrast, researchers have found specific patterns of AMT use for different types of production systems (Shapira and Rephann, 1996; Luria, 1997).

While it is generally agreed that the usefulness of specific technologies differs by industry, there is no commonly used framework for analyzing these differences. Industry classifications based on the type of production system give different answers than sector-based classification systems. For example, manufacturers of discrete parts in both the plastics and automobile sectors use similar production processes, even though they are assigned to different sectors. Moreover, sector classification systems combine sub-sectors that use very different manufacturing processes. For example, the plastics industry includes both sub-sectors that use continuous process technology (e.g. resin suppliers) and sub-sectors that use discrete products technology (e.g. bucket manufacturers). One solution to this problem is to survey industries that use similar production processes (U.S. Bureau of the Census, 1994; Swamidass and Kotha, 1998), or to recombine sectors after the survey on the basis of their dominant production systems. Many of these types of surveys report significant differences in AMT use. For example, among small metal-working shops, non-AMT users are more likely to have a repetitive production process than AMT users (Rishel and Burns, 1997).

The association between different production systems and AMT use suggests that the nature of the production processes used in an industry, as described by its production system, influences the opportunity for applying AMTs. Simply put, functional use matters. For example, automatic storage and retrieval systems (AS/RS) increase the productivity of inventory handling and are therefore suited to large volume industries with long production runs. As a result, the adoption of AS/RS systems may proceed more slowly in firms that have smaller national markets, as is the case in Canada. Historically, Canada's small markets have been considered an obstacle to capturing economies of scale (Britton, 1991).

Also, many AMTs were developed to replace conventional machine tools. Consequently, these AMTs have wider applicability in discrete products industries than in continuous production systems. In contrast, continuous process industries are excellent candidates for the application of integration technologies. For example, wide-scale application of distributed control systems (DCS) in oil refining goes back to the 1970s.

4.2.1 Production System Indicator

The production system indicator developed here is based on whether an industry predominantly uses either a "continuous process" or a "discrete parts" production system.[8] The latter group is further divided into "high value-added/low volume" industries and "low value-added/high volume" industries. This corresponds roughly to dividing discrete parts manufacturers into "engineering industries" and "other" discrete parts industries.

The 1998 AMT survey only contains information on each plant's sector at the two-digit level. The use of two-digit sectors to assign each plant to a production system introduces some noise because many sectors at the two-digit level include both discrete parts and continuous flow systems. A few sectors can not be classified by a dominant production mode because both continuous and discrete parts manufacturing are widely used. To overcome this problem, a fourth production system category, labeled "mixed", includes industries with no dominant production system. Table 4.1 summarizes the classification of manufacturing sectors by production system.

[8] This classification is consistent with the engineering literature, which divides industrial plants into two basic categories: continuous process industries and discrete parts manufacturing. Continuous process industries involve continuous production of product. Discrete parts production involves production of individual items and is further sub-divided into mass, batch and job shopping.

Table 4.1 Classification of Two-Digit Sectors[1] by Production System Type

Discrete Non-Engineering	Discrete Engineering	Continuous Flow	Mixed
Leather goods	Machinery	Beverages	Tobacco products
Textile products	Transport equipment	Primary textiles	Paper products
Clothing	Electrical equipment	Primary metals	Printing & publishing
Wood products	Fabricated metals	Non-metallic minerals	Other manufacturing
Furniture		Petroleum refining	
Plastic products		Chemicals	
Rubber products			

1. Food processing establishments were not included in the 1998 AMT Survey.

4.2.2 AMT Use by Production System Type

Table 4.2 gives AMT use rates by production system. The highest use rates are for plants from the discrete parts engineering industries, where 85% of plants use one or more AMTs, compared to 67% of discrete non-engineering plants. Many AMTs, such as NC/CNC and FMS, were designed to replace the conventional machine tools used in these industries. The high value-added content of products from these industries could explain the relatively high AMT use rates since firms in these industries are able to capitalize on AMT economies of scope.

Table 4.2 AMT Use Rates by Production System

	Production System			
	Continuous flow	Discrete non-engineering	Discrete engineering	Mixed
Percent of plants using system[1]	12.4%	30.2%	37.9%	19.4%
Use one or more AMTs	75%	67%	85%	75%
Use 5 or more AMTs	48%	34%	57%	40%
Only use mature AMTs	14%	18%	15%	19%
AMT invest > 25%	19%	21%	33%	30%
Mean number of AMTs in use	5.5	4.0	6.3	4.6

1: The percentages for this row total 100%, accounting for all plants in the survey.

By several measures, AMT use is second highest among plants in continuous flow sectors, even though many of these sectors are traditionally viewed as 'low technology'. This could be due to the opportunities for economies of scale, which permit the recovery of high AMT investment costs through large production runs. Furthermore, continuous flow production requires automatic control of the manufacturing process and is therefore ideally suited for the application of microelectronics to control functions. The lowest rates of AMT use are in the discrete non-engineering industries. While the applicability of AMTs to these industries is high, the low value-added of products from these industries may be a significant obstacle to adoption.

Table 4.3 provides planned adoption rates by production system. Although differences among current AMT users are slight, the highest planned adoption rates for both current users and non-users are in the discrete engineering industries, where 80% of AMT users plan to adopt an additional type of AMT. This is also the production system with the highest current AMT use rates. The high planned adoption rates probably reflect both the high number of AMTs with applications in these industries and competitive pressures.

Table 4.3 Percentage of Current and Non AMT Users by Production System that Plan to Adopt a New Type of AMT Within Two Years

Production system	Current AMT user	Non AMT user
Continuous flow	70%	45%
Discrete non-engineering	72%	34%
Discrete engineering	80 %	48%
Mixed	61%	39%

4.3 Conclusions

The main findings on AMT use patterns by AMT maturity and production system are as follows:

- Nine AMTs can be characterized as 'mature', with comparatively high adoption rates across most industries. 11 AMTs have low adoption rates and are only applicable in a few sectors.
- AMT use rates are strongly influenced by the applicability of the technology across all sectors. AMTs with a wide range of applications generally have higher penetration rates than those with a limited number of applications.
- AMT use rates vary by the dominant production system in use in a sector. The highest AMT use rates are in industries with high value-added discrete parts production, followed by industries with continuous flow production systems. AMT use rates are lowest in industries with low value-added discrete parts production.
- The highest planned adoption rates for both current users and non-users are in the high value-added discrete parts industries.

5 Plant-Level Factors

This chapter analyzes patterns of AMT use by several plant characteristics: plant size, ownership status and export status. No information was available for the 1998 AMT Survey for two additional plant-level factors, plant age and plant growth.

5.1 Plant Size

In previous empirical studies, plant size, as measured by the number of employees, has consistently figured as a major determinant of technology use.[9] Plant size was the most powerful indicator of technology use in the 1989 Canadian survey results (Baldwin and Diverty, 1995). Plant size is also a factor in differences in the rates of use for particular technologies (Swamidass and Kotha, 1998).

The adoption lag between large and small plants or firms is generally attributed to the greater financial and technical resources of larger plants. Smaller plants face greater risks in adopting a new technology since the investment is a larger proportional share of their budgets and other resource commitments (Mansfield, 1993). New technology implementations are more likely to interrupt operations or have an adverse effect on workflow in smaller plants as well. Many of the advanced technology systems, such as CIM, are highly capital intensive, which explains their near absence in smaller firms (Swamidass and Kotha, 1998). Larger plants or firms have the scale advantage of being able to spread the risk and fixed costs of adoption over more output (Kelley and Helper, 1997). Researchers have also suggested that because of a greater number of products and processes in large plants, there is a wider potential scope for advanced technology applications (Baldwin and Diverty, 1995; Swamidass and Kotha, 1998). A greater amount of internal technical resources, particularly technical specialists, are thought to be associated with a better awareness of new technology and its benefits (Northcott and Vickery, 1993). Because large plants are more likely than small plants to have the necessary expertise in-house, they are able to more effectively exploit the benefits of advanced technologies.

5.1.1 AMT Use by Plant Size

Table 5.1 gives results for four plant size categories. With one exception, AMT use increases monotonically with the number of employees. The exception is a decline with plant size in the percentage of firms that only use mature AMTs. However, this result fits the general pattern, since it shows that small plants have greater difficulties in adopting more complex AMTs.

The 1998 AMT Survey data corroborates the significance of a lack of resources among smaller plants as a contributing factor in their lower AMT use rates. Of ten obstacles to AMT use listed in the 1998 AMT Survey, the three obstacles which show a statistically significant difference by plant size relate to the issue of the level of resources required for adoption. The full results are provided in Section 8.2 on obstacles to AMT use.

[9] See Fortier et al., 1993; Northcott and Vickery, 1993; Shapira and Rephann, 1996; Kelley and Helper, 1997; Baldwin and Sabourin, 1999.

Table 5.1 1998 AMT Use Rates by Plant Size

	Number of employees			
	10 - 49	**50 – 99**	**100 - 249**	**> 250**
Percent of all plants in size class[1]	68.3%	14.7%	11.3%	5.7%
Use one or more AMTs	69%	89%	95%	99%
Use 5 or more AMTs	34%	59%	77%	96%
Only use mature AMTs	19%	15%	11%	2%
AMT investment > 25% of total plant investment	23%	33%	35%	49%
Mean number of AMTs in use	3.8	6.1	8.6	12.8

1: The percentages for this row total 100%, accounting for all plants in the survey.

5.1.2 Planned Adoption

Table 5.2 gives planned adoption rates by plant size for plants that currently use at least one AMT and for plants that currently do not use any AMTs.

Table 5.2 Planned AMT Adoption Rates in Two Years by Plant Size

Employees	Current AMT users	Non-AMT users
10 - 49	69%	39%
50 to 99	79%	46%
100 to 249	80%	48%
250+	81%	-
All plants	73%	40%

The lowest planned adoption rates for both AMT users and non-users are among plants with less than 50 employees. At the same time, 89% of all potential adopters among current non-users have less than 50 employees, which is linked to the fact that 90% of current non-users are in this size class. Most of the expected growth in AMT use is by plants that already use AMTs.

5.2 Ownership Status

Previous research in Canada and the United States shows that AMT use is higher among foreign-owned plants compared to domestically-owned plants and among plants owned by multi-plant firms compared to stand-alone plants (Baldwin and Diverty, 1995). The latter is explained by the potential of multi-plant enterprises to spread the costs of adoption over a number of plants. Also, multi-plant firms employ a larger number of AMT technologies that integrate operations between establishments, such as communications technologies (Shapira and Rephann, 1996; Gate, 1997).

As shown in Table 5.3, AMT use rates are higher among foreign-owned plants. Part of the difference in AMT use rates between foreign- and Canadian-owned plants is due to differences in their size distribution. Foreign-owned plants have consistently higher use rates for at least one AMT, for five or more AMTs, and for the mean number of AMTs, but the differences are not as great as the average for all plants combined. Furthermore, a higher percentage of small Canadian-owned than foreign-owned plants invested more than 25% of their total equipment and machinery investment in AMTs, and slightly fewer Canadian-owned small plants only used mature AMTs.

Table 5.3 1998 AMT Use Rates by Geographic Region of Head Office

	All plants		< 100 Employees		100 + Employees	
	Canada	Foreign	Canada	Foreign	Canada	Foreign
Use one or more AMTs	75%	88%	72%	78%	95%	98%
Use 5 or more AMTs	43%	67%	38%	46%	80%	92%
Only using mature AMTs	24%	16%	18%	21%	9%	5%
AMT investment > 25%	*27%	29%	25%	15%	37%	44%
Mean number of AMTs in use	4.9	7.9	4.1	5.3	9.6	11.1

All differences between Canadian and foreign plants are statistically significant ($p < 0.05$), except where marked with a '*'.

One explanation for why foreign-owned firms use more AMTs is that they are more likely to be part of a multi-plant firm. The 1998 AMT survey does not contain a direct question on multi-plant status, but it does ask plants that use at least one AMT if "related plants…play an important role in providing ideas for the adoption of advanced technology in your plant". Three response categories are provided: yes, no, and not applicable. We assume that a 'yes' or 'no' response indicates whether the plant is part of a multi-plant firm, while a 'not applicable' response indicates that the plant is a stand-alone plant. The analyses are limited to plants with less than 100 employees because of a lack of sufficient responses for large, stand-alone plants.

The mean number of AMTs in use and the percentage of plants that only use mature AMTs are given in Table 5.4 for Canadian and foreign-owned plants by plant status. Foreign-owned plants use a higher average number of AMTs in all four comparisons, although the difference is only statistically significant in one—for stand-alone plants with 10 to 49 employees. The direction of the result for the percentage of plants that only use mature AMTs is mixed, although only one comparison is statistically significant. Fewer Canadian (27%) than foreign (41%) plants with 10 - 49 employees only use mature AMTs.

Table 5.4 Measures of AMT Use by Canadian- and Foreign-Owned Plants for Plants Owned by Multi-Plant Firms and Stand-Alone Plants

	10 - 49 employees			50 – 99 Employees		
	Canadian	Foreign	P[1]	Canadian	Foreign	p
Mean number of AMTs in use						
Plants owned by multi-plant firms	5.4	5.7	.70	6.6	7.4	.24
Stand-alone plants	5.1	6.7	.01	6.9	8.2	.19
Percent only using mature AMTs						
Plants owned by multi-plant firms	27%	41%	.01	20%	7%	.06
Stand-alone plants	31%	27%	.62	10%	23%	.17

1: P value for the difference between Canadian and foreign-owned plants.

5.3 Export Status

Studies of AMT use in the U.S. report higher rates of AMT use among plants that export compared to plants that only produce for the domestic market (U.S. Bureau of the Census, 1994; Shapira and Rephann, 1996).

Table 5.5 gives AMT use rates for plants that export some of their output and for plants that only sell their output in the domestic market. All AMT indicators show that plants with some exports score higher on AMT use. For example, 84% of exporting plants with less than 100 employees use one or more AMTs compared to 66% of plants with no exports.

Table 5.5 AMT Use Rates by Export Status

	< 100 Employees		100 + Employees	
	No exports	**Some exports**	**No exports**	**Some exports**
Use one or more AMTs	66%	84%	95%	97%
Use 5 or more AMTs	31%	51%	68%	89%
Only use mature AMTs	19%	17%	18%	4%
AMT investment > 25%	22%	29%	30%	43%
Mean number of AMTs in use	3.5	5.4	7.8	10.9

All differences between non export and export plants are statistically significant ($p < 0.05$)

5.4 Conclusions

The following conclusions on AMT use by basic characteristics of the plant can be drawn from the 1998 AMT Survey results:

- AMT use rates increase monotonically by plant size, as measured by the number of employees. The percentage of plants that only use mature AMTs declines with plant size.
- The percentage of plants that plan to adopt a new type of AMT within two years increases by plant size for both current AMT users and non-users. Planned adoption rates are higher among plants that currently use at least one AMT.
- Most of the expected growth in AMT use over the next two years is due to the adoption of new types of AMTs by plants that currently use AMTs. Very little growth in AMT use is expected from the adoption of AMTs by non-AMT user plants.
- AMT use rates are higher among foreign-owned plants than among Canadian-owned plants. Foreign-owned plants use an average of 7.9 AMTs compared to 4.9 among Canadian-owned plants. Part of the difference in AMT use rates between foreign- and Canadian-owned plants declines after controlling for differences in the number of employees and whether or not the plant is part of a multi-plant firm.
- Plants that export have higher AMT use rates than plants that do not export.

6 Management-Related Factors

Management choices about how to organize manufacturing and support operations, and how much to invest in their development, are major factors in both technology adoption and the successful use of new technology. This section evaluates the relationship between AMT use and several management-related factors: the extent of external networks, the diversity of internal resources, the presence of training programs, the firm's R&D capabilities, business strategies, and the methods used by the firm to introduce AMTs.

6.1 External and Internal Information Sources

Evidence from past research indicates that the establishment of external linkages has a positive effect on technology adoption.[10] Technology suppliers and consultants, in particular, are critical sources of information. More generally, participation in external networks could be an indicator for the capacity to absorb new technologies.

All firms, to some degree, rely on external organizations to supply the information and resources that they need to innovate. According to communication and transaction cost theories, information market failures are a principal cause of slow technology diffusion (Britton, 1991; Hottenstein et al., 1999). Kelly and Helper (1997) argue that the more information sources a potential user has, the higher the incidence of information exchange, and the greater the likelihood of technology adoption. They found that the development of external networks has a greater effect on the likelihood of adoption in small plants.

However, the type of external information sources could play a more critical role in adoption than the number of information sources. Also, the impact of different sources of information on adoption is known to vary with firm size. A common problem among small firms is the lack of resources to evaluate the claims of technology consultants and suppliers. In implementing AMTs, small firms benefit from the technical assistance of their major industrial customers (Shapira and Rephann, 1996). Customer requirements for suppliers to use specific AMTs have substantially increased their adoption (Britton, 1991).[11]

The development of internal resources that complement the efficient operation of AMTs promote the successful integration of these technologies into existing plant. Much of the process of developing this capability takes place through learning-by-using and learning-by-doing, that is, firms build their technological capabilities through cumulative experience with the technologies. This affects AMT use rates as firms that profit from the introduction of AMTs have a greater propensity to adopt additional AMTs (Kelly and Helper, 1997; Hottenstein et al., 1999).

Production-related staff are the most common internal source of ideas for AMT adoption (Baldwin and Sabourin, 1995, Millen and Sohal, 1998). The participation of manufacturing managers in formulating corporate strategy has also been found to enhance AMT use (Tracey et al., 1999).

[10] See Britton, 1991; Baldwin and Sabourin, 1995; Kelley and Helper, 1997; Hottenstein et al., 1999.

[11] Most surveys of AMT adoption have not included this factor in their evaluation, but many manufacturing extension practitioners consider a change in customer requirements to be the main force behind AMT adoption.

Process engineering capability could also increase AMT adoption rates. However, the presence of in-house manufacturing engineering staff was not a significant predictor of AMT use in one study (Shapira and Rephann, 1996). The level of internal resources that can be committed to implementing change also positively affects the adoption of new technologies. Larger firms have an advantage in this regard.

Other internal sources of technological expertise, such as manufacturing executives and in-house technology centres, do not seem to influence the rate of adoption (Hottenstein et al., 1999). This suggests that it is not the presence of internal resources, but the linkages between these resources, that is critical to increasing AMT use. The practice of concurrent engineering, which involves the integration of product and process design, and the use of cross-functional design teams, can serve as proxy measures for these internal linkages. Both are evaluated in Section 6.6.

6.1.1 AMT Use Rates by External Information Sources

The 1998 AMT Survey asks respondents from plants that use at least one AMT if nine external sources "play an important role in providing ideas for the adoption of advanced technology in your plant". Each question is asked on a yes or no basis.[12] Basic results by plant size are provided in Table 6.1, listed in descending order of the frequency with which each source is cited by all plants.

With the exception of customers, the percentage of plants that cite a source increases with the number of employees. The result is that the average number of cited external sources also increases with plant size, from 3.5 for plants with less than 50 employees to 5.2 for plants with 250 or more employees.

Table 6.1 Percent of AMT Users that Cite External Sources for Providing Ideas for AMT Adoption, by Plant Size

	Number of employees				All
External Sources	**10 - 49**	**50 - 99**	**100 – 249**	**250 +**	**Plants**
Trade fairs, conferences, publications	71%	85%	79%	87%	76%
Suppliers	66%	73%	75%	86%	70%
Customers*	65%	66%	69%	65%	66%
Other producers in your industry	41%	49%	46%	56%	44%
Consultants	35%	48%	52%	66%	42%
Related firms	35%	37%	49%	66%	39%
Governments/institutes/associations	16%	23%	21%	32%	19%
Universities	11%	15%	22%	33%	15%
Patents	11%	17%	18%	29%	14%

* No statistically significant differences from the average. For all other external sources, there are statistically significant differences from the average frequency of use.

[12] The question also includes a 'not applicable' category. Plants that checked this response category are included in the 'no' response group.

Although a higher percentage of large than small plants cite each external information source, Table 6.1 shows that rankings are similar for all plant size classes. For instance, the most commonly cited external source for all size classes is trade fairs, conferences & publications, followed in second place by suppliers. If "related plants", which are only available to multi-establishment firms are excluded, the rankings are closely correlated across all size classes.

Customers are the third most important external source for all plants except for those with more than 250 employees, where related firms are in third place, although the number of large plants citing customers is very close to those citing related firms. The high percentage of plants that find customers to be an important source of ideas for AMT adoption provides indirect support for case studies that find customer requirements to be a major reason for AMT adoption.

The two sources with the greatest difference in citation rates by plant size are consultants and related firms, with a 31% difference between the smallest and largest plants in both cases. The large difference for consultants substantiates previous research that finds consultants more likely to target larger firms for their services. The results for related plants is probably due to the fact that large plants simply have more related plants, R&D facilities, or other intra-firm units that can serve as an information source.

It is important to note that rankings do not necessarily reflect perceptions of the quality of different sources. A high frequency rating should be interpreted conservatively with regard to the value of the source. For example, trade magazines report on a wide range of technologies, but a consultant will be of more assistance in evaluating a particular AMT for a specific plant.

6.1.2 AMT Use Rates by Internal Information Sources

The survey question on internal information sources is identical in structure to the question on external sources. Nine internal sources are queried. Table 6.2 gives the results by plant size, listed in descending order of the frequency with which each source is cited by all plants.

Table 6.2 Percent of AMT Users that Cite Internal Sources for Providing Ideas for AMT Adoption, by Plant Size

	Number of employees				All
Internal Source	**10 - 49**	**50 - 99**	**100 – 249**	**250 +**	**Plants**
Production staff	64%	76%	76%	83%	69%
Design staff	54%	63%	62%	73%	58%
Production engineering	47%	64%	67%	82%	55%
Sales and marketing*	54%	60%	55%	59%	56%
Research	50%	55%	58%	64%	47%
Experimental development	42%	51%	52%	60%	46%
Corporate head office	36%	49%	56%	64%	43%
Related plants	20%	34%	51%	66%	30%
Technology watch program	22%	25%	20%	37%	23%

* No statistically significant differences from the average. For all other internal sources, there are statistically significant differences from the average frequency of use.

Production staff is the most frequently cited source by all size classes. The next most commonly cited sources are production engineering and design staff, with the exception of the ranking for production engineering by plants with less than 50 employees. One explanation is that many smaller plants are less likely to employ production (process) engineers.

As with external sources, the rank order of internal sources is similar across plant size categories. The most striking differences between the smallest and largest size class are for sales & marketing and production engineering. The ranking for sales and marketing declines from third place for the smallest plants to sixth place for the largest plants, while the ranking for production engineering increases with plant size from fifth place for the smallest plants to second place for all other size classes. The difference by plant size in the importance of production engineering highlights the comparative lack of resources in smaller plants.

6.1.3 AMT Use by the Number of Information Sources

How are internal and external information sources related to AMT use? Specifically, we are interested in the following three questions.

1. Does an information network, that is, a diversity of sources, play a role in AMT use? In other words, is there a correlation between the average number of sources cited and the number of AMTs that have been adopted?
2. Do the use patterns for specific sources vary by the intensity of AMT use? For instance, do plants that only use a few AMTs access different sources than plants that use a large number of AMTs? The answer to this question is particularly relevant to external sources, where policy could assist plants to learn more about potentially beneficial AMTs.
3. Do external information sources provide an adequate substitute for internal sources?

Table 6.3 provides some answers to the first question on the effects of information networks.

Table 6.3 Correlation Coefficients (Cf) between the Number of AMTs in Use and the Number of Internal and External Information Sources Cited

	Number of employees							
	10 - 49		50 - 99		100 - 249		250 +	
Information source	Average number cited[1]	Cf.	Average number cited[1]	Cf.	Average number cited[1]	Cf.	Average number cited[1]	Cf.
Internal & external combined	7.4	.321	8.9	.330	9.3	.389	11.1	.330
Internal only	3.9	.336	4.8	.332	5.0	.409	5.9	.322
External only	3.5	.220	4.1	.243	4.3	.254	5.2	.258

All coefficients are statistically significant with $p < .000$.
1: Average number of information sources cited per size class.

For all four firm size classes, there is a significant and positive correlation between the number of information sources cited and the number of AMTs in use. In general, the correlation coefficients are higher for internal sources, indicating that they have a stronger relationship with the number of AMTs in use than external sources.

Table 6.4 provides relevant results for the second question - are there differences in the types of external sources that are used by plants with different patterns of AMT use? The comparison is between plants that only use mature AMTs versus plants that use other types of AMTs and between plants that use five or more AMTs compared to plants that use less than five AMTs. The results given in Table 6.4 are limited to plants with less than 100 employees and are given in descending order for plants that only use mature AMTs. The results for large firms (not shown) are similar.

A smaller percentage of plants that only use mature AMTs, or which use less than 5 AMTs, cite each external information source. For example, 67% of plants that only use mature AMTs cite trade fairs compared to 77% of other plants. Second, the rank order for each external source is identical with one minor exception: the ranking for suppliers and customers is reversed in the comparison of the use of five or more AMTs. The similarity of the rankings indicates that plants that are less intensive users of AMTs do not use different external information sources. They are simply less likely to cite each of them.

Table 6.4 Percentage of Plants by AMT Use that Cite an External Information Source

	Uses Mature AMTs only		Uses 5 or more AMTs	
External Source	**No**	**Yes**	**No**	**Yes**
Trade fairs, confs., publications	77%	67%	73%	*76%
Suppliers	71%	57%	61%	72%
Customers	70%	53%	55%	75%
Other producers in industry	46%	33%	38%	47%
Consultants	41%	30%	34%	42%
Related firms	39%	25%	29%	40%
Governments/institutes/associations	19%	12%	15%	20%
Patents	15%	5%	9%	16%
Universities	14%	5%	8%	15%

* Difference is not statistically significant. All other differences are statistically significant with $p < 0.05$.

The third question is if external sources can substitute for internal sources. This is a difficult question to answer because it concerns not only the existence of internal sources, but internal capabilities in general.

A simple method of evaluating this question, presented here, is to determine the average number of external sources that are cited by plants that cite zero, one, two, and up to nine internal sources. We would expect that plants that cite very few internal sources would, on average, cite more external than internal sources. This contrasts with the general pattern in which plants cite more internal than external source.

The results support this expectation, with a change in the citation pattern between plants that cite three or fewer internal sources compared to plants that cite four or more. Plants that cite three or fewer internal sources cite, on average, 1.8 internal sources and 2.7 external sources. The reverse pattern occurs for plants citing four or more internal sources, with an average citation of 5.8 internal and 4.5 external sources. These results suggest that plants with very few internal sources turn to external information sources.

6.2 Training

AMT use requires a complementary skill base. Efforts to meet this need increase the chances of successful AMT use, leading to the adoption of additional AMTs. Thus, higher use rates are expected in companies with formal skills training programs. Other research has found a positive association between training and AMT adoption (Shapira and Rephann, 1997) and with the probability of successful AMT implementation (Hottenstein et al., 1999).

The 1998 AMT Survey asked the respondents from AMT user plants if they provided five different types of training "pertaining to the adoption of advanced technology in the last three years": basic literacy, computer literacy, technical skills, quality control skills, and safety skills. The percentage of plants that provide any staff training and each of the five types of training increases with plant size. Relevant results are given in Table 6.5.

Table 6.5 Percentage of Plants that Provide Training by Use of Mature AMTs and Plans to Adopt Additional AMTs in the Future

	10 - 99 employees		100+ employees	
Type of training	**Other AMTs**	**Only mature**	**Other AMTs**	**Only mature**
Basic literacy/numeracy	20%	13%	41%*	27%*
Computer literacy	64%	41%	81%	68%
Technical skills	66%	44%	83%	64%
Quality control skills	60%	37%	80%	47%
Safety skills	61%	44%	82%	61%
	Plan to adopt	**No plans**	**Plan to adopt**	**No plans**
Basic literacy/numeracy	19%*	18%*	39%*	40%*
Computer literacy	63%	46%	80%*	82%*
Technical skills	65%	50%	81%*	84%*
Quality control skills	59%	42%	77%*	80%*
Safety skills	61%	45%	80%*	83%*

* Difference is not statistically significant. All other differences are statistically significant with $p < 0.05$.

Generally, a relatively high prevalence of training is associated with AMT use. With the exception of basic literacy, each type of training is provided by over 50% of plants in each size class. However, a significantly lower percentage of firms that only use mature AMTs provide training. Differences in training by plans to adopt additional AMTs is limited to plants with less than 100 employees. A higher percentage of small firms that plan to adopt provide training, with the exception of training in basic literacy.

6.3 R&D Capabilities

R&D can improve a firm's ability to employ technical knowledge and thereby enhance its absorptive capacity (Papaconstantinou et al., 1996). In the 1989 survey of Canadian manufacturers, whether or not a plant conducted R&D strongly influenced the use of technology (Baldwin and Diverty, 1995). Plants that performed their own R&D were also more likely to use AMTs than plants that contracted out R&D.

The 1998 Canadian AMT survey contains questions on the R&D capabilities of either the plant or the firm to which it belongs and the methods that the plant uses to adopt AMTs. Some of these questions were not included in the two previous Canadian AMT surveys and therefore deserve extra attention. In addition, these questions are relevant to recent theories of innovation, such as the role of absorptive capacity in innovation and the need for formal R&D versus other internal capabilities in order to innovate.

Table 6.6 gives AMT use rates by three categories of the R&D activity of the firm that owns the plant: the firm conducts no R&D, the firm performs R&D on an occasional and/or contract basis only, and the firm conducts R&D on an ongoing basis in-house. The latter category also includes some firms that conduct occasional or contract R&D *in addition to* continuous in-house R&D. By all measures of AMT use, plants from firms that perform R&D on an ongoing basis have the highest AMT use rates.[13]

Table 6.6 AMT Use by the R&D Activity of the Controlling Firm

	No R&D	Occasional and/or contract R&D	Ongoing, in-house R&D
Percent of plants by category[1]	45.1	22.5*	32.4
Use one or more AMTs	63%	82%	91%
Use 5 or more AMTs	30%	50%	65%
Only use mature AMTs	18%	18%	14%
AMT investment > 25% of total plant investment	22%	28%	33%
Mean number of AMTs in use	3.3	5.7	7.4

There are statistically significant differences ($p < 0.05$) from the average for all measures of AMT use.
* Slightly more occasional R&D performers (30.2%) use contract R&D than ongoing R&D performers (24.6%).
1: The percentages total 100% across this row, accounting for all surveyed plants.

Table 6.7 gives the basic indicators for AMT use rates among R&D performing firms by the responsibility of the R&D department. Respondents from firms that performed any type of R&D were asked whether the R&D department was responsible for each of four activities: to create original products, to introduce off-the-shelf equipment or process technology, to substantially adapt technology acquired from others, and to create original production equipment or new process technology. The number of AMTs in use is highest among plants that can create original production equipment. Plants with R&D departments that only develop product innovations consistently have the lowest use rate for AMTs. Firms that adapt production technology acquired from other firms have the highest use of at least one AMT.

[13] The results are similar when determined separately for small (< 100 employees) and large (100 + employees) plants.

In sum, AMT use rates are higher among plants that perform R&D or use external R&D resources than in firms with no R&D capabilities. However, there are significant differences in AMT use rates among R&D performing firms by the type of R&D that they perform. AMT use rates are highest among firms that can adapt or develop new production technology. Having process R&D capability increases the use of AMTs compared to plants with product R&D capability alone.

Table 6.7 AMT Use by the R&D Activity of the Controlling Firm (Results for R&D performing firms only)

	Firm R&D activities[1]			
	Only product R&D	**Off-the-shelf process**	**Technology adaptation**	**New production technology**
% R&D performing firms in class[2]	14.4	6.1	21.0	58.5
Use one or more AMTs	84%	87%	94%	89%
Use 5 or more AMTs	49%	56%	62%	62%
Only use mature AMTs*	14%	18%	19%	15%
AMT invest > 25%*	25%	35%	33%	32%
Mean number of AMTs in use	5.2	5.6	6.5	7.4

* Differences are not statistically significant from the average. Otherwise, statistically significant differences ($p < 0.05$) from the average for all other measures of AMT use.
1: Responsibility for the four activities as reported in the table is cumulative from left to right. For example, firms with responsibility for introducing "off-the-shelf equipment or process technology", can also perform product R&D, but firms that perform only product R&D do not perform any of the other three activities. Firms that create 'original production equipment or new process technology', can have any of the other three R&D responsibilities.
2: The percentages total 100% across this row, accounting for all surveyed plants.

6.4 Method of AMT Introduction

The amount of effort it takes to successfully introduce a new manufacturing technology into existing plant is often underestimated by manufacturers, leading to a high rate of AMT implementation failures (Montgomery and Levine, 1996). Process engineering capabilities may substantially reduce these risks.

The 1998 AMT Survey asks if the firm used each of four methods of introducing AMTs: "by purchasing off-the-shelf equipment", "by licensing new technology", "by customizing or significantly modifying existing technology", and "by developing brand new advanced technologies (either alone or in conjunction with others)". There is a clear trend in the internal capabilities required by the plant to use each method, ranging from minimal for purchasing off-the-shelf equipment to extensive for developing brand new advanced technology. In order to simplify the analysis, two methods, off-the-shelf purchases and licensing, are combined. All plants that responded to this question are then assigned to one of three classes depending on their most advanced method of introducing an AMT. For example, a firm that uses both in-house customization and which develops brand new AMTs is classified in the latter category.

The method used to introduce AMTs varies by plant size: 53% of plants with 10 to 49 employees only acquire AMTs off-the-shelf, compared to 23% of plants with over 250 employees. The percentages are reversed for the ability to develop new AMTs in-house, which is present in 23% of plants with 10 to 49 employees compared to 48% of the largest plants.

Table 6.8 gives AMT use rates by the method used to introduce advanced technologies into the plant. The results are limited to firms that have adopted at least one AMT. AMT use clearly increases with the ability of the plant to adapt AMTs to its own needs, with much lower AMT use rates among plants that only purchase off-the-shelf equipment or license new technology.[14]

Table 6.8 AMT Use by the Method of Introducing AMTs into the Plant

	Only purchase AMTs off-shelf or license	In-house customization	Develop new AMTs in-house
% AMT users in category[1]	46.1	25.7	28.2
Use 5 or more AMTs	47%	61%	76%
Only use mature AMTs	30%	19%	11%
AMT investment > 25%	30%	33%	40%
Mean number of AMTs in use	5.2	7.0	8.8

Statistically significant differences ($p < 0.05$) from the average for all measures of AMT use.
1: The percentages total 100% across this row, accounting for all surveyed plants

Table 6.9 looks at the effect of R&D capability on the method of introducing new technology. As expected, plants that are owned by firms that do not perform R&D are the most likely to rely on off-the-shelf purchases or licensing (61%), while plants that perform ongoing R&D in-house are most likely to develop AMTs in-house (42%).

Table 6.9 Methods Used to Adopt AMTs by the *Firm's* R&D Activities

	Method used at the plant level to introduce AMTs (Limited to plants that use AMTs)			
Firm's R&D Activities	**Only off-the-shelf or license**	**Customization/ modification**	**In-house development**	
No R&D	61%	24%	16%	100%
Occasional/contracted	43%	31%	26%	100%
Ongoing, in-house	34%	24%	42%	100%

[14] The results are similar when determined separately for small (< 100 employees) and large (100+) plants.

A notable percentage of plants without R&D capabilities customize AMTs (24%) or develop them in-house (16%), while plants with in-house R&D capabilities also acquire AMTs off-the-shelf (34%). These results show that the process engineering capability, as defined by the ability to either develop or customize AMTs, overlaps with R&D capability, but is not synonymous with R&D capability. Some plants with no access to formal R&D can develop AMTs in house or adapt them to their own needs.

The distinction between process engineering and "generic" R&D capability is further highlighted by examining the relationship between R&D responsibilities and the method of introducing AMTs. We would expect plants that are owned by firms that only perform product R&D, or which do not create or adapt production equipment, to be more likely to acquire AMTs off-the-shelf. This is what happens, as shown in Table 6.10.

Plants from firms with R&D departments that only develop new products have the highest off-the-shelf AMT adoption rate (56%) and the lowest rate of in-house development of AMTs (17%). In contrast, plants that belong to firms with R&D departments that create "original production equipment or new process technology" have the lowest rate of off-the-shelf adoption (29%) and the highest rate of in-house AMT development (46%).

Table 6.10 Method of Adopting AMTs by the R&D Department's Responsibility

	AMT adoption method of *plant* (Limited to R&D performing firms that use AMTs)			
R&D responsibility of *firm*	**Only off-shelf or licensing**	**Customization or modification**	**In-house development**	
Only product R&D	56%	27%	17%	100%
Off-the-shelf process introduction	51%	24%	25%	100%
Technology adaptation	46%	29%	25%	100%
Process creation	29%	25%	46%	100%

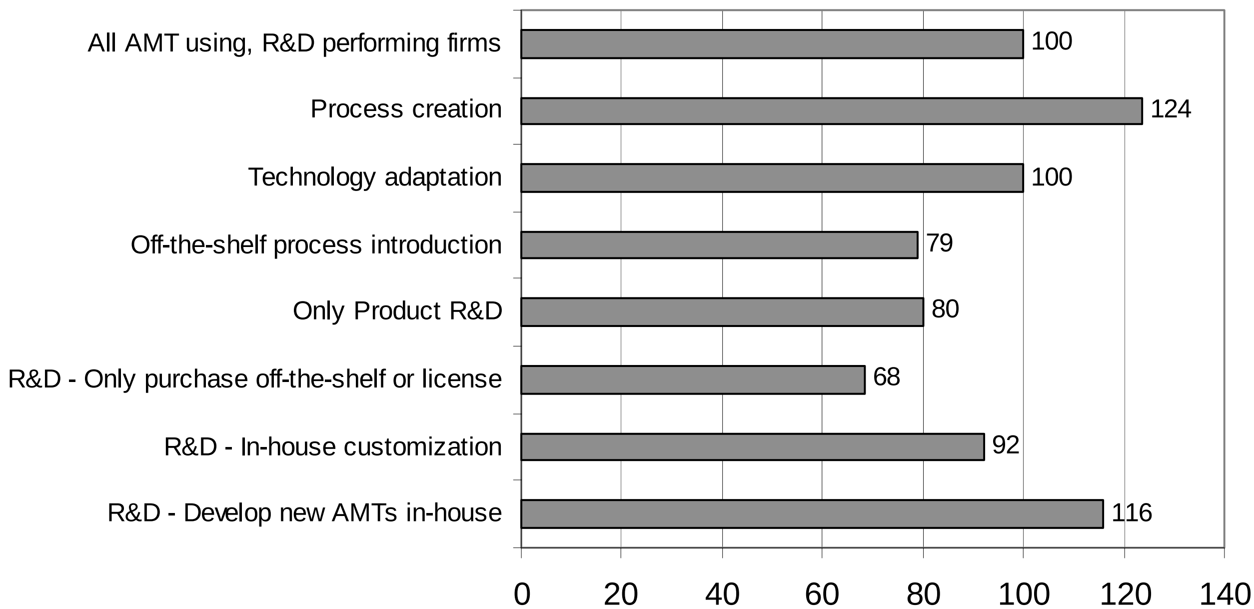
1: Responsibility for the four activities as reported in the table is cumulative reading down the table.

Chart 6.1 provides AMT mean use rate indexes[15] by two measures of the plants' capabilities: the method of introduction and the responsibilities of the R&D department. The AMT mean use rate indexes again demonstrate that process engineering capability is an important factor in AMT adoption. For instance, the AMT mean use rate index for developing new AMTs in-house (124) is greater than the use rate index for firms with R&D process creation responsibilities (116). Similarly, the use rate index for in-house customization is greater than that of firms whose R&D departments are responsible for technology adaptation. These differences indicate that the contribution of other departments to the technology implementation process has an effect on AMT adoption. Referring back to the results for the importance of various internal resources as sources of information on AMT adoption (Section 6.1), we would assume these to be the production and engineering staff.

[5] The index is equal to the average number of technologies used by firms in a specific category divided by the mean number of technologies used in the population times 100.

In conclusion, the results suggest that product R&D and process engineering capabilities are distinct and that process engineering capabilities have a greater effect on AMT adoption than "generic" R&D capabilities. While R&D capabilities lead to increased technology use, the *type* of R&D performed by the firm plays a crucial role. Product R&D and process engineering capabilities are distinct, with the latter having a greater effect on AMT adoption.

Chart 6.1 R&D and Process Engineering Capabilities
Mean Use Rate Indexes



6.5 Business Strategies

AMTs offer firms the technological capability to compete in new ways. Business strategies that build on these capabilities should then be positively correlated with greater AMT use.

Among the many different business strategy models, Michael Porter's (1980) is widely referenced since its elements can be readily linked to operational characteristics. Porter's 1980 model featured three generic strategies—cost leadership, product differentiation, and focus—representing alternative strategic positions in an industry. These three strategies encompass two dimensions: product differentiation and market focus (or scope). Focus represents the choice of where to compete in the market (e.g., in which product segments), while a product differentiation strategy emphasizes competing on product characteristics, such as cost or quality.

While cost reduction is an important business strategy, product differentiation strategies in today's markets are equally critical. Primary among these are superior quality, faster time-to-market, and product customization. Within Porter's schematic, researchers have pointed to product differentiation as the dimension pertaining most directly to technological capabilities (Kim and Lee, 1993; Swink and Hegarty, 1998). In this regard, we would expect business strategies that emphasize product differentiation to lead to greater use of AMTs.

While researchers have not specifically studied business strategies as a determinant of AMT use, there is a significant body of work that relates the technical advantages of AMTs to competitive strategy. Small (1998) examined whether AMT users ascribed different levels of importance to these benefits when making the decision to adopt an AMT. His findings indicate that improving product quality and reducing manufacturing lead times (both means of product differentiation) were the most important objectives. Less important were more general business objectives, such as gaining market share.

The 1998 AMT survey asks respondents about the importance to their firm of seven business strategies. The data presented below are based on the most important score (the percentage of respondents in a given class that give their highest rating to each business strategy).[16]

Table 6.11 presents AMT use rates for firms that give their most important rating (high) or any other rating (low) to each business strategy. The percentage of plants using 5 or more AMTs and the mean number of AMTs in use appear to be the best measures of differences in AMT use by strategy. Using these two indicators, four of the seven strategies are strongly linked to AMT use: developing new products, developing new manufacturing technology, using teams, and ongoing technical training. The strongest relationship between business strategies and AMT use is for cross-functional teams and ongoing technical training. Both are strategies to build up the firm's internal capabilities.

[16] For example, assume that the highest score given by a respondent is 4, and that this score is given to 'develop new products' and to 'use teams'. This respondent has given their 'most important' score to these two strategies and a 'low' score to the other five strategies.

Table 6.11 AMT Use by Business Strategy

Business strategy	Strategy rating	AMT use indicator (percent of plants in each strategy class or mean): 1 + AMTs	5+ AMTs	Mature AMTs Only	AMT invest > 25%	Mean no. AMTs in use
Develop new products	Low	75	42	**18**	27	4.8
	High	**79**	**50**	14	27	**5.8**
Enter new markets	Low	**78**	46	18	27	5.3
	High	74	45	16	26	5.0
Reduce manuf. costs	Low	75	43	18	23	4.7
	High	77	47	16	**28**	**5.3**
Develop new manufacturing technology	Low	76	43	18	22	4.8
	High	76	**50**	15	**36**	**5.8**
Use new materials	Low	**79**	**48**	17	27	**5.3**
	High	70	39	16	27	4.8
Use teams	Low	76	43	**19**	25	4.7
	High	77	**51**	12	**30**	**6.1**
Ongoing tech training	Low	76	43	**18**	24	4.8
	High	77	**50**	14	**32**	**6.0**

Statistically significant differences ($p < .05$) in AMT use between firms that give each strategy a 'low' and a 'high' importance rating are marked in bold type.

Table 6.12 gives the percentage of plants in each size class that give their most important rating to each business strategy. More respondents from large than from small plants are concerned with reducing costs and using teams. However, the differences by plant size are relatively minor. Of note, reducing costs is the most important strategy across all plant size classes.

Table 6.12 Percentage of Respondents by Plant Size that Give a 'Most Important' Rating to a Business Strategy

	Number of Employees: 10 - 49	50 - 99	100 - 249	250+
Develop new products	38	43	43	42
Enter new markets*	44	47	41	41
Reduce manufacturing costs	73	75	80	81
Develop new manufacturing technology*	38	39	32	35
Use new materials	30	21	19	17
Use teams	33	34	33	43
Ongoing technical training*	34	32	30	38

* No statistically significant differences from the average for all plants combined.

6.6 Advanced Practices

It is widely recognized that firms must undergo extensive changes in their organizational structures and management practices (advanced practices) in order to successfully integrate AMTs into existing operations.[17] The firm can make these changes before or after AMT use commences, but their implementation is likely to require considerable investment.

The degree of integration between business and manufacturing functions affects the quantity and type of benefits from AMT use. There is a strong association between AMT use and cross-functional teams and concurrent engineering, which suggests a complementary relationship (Hottenstein et al, 1999). Concurrent engineering and cross-functional teams support the use of the firm's knowledge bases. The use of advanced organizational practices aimed at systematizing knowledge and resources increases the firm's manufacturing capabilities. Gate (1997) found differences in the implementation rates of practices for large versus small plants and for plants that are part of multi-plant enterprises versus stand-alone plants.

The AMT questionnaire asks respondents whether they regularly use each of 12 advanced practices related to manufacturing.[18] Three response categories are given: yes, no, or 'not applicable'. We assume that a 'not applicable' response indicates that the plant does not use the practice. The results by plant size are given in Table 6.13.

The use of each practice increases monotonically by plant size for every business practice. The mean number of practices in regular use increases from 2.7 for the smallest to 7.2 for the largest size class. The strong association of advanced practices with plant size could indicate both a need for more systematic practices with increasing size as well as a greater awareness of these techniques among larger plants.

[17] See OECD, 1997; Millen and Sohal, 1998; Hottenstein et al., 1999; Tracey et al., 1998.

[18] Although the term "business practices" is used in the 1998 Survey, we use "organizational and management practices" as a more accurate description of them.

Table 6.13 Percentage of Plants by Employment Category Reporting the Use of an Advanced Practice

Advanced Practice	Number of employees: 10 – 49	50 – 99	100 - 249	250+	All plants
Continuous improvement	40	55	72	84	49
Just-in-time inventory control	36	42	50	60	40
Supplier certification	28	45	55	70	36
Benchmarking	27	39	60	75	35
Plant certification	24	49	60	74	34
Electronic work order management	23	31	49	64	29
Cross-functional design teams	23	29	50	68	29
Concurrent engineering	24	33	40	59	29
Statistical Process Control (SPC)	14	29	41	68	23
Quality function deployment (QDP)	18	24	34	46	22
Process simulation	7	11	16	31	10
Distribution resource planning (DRP)	8	9	20	23	10
Mean number of practices in use	2.7	4.0	5.5	7.2	3.5

Each practice contains significant differences by plant size from the average for all plants ($p < 0.000$).

Table 6.14 gives the prevalence of each advanced practice by production system. The highest rates for nine of the 12 practices are for plants in continuous flow production sectors. The larger average size of continuous flow plants is not the cause, since the prevalence rates among small continuous flow plants are highest for ten of the 12 business practices (results not shown). This suggests that advanced practices may be used in plants where there is a greater need for systematization. This need is characteristic of continuous flow production systems in comparison to discrete parts production.

Table 6.14 Percentage of Plants by Production System that Use an Advanced Practice

Advanced Practice	Discrete non-engineering	Discrete engineering	Continuous flow	Mixed
Continuous improvement	42	52	**59**	45
Just-in-time inventory control	36	43	**44**	36
Supplier certification	26	45	**48**	26
Benchmarking	31	37	**47**	32
Plant certification	24	44	**46**	25
Electronic work order management	22	**34**	33	31
Cross-functional design teams	21	**36**	33	26
Concurrent engineering	23	**40**	27	19
Statistical Process Control (SPC)	17	25	**37**	18
Quality function deployment (QDP)	20	23	**27**	20
Process simulation	7	12	**17**	8
Distribution resource planning (DRP)	9	11	**17**	7
Mean number of practices in use	2.8	4.0	**4.3**	2.9

Results in **bold** mark the highest prevalence.

The use of cross-functional teams and concurrent engineering practices is highest in discrete parts manufacturing where AMT use is also highest. This result indicates that practices that promote functional integration and the use of knowledge bases complement AMT use.

6.6.1 AMT Use by Advanced Practice

The percentage of firms that use specific organizational practices also increases with AMT use, as shown in Table 6.15. Only 20% of plants that do not use AMTs regularly use continuous improvement, compared to 41% of plants that only use mature AMTs and 71% of plants that use five or more AMTs.

Table 6.15 Percentage of Plants by Selected AMT Use Indicators that Use an Advanced Practice

Advanced practice	No AMT use	Only use mature AMTs	Use 5 or more AMTs	All Plants
Continuous improvement	20	41	71	49
Just-in-time inventory control	23	27	52	40
Supplier certification	13	29	54	36
Benchmarking	12	21	55	35
Plant certification	10	27	52	34
Electronic work order management	5	19	49	29
Cross-functional design teams	8	19	48	29
Concurrent engineering	7	19	47	29
Statistical Process Control (SPC)	5	12	39	23
Quality function deployment (QDP)	7	13	35	22
Process simulation	1	5	18	10
Distribution resource planning (DRP)	2	4	18	10

6.7 Conclusions

Several different indicators of manufacturing resources are covered in the 1998 AMT Survey: the use of internal and external information sources, staff training programs, R&D capabilities, and the method of introducing AMTs, which varies from off-the-shelf purchases to in-house development. The main findings are as follows:

- There is a significant and positive correlation between the number of information sources cited and AMT use, suggesting that a diversity of information sources plays an important role in the adoption of AMTs.
- The use of both internal and external information sources varies by plant size, but the relative frequency of use of the different sources is similar for all size classes. Small plants do not use different information sources – they are simply less likely to cite as many of them.

- There is a significant and positive correlation between the number of AMTs in use and the number of cited information sources. The effect is strongest for internal sources.
- The average number of cited external sources increases from 3.5 sources (out of 9) for plants with less than 50 employees to 5.2 for plants with 250 or more employees. Trade fairs, conferences & publications is the most commonly cited source, followed by suppliers. Consultants are cited far more frequently by large than by small plants.
- The most frequently cited internal source of ideas for AMT adoption is production staff. The greatest differences by size are for sales and marketing and for production engineering. The ranking for production engineering increases with plant size from fifth place for the smallest plants to second place for all other size classes.
- Plants that have access to very few internal information sources are able to make up partly for this lack by using external sources.
- Internal information sources have a greater effect on AMT use than external sources.
- Staff training programs are positively correlated with AMT use. These include: basic literacy, computer literacy, technical skills, quality control skills, and safety skills. With the exception of basic literacy, each type of training is provided by over 50% of plants in each size class.
- A significantly lower percentage of plants that only use mature AMTs provide staff training compared to plants that use one or more advanced AMTs. Training only influences future adoption plans among plants with less than 100 employees. Among these plants, planned adoption rates are higher among plants that provide training than among plants that do not.
- AMT adoption rates increase with the R&D capabilities of the controlling firm. Plants that perform R&D on an ongoing basis have the highest AMT use rates. Firms that only perform product R&D adopt fewer AMTs than firms with process R&D capability.
- Process engineering capabilities have a strong effect on the rate of AMT adoption. AMT adoption rates are lower among plants that can only purchase AMTs off-the-shelf or license AMTs than plants that are capable of customizing or developing AMTs. Almost three times as many plants that only obtain AMTs off-the-shelf or via licensing only use mature AMTs.
- R&D capabilities are not a prerequisite for the ability to develop AMTs. 40% of plants that lack access to R&D capabilities customize or develop new AMTs.
- Plants controlled by firms that stress four business strategies—developing new products, manufacturing technology, using teams, and ongoing technical training—have higher AMT use rates than plants that find these strategies of less importance.
- Two business strategies, ‘on-going technical training’ and ‘using teams’, can build up internal technical capabilities.
- The use of advanced organizational and management practices increases monotonically by plant size.
- The use of cross-functional teams and concurrent engineering practices is highest in engineered discrete parts industries. This result supports the hypothesis that practices that promote functional integration for the utilization of knowledge bases complement AMT use. Nine of the other ten practices are most prevalent in the continuous flow production industries.

7 Environmental Factors

The 1998 AMT Survey contains questions on three environmental, or external, factors that shape the decision to adopt AMTs. These questions apply to the availability of skilled workers, external obstacles to the adoption of AMTs, and the number of competitors.

7.1 Shortages of Skilled Workers

Public investment in developing curricula and training programs to increase the supply of skilled workers is a key policy issue related to advanced technology use. AMTs, by definition, require skills related to computer usage that are not necessary to operating conventional production technologies. Several studies have found a lack of skilled workers is a major barrier for AMT adoption (Northcott and Vickery, 1993).

The inferred relationship between AMT use and skills shortages should be treated cautiously. Non-AMT users could experience skills shortages as well if there is a general shortage of qualified workers (Texeira, 1998). In surveys during the 1980s, no apparent difference in skill shortages could be found between AMT users and non-users, or between plants that used simple, stand-alone AMTs or complex, integrated systems (Northcott and Vickery, 1993). Acquiring skilled workers is possibly more a cost than an obstacle to adoption.

The 1998 AMT survey asks AMT users about plant-level shortages of 20 skilled occupations, within four occupational groups, within the previous year. The four occupational groups include: professionals with university degrees (six types), management personnel (three types), technicians (seven types), and skilled trades (four types). The results are limited to the four groups of skilled personnel. Plants that reported a shortage of any of the job types within each group are classified as reporting a shortage for that group. The results are shown in Table 7.1.

Table 7.1 Percentage of Plants that Report Shortages of Skilled Personnel by Four Occupational Groups

	Number of employees				
	10 - 49	**50 - 99**	**100 - 249**	**250+**	**All Plants**
Professionals[1]	36%	44%	50%	67%	42%
Skilled trades[2]	42%	40%	33%	41%	40%
Technicians[3]	32%	38%	39%	62%	36%
Management[4]	27%	34%	34%	44%	31%
Mean # shortages	*2.3*	*2.8*	*2.9*	*4.4*	*2.6*

All occupational groups show statistically significant differences from the average by plant size ($p < 0.000$).

1: With a university degree in mechanical/aerospace, electronic/computer, chemical/chemical process, industrial/manufacturing process, science professionals, or computer scientists.

2: Machinists, machine operator, electrical equipment operator, process plant operator.

3: Electronics/computer hardware, science, engineering science, computer programmers, communication network administrators, computer aided design, and instrumentation.

4: Production, design, and human resource managers.

For three occupational groups, the percentage of plants reporting shortages increases with plant size. The exception is skilled trades, where there is no trend by plant size. Except for plants with 10 to 49 employees, the most frequently cited shortages are for professional personnel.

Table 7.2 gives the prevalence of personnel shortages for plants that only use mature AMTs and for plants that use developing AMTs, plus data on the percentage of plants that find all shortages in an occupational group to be 'not applicable'. Compared to plants that use developing AMTs, a higher percentage of plants that only use mature AMTs report that shortages within the occupational group are 'not applicable' and a lower percentage report skill shortages. An exception is for plants with 10 to 99 employees, where there is no difference for technicians.

Plants that report shortages of skilled personnel also use more AMTs than plants that do not report shortages (results not shown). These results, combined with the results given in Table 7.2, show that the prevalence of shortages increases with both the number and technical complexity of the AMTs in use.

Table 7.2 Percentage of Plants that Report Shortages of Skilled Personnel by Use of Mature versus Developing AMTs

	10 - 99 employees				100+ employees			
Occupational	**Developing AMTs**		**Only mature AMTs**		**Developing AMTs**		**Only mature AMTs**	
Group[1]	**Shortage**	**NA**	**Shortage**	**NA**	**Shortage**	**NA**	**Shortage**	**NA**
Professionals	39%	17%	33%	27%	57%	7%	40%	21%
Skilled trades	43%	7%	36%	15%	37%	5%	21%	13%
Technicians	34%	13%	32%	17%	49%	5%	25%	8%
Management	31%	8%	24%	11%	40%	4%	19%	6%

1: See Table 7.1a for a description of each occupational group.

7.2 Obstacles to AMT Use

The 1998 AMT Survey lists ten obstacles to AMT adoption and asks respondents to rate their importance on a five-point scale. Three of them; 'worker resistance, 'inability to evaluate new technology', and 'management resistance' are wholly or partially under management control. Four are cost-related: high equipment costs, integration costs, capital costs, and software development costs. The other three are small market size, skill shortages, and a lack of technical support from vendors.

Baldwin and Sabourin (1995) and Baldwin and Lin (1999) found cost-related obstacles to be the most prevalent in Canada. Capital turnover rates have an obvious relation to the diffusion of new technologies. However, capital costs may not be a factor in selecting AMTs over conventional equipment. In a study of small metal working shops, the difference in capital equipment investment between AMT users and non-users was not statistically significant (Rischel et al., 1997).

In addition to the cost of AMT equipment, there are two ancillary costs to adoption identified in the 1998 AMT Survey—software costs and technology integration costs. Costs that increase the initial investment cost, as opposed to the life cycle cost of the equipment, tend to depress investment. This is because cash flow considerations often weigh heavily in investment decisions, particularly in smaller firms.

Worker resistance has not been found to slow technology adoption (Northcott and Vickery, 1993; Shapira and Rephann, 1996). There is evidence to suggest that workers welcome the increased autonomy and job responsibilities that are associated with AMT production (Northcott and Vickery, 1993). Management resistance to change could be more of a problem (Millen and Sohal, 1998).

The inability to evaluate new technology has both technical and financial dimensions. Several studies found that conventional financial assessment procedures underestimate AMT potential (Lefley and Sarkis, 1997; Small and Chen, 1997).

The importance that firms give to obstacles generally *increases* with measures of AMT use or innovativeness (Baldwin and Lin, 1999; Arundel, 1997), possibly because experience with AMTs leads to a greater understanding of the problems. However, most surveys, including the 1998 AMT survey, ask about obstacles to *adoption* rather than with daily use. This creates problems in interpreting AMT survey results. This problem is of policy significance because the types of policies that are needed to encourage adoption could differ from the types of policies to promote successful use.

Table 7.3 gives the percentage of AMT users by plant size that find each obstacle of high importance (a score of 4 or 5 out of the five point importance scale). The results given here are limited to AMT users because the majority of plants, accounting for over 90% of production, use at least one AMT. For AMT users, the questions on obstacles refer to the adoption of past or future AMTs. The most frequently cited obstacles are cost-related, while the three obstacles influenced by management control are cited least often.

More small than large plants report that small markets, high equipment costs, and skill shortages are an important obstacle to AMT use, although the rank order of the obstacles is very similar among all size classes. Capital cost is also more frequently cited by small plants, but this result is less robust. There are no statistically significant differences by plant size for the remaining obstacles. Although statistically significant, there is only a very weak negative correlation between the number of AMTs in use and a sum of scores across the ten obstacles.

Two of the obstacles cited by more small than large firms, high equipment costs and skill shortages, concern the level of resources required for AMT adoption. The third statistically significant barrier, small market size, could also create a size-related obstacle to adoption: larger plants can use economies of scale to spread the costs and risks of adopting AMTs.

Table 7.3 Percentage of AMT User Plants by Size that Find Each Obstacle of Importance (Score of 4 or 5)

	Number of employees				
	10 - 49	**50 – 99**	**100 – 249**	**250+**	**All**
High equipment cost[1]	**64**	**67**	**53**	**57**	63
Capital costs[2]	*53*	*51*	*44*	*45*	51
Technology integration costs	43	45	35	39	42
Skill shortage[1]	**41**	**37**	**27**	**33**	38
Software development costs	36	39	32	33	36
Small market size[1]	**35**	**30**	**25**	**18**	32
Lack of tech support from vendors/consultants	19	18	17	19	19
Worker resistance[1]	**17**	**25**	**19**	**19**	19
Inability to evaluate new technology	17	22	17	17	18
Management resistance	13	19	14	15	14

1: Differences from the average are statistically significant in four comparisons: extreme scores including and excluding same-score respondents and most important scores excluding and including same-score respondents.
2: Statistically significant differences in at least two of the four analyses.

Table 7.4 gives results by production system. In the group of market and cost-related obstacles, only the differences by market size are robust, where a higher percentage of plants in the mixed production-system sector report 'small market size' as an obstacle. A comparatively high percentage of plants in discrete engineering industries report three obstacles as significant: skill shortages, an inability to evaluate new technology, and a lack of technical support from vendors.

Table 7.4 Percentage of AMT Users by Production System that Give a High Score (4 or 5) to an Obstacle

	Production System			
	Discrete non-engineering	**Discrete engineering**	**Continuous flow**	**Mixed**
Small market size[1]	31	30	34	**37**
High equipment cost	59	66	61	61
Capital costs	48	54	50	51
Software development costs	36	38	34	33
Technology integration costs	41	44	43	41
Skill shortage[1]	36	**44**	24	33
Worker resistance	19	19	18	19
Management resistance[1]	**16**	15	10	13
Inability to evaluate new technology[1]	16	**23**	13	12
Lack of technical support[1]	16	**22**	15	19

1. Highest percentage for significant differences (in four methods of analysis) in bold.

7.3 Degree of Competition

AMT adoption is widely thought to be necessary for competitive performance in today's markets. It might then be argues that more competition leads to higher AMT use rates. However, too many competitors could reduce AMT adoption, particularly among small supplier firms. This is because small supplier firms in highly competitive and volatile cost environments will seek to avoid large fixed costs. (Luria, 1997)

These effects could differ by industry. For example, firms in commodity markets compete on price. These firms invest heavily in AMTs suited to long production runs, even though they are often in highly consolidated industries. In highly fragmented industries, such as some discrete parts sectors, market failures associated with low returns from marketing AMTs to a diffuse group of small manufacturers could cause low diffusion rates (Guile, 1987).

These results suggest two alternative hypotheses for the relationship between competition and AMT use. The main hypothesis is that competition should drive firms to adopt AMTs. The alternative hypothesis suggests that the relationship between AMT use and the degree of competition will vary by sector and firm size, with competition reducing AMT use among small supplier plants in highly competitive markets and increasing AMT use in commodity markets with long production runs, such as found in the continuous flow industries.

The 1998 AMT survey asks respondents to estimate the number of competitors producing "products directly competing with your plant's primary product". Four options were provided: zero, 1 to 5, 6 to 20, and over 20. Very few large plants reported zero competitors. For this reason, some analyses combine the zero and 1 to 5 groups. Basic results are given in Table 7.5.

Table 7.5 AMT Use by Number of Competitors

	Number of competitors			
	0	1 – 5	6 - 20	> 20
< 100 employees				
Use one or more AMTs	58%	77%	73%	73%
Use 5 or more AMTs	37%	36%	36%	40%
Only using mature AMTs	13%	25%	20%	16%
AMT investment > 25% of total plant investment	18%	17%	22%	30%
Mean number of AMTs in use	4.0	4.0	4.1	4.3
100 + employees				
Use one or more AMTs	-[1]	97%	97%	96%
Use 5 or more AMTs	-	83%	90%	78%
Only using mature AMTs	-	12%	6%	9%
AMT investment > 25% of total plant investment	-	35%	38%	41%
Mean number of AMTs in use	-	9.9	10.6	9.6

In all comparisons for small plants there are statistically significant differences by the number of competitors from the expected frequency or overall mean.
1: There are too few unweighted observations of large plants with zero competitors for meaningful analysis.

Table 7.5 shows that AMT use tends to be higher among plants with a large number of competitors than among plants with fewer competitors, but the relationship is not straightforward. For instance, a higher percentage of large plants with 6 to 20 competitors use five or more AMTs than those with more than 20 competitors.

Table 7.6 provides the mean number of AMTs in use by type of production system, number of competitors, and plant size. The type of production system decreases AMT use by the number of competitors only among small plants in the discrete non-engineering sectors and for discrete engineering plants with 100 to 249 employees. AMT use increases with the number of competitors for larger plants in the discrete non-engineering sector, for mixed plants with 50 to 99 employees, and for continuous flow plants with 50 to 99 employees. The most common result, however, is no relationship between AMT use and the number of competitors, which holds for nine of the 16 comparisons.

Table 7.6 Mean number of AMTs in Use by Production System, Number of Competitors, and Plant Size

Production system	Number of competitors	Number of employees			
		10 - 49	50 – 99	100 - 249	250+
Discrete non-engineering	< 5	2.8	5.4	7.3	8.8
	5 – 20	2.3	5.3	8.2	12.0
	> 20	2.2	5.1	8.5	12.1
Discrete engineering	< 5	4.9	5.7	10.2	14.7
	5 – 20	4.2	7.6	9.9	14.1
	> 20	5.6	7.3	8.4	15.0
Continuous flow	< 5	3.2	6.6	8.4	12.1
	5 – 20	3.7	6.9	10.0	12.8
	> 20	3.5	8.4	8.3	12.2
Mixed	< 5	3.5	4.7	6.7	12.2
	5 – 20	3.7	5.1	7.5	10.7
	> 20	3.7	5.5	7.0	11.6

The interaction between the production system, plant size and competition may also influence the use of developing versus mature AMTs. Several mature AMTs, such as LAN, are relatively inexpensive, which should reduce obstacles to their adoption. Table 7.7 provides relevant results for small plants that only use mature AMTs. No results are given for larger plants because very few of them only use mature AMTs.

For plants with 50 – 99 employees, the percentage of plants that only use mature AMTs declines with the number of competitors, with the exception of discrete non-engineering plants, where the relationship is "U" shaped. The decline for the other three production systems suggests that competition compels plants to adopt more advanced technology. The results are mixed for plants with between 10 and 49 employees.

These analyses show that the relationship between AMT use and the number of competitors is complex, with only four monotonic increases after controlling for plant size effects and a decline in the use of only mature AMTs in three out of eight analyses. There is only weak evidence to support a mediating effect by the production system on the relationship between AMT use and competition. This could be due to a lack of accuracy in the classification of firms by production system. The effect of competition on AMT use is explored further in Section 9 using multivariate regression.

Table 7.7 Percentage of Small Plants that Only Use Mature AMTs by Production System, Number of Competitors, and Plant Size

Production system	Number of competitors	Number of employees	
		10 – 49	50 – 99
Discrete non-engineering	< 5	21	14
	5 – 20	20	1
	> 20	16	13
Discrete engineering	< 5	17	45
	5 – 20	27	10
	> 20	17	1
Continuous flow	< 5	12	22
	5 – 20	23	11
	> 20	15	1
Mixed	< 5	28	32
	5 – 20	12	10
	> 20	21	10

7.4 Conclusions

The major findings on the patterns of AMT use in relation to environmental influences are as follows:

- The prevalence of skills shortages increases with plant size, the use of developing AMTs, and by the number of AMTs in use.
- Of four occupational categories—professionals with university degrees, management personnel, technicians, and skilled trades—the percentage of plants reporting shortages increases with plant size, with the exception of skilled trades, where there is no trend. Shortages of each occupational type are greatest among discrete parts manufacturers.
- The most frequently reported shortages, except for the smallest plants (10 to 49 employees), are for professional personnel. Shortages of machine operators is highest among smaller firms.
- A higher percentage of plants that only use mature AMTs report that skills shortages are not applicable and a lower percentage report difficulty in finding employees with the appropriate skills, which suggests that the skills requirements for mature AMTs are not as great as for developing AMTs.
- The four more prevalent obstacles to AMT use among non-users are cost related.
- Of the ten obstacles listed in the 1998 AMT Survey, three show statistically robust differences by plant size. More small plants than large plants report that small markets, high equipment costs, and skills shortages are obstacles to AMT use.
- The mean number of AMTs in use does not increase with the number of competitors after controlling for production system and plant size except in four of 16 comparisons: two groups of discrete non-engineering plants with more than 100 employees, and plants with 50 to 99 employees who use either continuous flow technology or are in industries with a mix of production system types. The number of competitors does appear to encourage plants with 50 to 99 employees to adopt developing AMTs.

8 Results of AMT Use

Firms adopt AMTs with the expectation that they can convert their technical advantages into improved business performance. A previous analysis of AMT use by Canadian firms concluded that AMT use improved relative market share and labour productivity (Baldwin, Diverty, and Sabourin 1995). Other studies have found no relationship between technology use and indicators of economic performance or, at best, a weak one.[19]

These mixed findings suggest that positive performance outcomes are dependent on other factors in addition to the adoption of the AMT, that is, the introduction of AMTs creates the possibility of performance improvement, but does not necessarily lead to improvement. In fact, there can be a notable reduction in performance following AMT adoption as firms struggle to adapt their operational practices to the new technology (Millen and Sohal, 1998). Financial benefits also lag behind the introduction of a new technology. Typically, it can take several years of AMT use before economic performance improves.

8.1 Self-Reported Competitiveness of Production Technology

The 1998 AMT survey asks respondents to "compare your plant's production technology with that of your most significant competitors" in Canada and the United States. Table 8.1 provides AMT use rates, for small and large firms, by the self-reported perception of the state of the plant's production technology compared to that of its Canadian competitors.[20] All measures of AMT use increase with the competitiveness of the plant's production technology.

Table 8.1 AMT Use Rates by Self-Reported Competitiveness of Production Technology Compared to Canadian Competitors

	10 - 99 employees			100 + employees		
	Less advanced	Equal	More advanced	Less advanced	Equal	More advanced
Percent of plants in group	18.1	48.9	33.0	9.8	38.9	51.3
Use any AMT	66%	70%	89%	95%	95%	99%
Use 5 or more AMTs	25%	33%	57%	63%	79%	91%
Only use mature AMTs	26%	19%	16%	25%	10%	4%
AMT invest > 25%	15%	20%	42%	25%	32%	48%
Mean number of AMTs in use	2.8	3.8	6.1	7.3	9.0	11.4

Note: Excludes 434 plants that either responded 'NA' to this question or with no competitors.
Statistically significantly differences from the average ($p < .05$) for all comparisons by competitiveness of production technology.

[19] See Beaumont and Scroder, 1997; Rishel and Burns, 1997; Swamdiss and Kotha, 1998.

[20] The comparison is made with Canadian rather than American competitors because there are notably fewer 'not applicable' responses to the former question.

These results suggest that AMT use increases the respondents' perception of the competitiveness of their plant. However, self-assessments of competitiveness are problematical because the plant managers may not have an adequate idea of what their competitors are using and their assessment could be influenced by the desire to perform well. As shown in Table 8.1, only 9.8% of large plants report that their production technology is *less* advanced than that of their main competitors, while 51.3% report that their technology is more advanced.

8.2 AMT Use and Performance Outcomes

The 1998 AMT Survey asks AMT users to rate, using a five-point importance scale, "the importance of [13] effects related to the adoption of advanced technology by your plant". Five of the results listed concern productivity improvements, three product improvements, two plant organizational changes, one plant efficiency, and two are on market performance.

There are three problems with the design of this question. First, the wording invites two interpretations: it could refer to the benefits plants expected before they acquired the AMT or to the actual results of AMT use. Second, smaller plants gave lower ratings than large plants to the importance of *all* outcomes of AMT use. And, third, 5.7% of respondents gave identical scores to all 13 outcomes. Since an important research question is to identify the benefits of AMT use to plants that use few AMTs and to smaller plants, all of the descriptive analyses reported here exclude same-score responses and use the most important measure. The former technique excludes biases from same-score responses while the latter reduces differences between large and small plants. There is no solution to the first problem.

Table 8.2 provides the percentage of plants by size that give a most important rating to each result. The most frequently cited result is an increase in profitability, followed by a reduced rejection rate and increased production flexibility. A "reduced capital requirement' ranks last, probably because most AMT use increases capital investment.

Larger plants are more likely than small plants to report an improvement in product quality and a reduction in rejection rates, labour needs, and material needs per unit of output. A higher percentage of smaller plants (50 to 99 employees) report reduced time to market.

The fact that 57% of all plants gave their highest rating to "increased profitability" is problematical. This result contrasts with the findings of other studies, which have rarely found AMT use to increase profitability. It suggests that many plants in the 1998 survey gave answers for their pre-adoption expectations.

There is greater variation in the results of AMT use by production system than by plant size. Table 8.3 shows that the greatest beneficiaries of AMT use by type of production system used are in the discrete engineering and continuous flow production sectors. This is expected since these sectors have the highest use rates for AMTs.

Table 8.2 Percentage of Plants, by Employment Class, that Give a Most Important Score to Each Result of AMT Use

	Number of employees				
	<50	50 - 99	100 - 249	250 +	All Plants
Increased profitability	55	58	60	55	57
Reduced rejection rate	47	54	49	**55**	49
Increased production flexibility	40	44	40	43	41
Reduced labour per unit	36	43	43	**49**	39
Reduced set-up time	37	41	35	37	37
Increased equip use rate	36	33	35	42	36
Reduced time to market	33	**40**	30	30	33
Increased market share	40	43	36	33	33
Improved product quality	28	35	32	**44**	31
Increased skill needs	27	25	22	28	28
New product features	26	28	28	24	27
Reduced material use per unit	21	32	38	**42**	27
Reduced capital requirement per unit	24	22	20	22	23

1. Results exclude plants that gave the same score to all thirteen outcomes of AMT use.
2. Bold type identifies the highest citation rate for results with statistically significant differences by plant size.

Table 8.3 Percentage of Plants, by Production System, that Give a Most Important Score to Each Result of AMT Use

	Discrete non-engineering	Discrete engineering	Continuous flow	Mixed
Increased profitability	54	58	58	57
Reduced rejection rate	49	52	47	45
Increased production flexibility	41	42	**44**	39
Reduced labour per unit	35	41	**43**	36
Reduced set-up time	35	**40**	32	39
Increased equip use rate	34	38	**40**	30
Reduced time to market	33	**36**	27	33
Increased market share	36	41	38	40
Improved product quality	28	32	**39**	29
Increased skill needs	23	**29**	27	23
New product features	25	26	21	**34**
Reduced material use per unit	33	23	**35**	22
Reduced capital needs per unit	20	**26**	22	21

Results exclude plants that gave the same score to all thirteen outcomes of AMT use. Highest percentage for outcomes that differ between sectors ($p < 0.05$) are marked in **bold**.

8.3 Conclusions

This chapter examines the relationship between the results of AMT use and several characteristics of the plant, including its focus on specific types of AMTs. The main findings are:

- AMT use is higher among plants that rate their production systems as being more advanced than that of their competitors.
- Plants rank an increase in profitability as the most important result from the adoption of AMTs. However, this result is not corroborated in other studies. One possible explanation is that respondents reported their pre-adoption expectations instead of the actual outcomes of AMT use.
- Plants in the engineered discrete parts industries rate reduced set-up time and reduced time to market as more important outcomes than plants in other industries.

9 Planned Use and AMT Investment

The preceding sections establish that current AMT use rates are related to a variety of plant or firm characteristics, management practices, and environmental conditions. One limitation in the interpretation of many of the preceding analyses of AMT use is that there is no information in the 1998 AMT Survey on *when* the AMTs were adopted. This means that it is not possible to draw conclusions about the determinants of AMT adoption because many AMTs could have been adopted under very different conditions. For example, a plant with current employment of more than 250 employees could have adopted many of its AMTs a decade earlier when it had less than 100 employees.

Two questions in the 1998 AMT survey provide information on the timing of AMT adoption: investment shares in AMTs over the previous three years and planned adoption, within two years, of a type of AMT that is currently not in use in the plant. Both questions permit the use of multivariate regressions to explore the determinants of AMT use.[21]

9.1 Regression Analyses of AMT Investment and Planned Use

This section discusses the regression models used to perform the analyses and the model variables.

9.1.1 Regression Models

The effect of different factors on planned use is explored using logistic regression. The dependent variable pa (planned adoption) is equal to 1 if the plant plans to adopt at least one new AMT and zero if there are no adoption plans for any AMT. The reduced form of the model is:

$$\text{(1)} \qquad \text{Prob}[\text{pa} = 1] = \frac{e^{B'\mathbf{x}}}{1 + e^{B'\mathbf{x}}}$$

where $B'\mathbf{x}$ equals the vector of dependent variables plus the error term:

$$\text{(2)} \quad = \text{Constant} + B_1(\text{Size}) + B_2(\text{Foreign}) + B_3(\text{Production system}) + B_4(\text{Invest}) + B_5(\text{Internal capabilities}) + B_6(\text{Obstacles}) + B_7(\text{Competition}) + B_8(\text{Strategies}) + B_9(\text{Results}) + \varepsilon.$$

Regression models are given for all current AMT user plants, current AMT users with less than 100 employees, and current non-user plants. A separate model is provided for small AMT user plants to find out if there are differences in the determinants by plant size.[22]

The 1998 AMT Survey asks respondents to estimate the amount of their total investment in equipment and machinery over the previous three years that was accounted for by AMTs. Five response options are provided: zero, 1% to 24%, 26% to 50%, 51% - 75%, and 76% to 100%.

[21] The regressions for investment share assume that the independent variables, such as the use of specific information sources or the number of employees, remained relatively stable over the three year investment period.

[22] No results are given for large plants because of poor results.

The influence of the same factors as above on the share of investment due to AMTs is investigated using two regression models, an ordered logit model and a logistic regression model. The results provide an estimate of the effect of these factors on the plant's focus on AMTs as a share of its total capital investment. Both regression analyses are limited to plants that use at least one AMT.[23]

The first regression model is an ordered logit that maximizes the information contained in the five categories of AMT investment.[24] The ordered logit model can be used to examine the impact of a range of exogeneous variables on a dependent variable which takes a finite set of ordered values (1,2 .. n). The method of estimation is maximum likelihood. The model assumes that the dependent variable y is generated by a continuous latent variable y* whose values are unobserved and that there are a set of ordered values (r1, r2, .. rn-1) and a variable y* such that:

(3) $$y = 1 \text{ if } y^* < r1$$
$$y = k \text{ if } rk\text{-}1 < y^* < rk \text{ for } 1<k<n$$
$$y = n \text{ if } rn\text{-}1 < y^*$$

The unobserved variable y* is modelled as a linear function of the (N,k) vector of exogeneous variables X:

(4) $$y^*_i = \beta X_i + \varepsilon_i \qquad i = 1,...N$$

where ε_i has a distribution function f derived from the logistic cumulative distribution function:

(5) $$F(x) = 1/(1+ e^{-x})$$

Given the characteristics X_i of plant i, the probability that y_i is found in category k is:

(6) $$\text{Prob } (Y_i = 1/Xi) = F(r1-\beta X_i)$$
$$\text{Prob } (Y_i = k/Xi) = F(rk-\beta X_i) - F((rk-1) -\beta X_i)$$
$$\text{Prob } (Y_i = n/Xi) = 1- F((rn-1) -\beta X_i)$$

The ordered logit uses four categories, with the two highest categories of AMT investment (51% - 75% and 76% - 100%) combined to increase the number of observations in each category. Although this model provides the most accurate and unbiased measure of the influence of several variables on investment, it is difficult to interpret the coefficients for an ordered logit model, except for their direction (positive or negative) and whether or not they are statistically significant. Furthermore, there is no reliable method of calculating an R^2 value for an ordered logit model.

[23] Plants that do not use AMTs were included in several exploratory regressions. All of these plants have zero investments in AMTs in the previous three years. However, none of these regressions gave good results. In addition, including non AMT users requires excluding several variables that are only available for plants that use AMTs, such as the method of introduction and information sources. The interpretation of the obstacle variables also differs between users and non-users, which bars their inclusion in a regression that includes both types of plants. Given these problems, we only present regression results for AMT user plants.

[24] For a discussion of ordered logit models, see Green (1993) and Liao (1994).

The second model uses logistic regression, following the same form as given in equations 1 and 2. A dichotomous dependent variable is created by combining the five investment categories into two categories: below 25% (coded as zero) and above 25% (coded as 1). The logistic regression model determines the probability that AMTs accounted for over 25% of investment. The model provides the odds ratios for the logistic regression results. For dichotomous variables, the odds ratio equals the number of times that the presence of the variable, compared to its absence, increases the probability that the plant will spend more than 25% of its investment on AMTs.

In the ordered logit model, a positive coefficient indicates that the variable increases the probability of a higher share for AMT investment. The equivalent in the logistic regression is an odds ratio above 1.0. Conversely, a negative coefficient in the ordered logit is equivalent to an odds ratio of less than 1.0 in the logistic regression. In both cases the coefficient indicates that the variable reduces AMT investment.

The ordered logit and logistic regression models produce similar results. Where there are differences, the ordered logit is assumed to provide more accurate results. Most of the differences between the two models are limited to minor increases in statistical significance, with no change in the direction of the effect. For example, the business strategy of developing new products reduces investment in the ordered logit, but the level of reduction is not significant in the logistic regression model. The discussion of the results (Section 9.3) is based on the logistic regression models, unless the ordered logit regressions provide a different interpretation.

9.1.2 Independent Variables

With two exceptions, all of the independent variables are defined in previous chapters. At least one variable is drawn from each of five groups: internal capabilities, obstacles to adoption, competition, results of AMT use, and business practices and strategies.

The two exceptions are a control variable and a measure of past experience.

First, the number of AMTs that can potentially be adopted in the future declines with the number of AMTs already used in the plant. To control for this effect, the regression for planned use includes a variable for the number of different AMTs that are not in use and therefore available for adoption.

Second, previous experience with related technologies makes it easier to manage new technology implementation, thus lowering the costs and increasing the likelihood of adoption (Kelley and Helper, 1997). Learning-by-doing and learning-by-using help to build the firm's internal capabilities. The role of past experience suggests that the probability of adopting additional AMTs should increase with the number of AMTs in current use. In the regression on planned use, AMT investment share in the previous three years is used as a proxy for previous experience. No suitable measure is available to represent past experience for the regressions on AMT investment.

The variables included in the regressions for planned adoption are similar to those included in the analyses of AMT investment shares, with a few exceptions.

- Only the regressions for planned adoption include variables for the results of AMT use.
- There are minor differences in the types of business practices and information sources that are included. These differences are due to problems with fitting the data to the model.

- The regressions for planned adoption do not include the variable for the relative competitiveness of the plant's production technology as this variable had no effect in any of the preliminary regressions or in the final models for planned adoption. However, the models for the planned adoption of a capital intensive AMT do include this variable.

The AMT investment models include the variable for the relative competitiveness of the plant's production technology compared to its most significant competitors in Canada. Including this variable results in the loss of up to 217 plants that replied 'don't know' to this question. This could create a small distortion in the weightings to produce a representative sample for all Canadian manufacturing firms. However, analyses that exclude this variable (and, thereby, include all respondent AMT user plants) produce similar results for all other variables. This indicates that the model results are reasonably robust to the inclusion or exclusion of the 217 plants.

9.1.3 Model and Variable Limitations

The 1998 AMT Survey questions on business strategies, information sources, results of AMT use, and obstacles to adoption contain lists of sub-questions, some of which are closely related. For example, the question on obstacles to adoption has a series of four questions on costs. The responses to similar and adjacent questions tend to be highly correlated which creates problems of collinearity in regression analyses. To overcome this problem, preliminary analyses were conducted to identify those factors that have a significant effect on AMT investment or planned use and that do not introduce collinearity problems.[25] These variables are then included in the final models. It is important to note that the exclusion of a variable from the list of information sources, obstacles, or results does not necessarily mean that the variable had no significant effect on investment or planned adoption.

A second limitation only applies to the regressions for AMT investment. The problem here is that there is no measure of the absolute amount of new capital investment in the preceding three years. A plant that spends 5% of a total investment of 100 million on AMTs will invest five times more in AMTs than a plant that spends 100% of a total investment of 1 million on AMTs. This means that the dependent variable is an imperfect measure of the plant's focus on AMT investment, since this will be linked to its total investment possibilities. Including plant size (number of employees) and the production system in the model will partly control for this problem, since the size of the total investment will be constrained by both of these factors. Plants with less than 50 employees are less likely, for instance, to invest 100 million in the last three years than plants with over 250 employees, unless they are in capital intensive sectors such as petroleum refining. Possible sectoral effects of this type are partly controlled for by including a variable for the production system in the regressions.

[25] Based on the contribution to the model chi-square, an evaluation of the goodness-of-fit, and the robustness of the results across a range of preliminary regressions.

9.2 AMT Investment

Table 9.1 provides the ordered logit results for AMT investment while Table 9.2 provides the logistic regression results.

All regressions include three variables for the basic characteristics of the plant: employment, production system, and foreign versus domestic ownership. The share of total investment in machinery and equipment that was spent on AMTs increases with plant employment. This suggests that the results are not biased by larger investments in larger plants, since this would result in a decline in the odds ratio with plant size.

The investment share is highest for plants in engineered discrete parts industries. Foreign ownership does not influence AMT investment in the analyses of all plants, but it reduces the AMT investment share of the smaller plants.

Four variables address internal capabilities: the extent of R&D, the introduction method, the use of various information sources, and the presence of training programs.[26] R&D does not influence AMT investment in the logistic regression presented in Table 9.2, but it is significant in the ordered logit given in Table 9.1, where plants from firms that perform R&D on a contract or occasional basis invest more in AMTs than the reference category of plants that perform no R&D. Plants from firms that perform R&D in-house on a continuous basis are less likely than plants with no R&D to have large AMT investment shares. The method used to introduce AMTs is not significant in the analyses for all AMT user plants. But, smaller plants that can develop AMTs in-house are less likely to have high AMT investment shares.

The lower AMT investment levels among firms that perform continuous R&D and among smaller plants with the capacity to develop new AMTs at the plant level are unexpected. One possible explanation is that these firms have above average investment levels in new machinery and equipment, reducing the share of AMTs in this total.

Plants that obtain ideas on AMT use from both of the information sources included in the models, internal technology watch programs and external suppliers, have higher AMT investment shares than plants that do not use these two information sources. Ongoing technical training increases AMT investment shares in all analyses. The effect is largest for small plants, where this strategy increases, by 81%, the probability that the investment share exceeds 25%.

Obstacles to AMT use can both increase and decrease AMT investment shares. Plants facing a small market size have lower AMT investment shares, possibly because the cost of AMTs cannot be justified for a small market. This result is contrary to the theory that AMTs should reduce the costs of low volume production through economies of scope. However, the overall throughput requirements of these AMTs remains large. They reduce the cost of increasing the mix of products, not the costs of producing single products in small lots. Thus, these AMTs may be more suitable for customizing products in large scale markets than for small-scale establishments.

[26] The data for this variable is taken from the question on business strategies to avoid collinearity problems.

Table 9.1 Ordered Logit Results for Investment in AMTs Above 25% of Total Investment in Machinery and Equipment

Variable		All AMT user plants B	p	AMT user plants with 10 – 99 employees B	p
Plant level variables					
Number of Employees					
	250+	**.41**	.01		
	100 - 249	**.29**	.00		
	50 - 99	.10	.11		
Foreign-owned		-.08	.36	**-.36**	.04
Production system	Mixed	**.41**	.00	**.58**	.00
	Continuous flow	.02	.87	.13	.54
	Engineered discrete parts	**.45**	.00	**.43**	.00
Internal capabilities					
Extent of R&D	Continuous in-house-	**.17**	.00	-.16	.08
	Occasional/contract	**.15**	.01	**.30**	.00
Introduction method	In house development	.04	.51	**-.22**	.01
	Customization	.09	.11	.09	.32
Internal info. source	Tech watch program	**.38**	.00	**.43**	.00
External info source	Suppliers	**.48**	.00	**.44**	.00
Ongoing tech training		**.39**	.00	**.59**	.00
Obstacles to AMT Use	Small market size	**-.26**	.00	**-.37**	.00
	High capital costs	**-.09**	.03	.01	.88
	Skill shortages	**.40**	.00	**.45**	.00
	Inability to evaluate new technology	-.11	.06	-.12	.20
	Lack of technical support from vendors	**.29**	.00	**.35**	.00
Competition variables					
Competitiveness of production technology					
	More advanced	**.91**	.00	**.90**	.00
	Equal	.11	.06	.05	.61
Number of competitors	Over 20	**.68**	.00	**.76**	.00
	6 - 20	**.38**	.00	**.49**	.00
Business strategies	Develop new products	**-.09**	.04	**-.19**	.01
	Reduce manufacturing costs	**.53**	.00	**.53**	.00
Constant		-.16	.07	-0.33	.02
N (unweighted number of plants)			2901		1438

Notes: The reference categories for the categorical variables are as follows: Employees, 10 - 49; number of competitors, 0 - 5; production system, discrete non-engineering; extent of R&D, none; method of AMT introduction, off-the-shelf only; competitiveness of production technology, less advanced. The reference categories for business practices and obstacles consist of a score of 'low importance' (1 to 3 on a five-point importance scale). For information sources, the reference category is a 'no' response to the question "did the following source play an important role in providing ideas for the adoption of advanced technology in your plant?'.

Table 9.2 Odds Ratios for a Logistic Regression of AMT Investment above 25% of Total Investment in Machinery and Equipment

Variable		All AMT user plants B	All AMT user plants p	AMT user plants with 10 – 99 employees B	AMT user plants with 10 – 99 employees p
Plant-level variables					
Number of Employees			.018		
	250+	**1.67**	.003		
	100 - 249	*1.25*	.098		
	50 - 99	1.21	.127	1.22	.10
Foreign-owned		.95	.750	.69	.108
Production system					
	Mixed	**1.50**	.002	**1.90**	.000
	Continuous flow	.84	.285	1.01	.923
	Engineered discrete parts	**1.63**	.000	*1.65*	.067
Internal capabilities					
Extent of R&D			.787		.653
	Continuous in-house	.92	.492	.98	.865
	Occasional/contract	.97	.789	1.10	.469
Method of AMT introduction			.714		.068
	In house development	1.03	.794	**.73**	.020
	Customization	.94	.550	.90	.396
Internal info. source	Tech watch program	**1.62**	.000	**1.84**	.000
External info source	Suppliers	**1.48**	.000	**1.43**	.002
Ongoing tech training		**1.42**	.000	**1.81**	.000
Obstacles to AMT use	Small market size	**.75**	.004	**.63**	.000
	Capital costs	**.82**	.037	.93	.534
	Skill shortages	**1.39**	.000	**1.50**	.000
	Inability to evaluate new technology	1.09	.494	1.07	.622
	Lack of technical support from vendors	**1.47**	.001	**1.71**	.000
Competition variables					
Competitiveness of production technology			.000		.000
	More advanced	**2.39**	.000	**2.49**	.000
	Equal	1.15	.356	1.09	.599
Number of competitors			.000		.000
	Over 20	**2.30**	.000	**2.87**	.000
	6 - 20	**1.67**	.000	**2.16**	.000
Business strategies	Develop new products	.98	.803	.90	.340
	Reduce manufacturing costs	**1.31**	.038	*1.28*	.088
N (unweighted number of plants)		2901		1438	
-2LL		3085.1		2450.0	
% correctly classified		69.4		74.1	
Goodness of fit (p value)		.009		.0000	
Nagelkerke estimated of R^2		.12		.16	

Notes: For a description of the reference categories, see the notes to Table 10.3a.

High capital costs also reduce AMT investment shares for all plants, although it has no effect for smaller plants. The remaining three obstacles, skill shortages, an inability to evaluate new technology, and a lack of technical support from vendors, could increase AMT investment shares by increasing the cost of implementing AMTs relative to other investment. This expectation is met for both skill shortages and a lack of technical support. In contrast, the results for an inability to evaluate new technology are much weaker and only significant at the 10% level in the ordered logit model for all plants, where plants that give a high importance to this obstacle are less likely to have high AMT investment shares. One possible explanation is that this obstacle directly reduces the probability of acquiring AMTs, while skill shortages and a lack of technical support increase the cost of implementation but do not prevent or reduce their acquisition.

Competition consistently increases the AMT investment share in all models. For example, the probability that the AMT investment shares exceeds 25% is 67% higher for all plants with 6 to 20 competitors compared to the reference category of zero to 5 competitors and more than doubles for plants with more than 20 competitors. Plants with comparatively advanced production technology have a higher AMT investment share than plants with less advanced or equal production technology to that of their main competitors. This suggests either that plants with less advanced production technology are not investing in AMTs in order to catch up or that leading plants continuously invest greater amounts to maintain their competitive edge.

Plants that give a high importance to the business strategy of reducing costs have significantly higher AMT investment shares than plants that give a lower rating to this strategy. This indicates that AMT use is an important component of cost reduction strategies. Conversely, a strategy of developing new products reduces AMT investment shares. As for a small market share, this result is unexpected, since many AMTs are designed either to reduce product development time or for low volume production. However, this result is consistent with the results showing that an emphasis on product R&D is not associated with high AMT use.

9.3 Planned Use of AMTs within Two Years

Table 9.3 presents the logistic regression results for the planned adoption, within two years, of any of the 26 AMTs listed in the survey. The interpretation of the results differs between users and non-users. The effects of business strategies and obstacles for AMT users will be influenced by their past experience with AMTs, whereas non-users, by definition, cannot be influenced by past AMT use. In general, the results for small plants that currently use AMTs are similar to the results for all AMT users.

Investment in the previous three years has the most pronounced influence of all variables on planned use by current AMT users. Plants with high levels of investment are over five times more likely to adopt another AMT than plants that have zero investment in AMTs. This result indicates the importance of learning-by-using and learning-by-doing in developing internal capabilities to adopt, implement, and manage AMTs. Another explanation is that investment programs in the previous three years could be continuing into the future two years.

Table 9.3 Odds Ratios for the Planned Use of a New AMT within 2 Years

Variable	All users B[1]	All users P	Current AMT users 10 - 99 Employees B[1]	Current AMT users 10 - 99 Employees P	All current Non-users B[1]	All current Non-users P
Number of AMTs available to adopt	**1.07**	.000	**1.05**	.002		
Plant-level variables						
Number of employees		.022				.192
250+	1.20	.423			.29	.601
100 - 249	**1.48**	.015			1.32	.572
50 - 99	**1.40**	.016	**1.44**	.04	**1.85**	.039
Foreign-ownership	**1.43**	.037	**1.94**	.005	.68	.296
Production system type		.000		.000		.049
mixed	**.58**	.000	**.58**	.000	.91	.675
continuous flow	.74	.068	.72	.08	1.49	.111
engineered discrete parts	**1.46**	.003	**1.69**	.000	**1.58**	.030
Investment in AMTs previous three yrs		.000		.000		
high (> 50%)	**5.35**	.000	**6.44**	.000		
medium (26 - 50%)	**3.82**	.000	**4.21**	.000		
low (1 - 25%)	**2.45**	.000	**2.51**	.000		
Internal capabilities						
Extent of R&D		.000				.000
continuous in-house	**2.13**	.000			**2.74**	.000
occasional/contract	**1.74**	.000			**1.69**	.021
Method of AMT introduction		.027		.003		
in-house development	**1.42**	.008	**1.85**	.001		
customization	1.19	.141	1.29	.065		
Information Sources						
sales & marketing	**1.53**	.001	**1.68**	.000		
production engineering	**1.30**	.030	1.13	.387		
suppliers	**1.60**	.000	**1.39**	.021		
customers	.79	.054	**.73**	.022		
Number of different information sources	**.96**	.045	.98	.452		
Technical training	.88	.295	.83	.151	**3.55**	.000
Cross-functional design teams	**1.47**	.001	**1.38**	.029	**5.11**	.000
Concurrent engineering			**2.13**	.000	**.41**	.000
Obstacles to AMT use						
small market	**.79**	.024	.83	.117	**.41**	.003
high capital costs	1.16	.142	**1.30**	.023	**2.57**	.000
skill shortages	**1.66**	.000	**1.66**	.000	**1.82**	.001
inability to evaluate new technology	1.27	.100	1.25	.156	1.14	.615
lack of tech support from suppliers	.79	.081	**.61**	.001	.64	.112
Number of competitors		.012		.000		.009
> 20	**.75**	.016	**.62**	.000	**1.84**	.002
6 - 20	1.01	.934	1.09	.590	**1.93**	.004

Results of AMT use					
reduced labour	**1.61**	.000	**1.81**	.000	
reduced capital/unit output	**.77**	.023	.78	.061	
reduced rejection rate	**1.54**	.000	**1.49**	.002	
increased equipment use rate	**1.48**	.000	**1.53**	.001	
N (unweighted)		3118		1552	584
-2LL		2739.5		2184.2	902.8
% correctly classified		78.1%		76.6%	73.5
Model chi-square p value		.0000		.0000	.0000
Nagelkerke estimate of R^2		0.17		.21	.27

1: Notes: For a description of the reference categories, see Table 9.3a.

As expected, the variables for plant capabilities have highly significant effects on planned use among current users. The two variables that measure plant R&D and process engineering capabilities—the extent of R&D and the AMT introduction method— are highly significant, with higher planned adoption among firms that can customize AMTs for their own needs or develop their own processes compared to firms that rely on off-the-shelf acquisitions (the reference category). The extent of R&D is also a significant factor in non-users' plans to adopt.

The questions on information sources were only asked of AMT users. A surprising result is that small plants that obtain information from customers are less likely to adopt than plants that did not use customers. The variable for the number of different types of information sources used to provide ideas for the adoption of AMTs decreases the probability of AMT adoption for all AMT users. A diversity of sources could indicate a lack of focused in-house expertise.

Technical training has no effect on the probability of AMT adoption by current AMT users, but it increases the likelihood of AMT adoption by non-users. Non-user plants that attribute a high importance to training are over three times more likely to adopt an AMT than plants that attribute less importance to training. The presence of cross-functional design teams or concurrent engineering is strongly related to planned adoption among both AMT users and non-users.

Of the plant-level variables, plant size and foreign ownership increases the probability of future adoption among current users. The results for current AMT users show large differences in planned use by the type of production system, with a lower probability among plants in continuous flow industries compared to the reference category of non-engineering discrete parts industries, and a higher probability in the engineered discrete parts industries. The lower probability for plants with continuous flow production systems could be due to the low applicability of many AMTs to continuous flow production.

The results for the number of competitors differ sharply between AMT users and non-users. For users, plants with more than 20 competitors are less likely to adopt than plants with zero to 5 competitors. There is no difference for plants with 6 to 20 competitors. These results suggest that too much competition hinders the adoption of additional AMTs. In contrast, competition among non-AMT users increases the probability of adoption by over 70%.

The list of obstacles includes a range of factors. Both AMT users and non-users with small markets are less likely to adopt. Several results run in the opposite direction from expectations, probably because planning to adopt leads to greater awareness of what is required. For instance, non-users that report high capital costs as an important obstacle to AMT use are more likely to adopt, and the perception of skill shortages increases the probability of planned use among both AMT users and non-users.

Not all variables for the results of AMT use can be included in a logistic regression due to collinearity problems. The effect of the different results variables was explored in a series of preliminary analyses. Variables for product improvement, such as new product features and improved quality, had no significant effect on adoption plans. Only three variables have a robust and positive effect on AMT use: reduced labour requirements per unit of output, an increased equipment utilization rate, and a reduced rejection rate. Not surprisingly, plants that report positive benefits from AMT use such as reduced labour needs and rejection rates are more likely to adopt. In contrast, plants that report "reduced capital requirements per unit of output" are less likely to adopt within two years.[27]

9.4 Conclusions

- Both the probability of a high AMT investment share and the probability of adopting a new type of AMT are highest among plants in discrete engineering production industries.
- Compared to firms with no R&D capabilities, in-house R&D capabilities at the level of the firm decreases AMT investment shares while the use of contract or occasional R&D increases investment shares. Similarly, for small plants, in-house development capabilities at the plant level decreases investment shares. One explanation is that in-house capabilities reduce costs, thereby decreasing the share of investment in AMTs.
- An emphasis on technical training as an important business strategy increases AMT investment shares.
- Skill shortages increase AMT investment shares and the probability of adopting a new type of AMT. This suggests that skill shortages increase costs, but they do not prevent plants from acquiring new AMTs. A lack of technical support from vendors decreases the probability that a plant will adopt a new AMT and it increases investment shares. This implies that this is a more serious obstacle than skill shortages.
- The regression analyses for planned AMT adoption show that several factors that correlate with both the incidence and intensity of AMT use are also determinants of future AMT adoption. These factors include plant size, production system, and foreign ownership.
- Indicators of internal capabilities, such as R&D performance at the firm level, and the ability at the plant level to develop AMTs, all increase the probability of planned adoption.
- Investment in the previous three years has the most pronounced influence of all variables on planned use by current AMT users. This result points to the importance of developing internal capabilities to adopt, implement, and manage AMTs through experiential learning.

[27] This result could be an artifact of the way the question was phrased. Respondents may not have interpreted "reduced capital requirements" to mean lower costs.

- The role of competition is more complex. Competition consistently increases AMT investment shares, but too much competition decreases the probability of future adoption for current users of AMTs, although it increases the probability that non-users will adopt.
- Plants that experience cost-reducing results from past AMT use are more likely to adopt an additional AMT.
- There is very little difference between small plants and all plants in the factors that affect the probability of adopting a new AMT.
- Plants with production technology that is less advanced or equal to that of their competitors, compared to plants with more advanced production technology, are more likely to rely on internal or external information sources that require less internal capabilities. This highlights the importance of advanced internal capabilities to both AMT use and competitive production technology.
- Small plants that find customers to be an important information source are less likely to plan to adopt a new AMT. This result provides some support for the hypothesis that volatile customer orders discourage small plants from adopting capital intensive AMTs, with the exception of AMTs that reduce costs.

10 Conclusions

In 1998, 74% of manufacturing plants in Canada reported using at least one AMT. This is a considerable increase in the incidence of AMT use since 1993, when only one-third of Canadian manufacturing plants reported AMT use. The use of multiple AMTs has also grown, with the percentage of plants using five or more AMTs increasing from 14% in 1989 to 46% in 1998. The 1998 AMT Survey results indicate that AMT use rates will continue to grow rapidly. Forty percent of plants that do not currently use an AMT plan to adopt one within two years while 73% of plants that currently use at least one AMT plan to adopt a new type in this time period.

This major shift in the population of Canadian manufacturers—from conventional production technologies to AMT use—has important implications for designing industrial modernization policies. Factors influencing first time adoption of an AMT may differ from those influencing more intensive use. Furthermore, the high use rate for at least one AMT in Canadian manufacturing means that simple statistics on the incidence of use of one or more AMTs are rapidly decreasing in value. Instead, future AMT surveys and analyses should focus on the development of indicators to describe the intensity of use and to explore the factors that influence firms to use multiple AMTs. The 1998 AMT Survey takes important steps in this direction by asking current AMT users several questions about factors that influence their AMT use, such as which methods they use to introduce advanced technology and which sources of ideas for AMT adoption are important to them.

10.1 Significant Factors Affecting AMT Use

The analyses described in this report confirm the results of previous studies on the importance of various influences on AMT use, notably plant size, the type of production system, ownership status, export status, and past use.

Plant size, measured by the number of employees, is a major determinant of AMT use in Canada. The average number of different types of AMTs in use is over three times higher in plants with more than 250 employees (12.8) compared to plants with between 10 and 49 employees (3.8). One of the principle factors underlying this effect is that larger plants have greater financial and technical resources than smaller plants. For example, plant size is positively correlated with the number of information sources that are cited as providing ideas on AMT adoption. Plant size also affects the extent of R&D activity. The percentage of plants owned by firms with in-house R&D activity nearly doubles from 33% of plants with 10 to 49 employees to 61% of plants with more than 250 employees. And, of the ten barriers to adoption listed in the 1998 survey, three show statistically robust differences by plant size, with smaller plants finding these barriers to be of greater importance than large plants. Two of these are resource-related: high equipment costs and skills shortages.

The type of production system that the plant uses also appears to have a significant influence on not only the number of AMTs adopted, but also which AMTs are adopted, and the subsequent results of adoption. Plants in discrete parts manufacturing industries producing higher value-added products use more AMTs on average than do plants in continuous flow industries and those in lower value-added discrete parts manufacturing industries. Also, a higher percentage of plants in the engineered discrete parts industries have plans to adopt additional AMTs in the next two years.

AMT adoption rates also vary in relation to the maturity of the AMT. Also, the use patterns for mature AMTs differ from that of 'developing' AMTs. Plants that only use mature AMTs provide training less frequently, cite fewer information sources, and are smaller than plants that use developing AMTs. A smaller percentage of plants that only use mature technologies report skill shortages as a barrier to adoption. Generally, the adoption of mature AMTs appears to pose few problems for plants and does not require specialized skills or advanced internal capabilities.

Perhaps the greatest influence on the growing use of AMTs is past experience with AMTs. This conclusion is supported by a number of the analyses. The group of plants by production system type with the greatest current use—plants in the engineered discrete parts industries—are the most likely to have plans to adopt additional AMTs. And, in the regression on planned use of AMTs, plants that invested heavily in AMTs in the past three years (over 50% share of investment in AMTs) are over five times as likely to have plans to adopt additional AMTs as plants that have not invested in the past three years. This effect of past use on the overall diffusion of AMTs is probably linked to the development of internal capabilities via learning-by-doing and learning-by-using.

The plant's internal capabilities are among the most significant influences on AMT use. The survey includes several measures of internal capabilities: the extent of R&D activity by the firm that owns the plant; the methods used, at the plant level, to introduce AMTs; the number and types of information sources on AMTs that the plant uses, the presence of training programs, and the presence of two advanced management practices that can build up internal competencies: concurrent engineering and cross-functional design teams.

The extent of R&D activity greatly influences AMT adoption. Plants that perform R&D on a continuous basis use more than twice the number of AMTs, on average, than plants that do not perform R&D. Another aspect of the plant's R&D capabilities, the type of R&D performed, also affects AMT use. AMT use rates are highest among firms whose R&D department is responsible for adapting or developing new process technology and lowest among firms that perform product R&D only. Similarly, AMT use increases with the ability of the plant to adapt AMTs to its own needs, with a much lower use rate among plants that only purchase off-the-shelf equipment or license technology compared to plants that customize AMTs or develop new ones in-house.

R&D capabilities also appear to be interrelated with the methods plants use to introduce AMTs. Plants that are owned by firms that only perform product R&D, or which do not create or adapt production equipment, use more off-the-shelf technology than plants associated with firms whose R&D departments are responsible for adapting or creating process technology. However, the results on the influence of R&D capabilities and on the method of AMT introduction indicate that there are additional influences on the ability of plants to adopt new technologies successfully. A notable percentage of plants that are owned by firms *without* R&D capabilities either customize AMTs (24%) or develop them in-house (16%).

We surmise that the importance of internal capabilities is related to process engineering capabilities. One reason for this conclusion is that the two most important internal sources of ideas for AMT adoption are production-related. The other reason is the heavy influence of past experience on AMT use. It is likely that that the responsibility for AMT implementation lies with the production engineering staff. This conclusion is also indirectly supported by the influence of plant size on the types of information sources cited. The ranking for production engineering as an important internal source of information increases with plant size from fifth place (out of nine possibilities) for the smallest plants (less than 50 employees) to second place for all other size classes.

The most important business strategy in respect to AMT use is ongoing technical training. Plants that adopt this strategy are consistently more likely to use any AMT, to use AMTs more intensively, and to plan to adopt AMTs within two years. This highlights the importance of skills, and possibly the need to continually upgrade skills, in order to use AMTs. It might also indicate that plants that invest in human resources expect a greater return through the concurrent adoption of AMTs.

Business strategies to reduce costs have a significant positive effect on current AMT investment. Several cost-related outcomes of past AMT use, such as reduced labour requirements per unit of output and an increase in the equipment utilization rate, also increase the probability of plans to adopt a new type of AMT within two years.

Environmental factors such as several obstacles to AMT use, shortages of skilled labour, and the number of competitors, appear to play less of a role in AMT adoption than those discussed above, or they have a mixed effect. An important environmental factor is a small market size, which depresses AMT use, as shown by the regressions on planned use and AMT investment. Another environmental factor is the cost of AMTs, which includes the four most commonly reported obstacles to AMT use among plants that do not currently use AMTs. However, other results for obstacles to AMT use, particularly for skill shortages, pose some questions. Skill shortages, as an obstacle to AMT adoption, consistently *increase* the probability of AMT use. The percentage of plants that report shortages of specific types of personnel in the last year also increases with plant employment, except for skilled trades, where there is no trend by plant size. This could be because smaller plants use more mature technologies and therefore have less of a need for skilled labour, or smaller plants might not be competing for skilled workers. The number of competitors appears to have two opposing effects on AMT use rates. On the one hand, moderate competition leads to higher adoption; on the other hand, too much competition could act to suppress adoption. Both the descriptive analyses and the regression on planned use provide evidence of this latter effect.

10.2 Final Remarks

The past decade has seen a major technological transition in Canadian manufacturing, from conventional production to computer- and microelectronics-based manufacturing. This study has found that many of the factors correlated with AMTs are similar to those reported in other studies. Yet, some of the results suggest that the relative importance of some factors could be changing over time. As AMT adoption becomes more prevalent, plant size could be a less important determinant of use. Skills shortages also seem to figure less prominently than in earlier surveys. On the other hand, the plant's internal capabilities to adopt, implement and manage AMTs could be playing an increasingly pivotal role as the use of multiple AMTs becomes more prevalent.

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