Managing Innovation in SMEs: A Multiple Case Analysis of the Adoption and Implementation of Product and Process Design Technologies

Roberto Panizzolo

ABSTRACT. This work offers the results of a study which describes the experiences of twenty-six small manufacturing firms, operating in the machine tool industry in Italy, which have recently adopted and implemented advanced production technologies. A multiple case study approach was used to explore the reasons for, and obstacles to adopting the new technology, to identify key critical factors in implementation management, and to describe the characteristics of an environment that nurtures innovation. Perceived advantages, internal constraints and external context were identified as the main variables that could explain the CAD-CAM adoption and implementation practices of these small firms. Based on an analytical framework comprising 26 factors regrouped into the three mentioned variables, three groups of firms, characterized by different technology management profiles are identified. However, the system of relationships that characterizes the customer-buyer-supplier relation and the network of "real" services offered to the firm appeared two critical factors.

1. Introduction

Over the past decade, many firms throughout the industrialised world have made substantial investments in new and advanced manufacturing technologies (AMTs). The acronym AMT refers to technologies which aim to improve the following: product and process design (Computer Aided Design-CAD and Computer Aided Manufacturing-CAM), production planning and control (Manufacturing Resources Planning systems-MRP-II), the manufacturing process (Flexible Manufacturing Systems-FMS) and integration (Computer Integrated Manufacturing systems-CIM) (Gerwin et al., 1992).

The various types of AMT offer new strategic opportunities and promise to revolutionize production processes. Large numbers of companies often try to enhance their manufacturing performance and their competitive position in global markets through the application of AMT (Tidd, 1991).

In recent years, especially small manufacturing enterprises (SME) have been implementing new computerized technologies at an every-increasing rate (Acs and Audretsch, 1990; Julien et al., 1993), and the trend is being accelerated by international competition, in particular by the opening up of national boundaries. Indeed, according to some authors, ". . . with their customer orientation and flexible nature, small firms are the logical innovators to adopt the new technologies necessary to enter international markets" (Mechling et al., 1995).

Notwithstanding the attractive claims made regarding the potential of AMTs, one factor which has proved a cause of considerable concern for many firms, has been the difficulty they have had in identifying both when such technologies would be appropriate and how to best exploit their potential so as to reap a comparative market advantage. Most of the current failures in advanced automated systems have been due to implementation approaches which do not, adequately, take into account interactions between human, organizational and technical elements (Bessant, 1993; Ramamurthy, 1995).

Final version accepted on January 22, 1997

Università di Padova
Dipartimento di Innovazione Meccanica e Gestionale
Via Venezia, 1
35131 Padova
Italy

Small Business Economics **11**: 25–42, 1998.

These considerations are even more true for SMEs, for whom introducing and implementing these technologies can be a very costly and risky venture insofar as substantial resources, both financial and human, have to be committed (Schroeder et al., 1989).

However, technology adoption and implementation have generally been studied from the point of view of large companies (Harvey et al., 1992; Lefebvre et al., 1996; Raymond et al., 1996). According to Mechling et al. (1995) "Past research on AMT adoption and implementation has focused on large manufacturing firms, since large firms have the resources to make extensive use of AMT, and small firms presumably do not. Unfortunately, little research has addressed the competitive strategies of small manufacturing firms, particularly the relationship of AMT to the global competitiveness of small manufacturing firms, the reasons why small firms adopt AMT, the AMT adoption patterns of small firms".

This appears even more strange if one remembers that, although still underinvestigated in the field of research, the major role SME's play in the economy is increasingly being acknowledged: they represent an important proportion of operating firms in most industrialized countries and they contribute significantly to new job creation and to innovative activities (Acs and Audretsch, 1993).

This article offers the results of empirical research carried out in order to study the process of adoption and implementation of advanced production technologies in twenty-six Italian small manufacturing enterprises.

The objectives of this empirical study were to:

– highlight reasons for, and obstacles to, adopting the new technology;
– identify key critical factors in implementation management;
– describe the characteristics of an environment that nurtures innovation.

The study is organized as follows:

– the section below contains a literature review of pertinent research and the proposed research framework;
– section 3 describes the research methodology;
– sections 4, 5 and 6 illustrate the results of the empirical study;
– lastly, the results are discussed.

2. Review of pertinent research

This review of the literature focuses on two topics: general research on AMT adoption and implementation and research on the specific context of small manufacturing firms.

General research on AMT adoption and implementation

There are essentially three stages in the process of application of AMT: adoption, including justification, implementation and post-implementation evaluation (Paul and Suresh, 1991; Voss, 1992). Many studies have tried to answer a number of critical questions about the management processes involved in these three stages: why firms choose to adopt these technologies and how they justify them; how firms manage their AMT implementation including identification of factors that contribute to or impede successful implementation; and, what are the difficulties in post-implementation evaluation of these technologies (for a recent review of the literature see: Son, 1992; Chen and Small, 1996; Sambasivarao and Deshmukh, 1995).

The most interesting results in these studies can be summarised as below:

– AMT have characteristics and attributes which could, potentially, offer valid reasons for firms to adopt them (see, for example: Hayes and Garwin, 1982; Goldhar and Jelinek, 1985; Meredith, 1987; Takanaka, 1991 and on CAD technology in particular, Primrose et al., 1985);
– decisions about investment in AMT usually require complex evaluations and estimates. In many studies, the benefits associated with the adoption of automation are split into two categories: "operating" benefits and "strategic" benefits. The former usually refers to efficiency (reduced wip, lead time, direct labor, scarp & rework, etc.), the latter to efficacy (improved opportunities for response to market demand and to competition). As many authors have stressed, it is difficult to incorporate, and evaluate, the more qualitative elements within

the models and quantitative techniques of classical investment analysis (Goldhar and Jelinek, 1983; Meredith and Suresh, 1986);

– the need for a strategic perspective, or rather, the alignment between the technological choices, the organizational structure and the overall firm's strategy (Adam and Swamidass, 1989; Parthasarthy and Sethi, 1992);
– the argument that simply applying the 'hardware' does not mean that the expected level of performance will, automatically, be attained. Experience has shown that the way in which a change is implemented can influence the effectiveness of the transition just as much as the contents of that change. In other words, the reason for the unsuccessful application of these systems frequently lies in not having solved the very delicate problems that have to be faced during the implementation phase (Ettlie, 1986; Adler, 1988; Weill et al., 1991; Beatty, 1993). Thus, the process of implementation would appear to be complex but is, undoubtedly, critical for the success of investments in AMT. The whole organisation is often involved in the implementation process so, the aims of the innovation have to be clearly defined from the outset, sufficient attention must be paid to planning and setting up the necessary resources and organisational structures (Davis, 1986).
– great emphasis is placed on the economic justification of these technologies, but there is evidence that careful and accurate post-implementation audits are rarely performed (Rosenthal, 1984; Meredith et al., 1986; Panisset, 1988; McDaniel, 1989). Given the high costs and potential risks associated with these large, technologically advanced projects, the overall lack of concern about a follow-up evaluation is somewhat perturbing.

Small manufacturing firms and advanced manufacturing technologies

Analysis of the literature in relation to the problems of adopting and implementing AMT highlights the fact that most of the case-studies mentioned were carried out on medium-large firms and almost no attention has been paid to small manufacturing firms. "In the manufacturing sector, we now have a fair amount of knowledge about the type of technologies adopted (what), the type of firms and the industrial sectors where this technological change is more prevalent (who), and about the macro and micro-economic factors that motivate this change in an increasingly complex and competitive environment (why). However, we have less knowledge about how technological change occurs in SMEs, i.e. on the process by which these firms manage the adoption and implementation of new technologies" (Raymond et al., 1996).

There are various reasons to explain why this situation has arisen. Firstly, it has always been, implicitly, assumed that large manufacturing firms have more resources to commit to the acquisition of manufacturing systems and technologies than small firms. Thus, it is expected that firm size and AMT adoption are positively related and this may affect the ability of small firms to acquire AMT technology. Size has long been identified as a determinant of AMT adoption (Noori, 1990). Size tends to be used ubiquitously as a proxy for slack, economies of scale or financial, and non-financial, resources in research on innovation adoption in general, and on the adoption of new technology in particular.

Second, it is postulated that technology adoption in smaller firms is often justified on the basis of trying to solve short-term operating problems. Therefore, small manufacturers are considered much less sophisticated than large companies and it is assumed that their decision-making processes to adopt new manufacturing technologies are not based on long-term strategic plans (Decks, 1976).

At a more general level, the problem also seems to be connected to the use of unsuitable research tools and methods "Many researchers continue to think that small businesses are considerably behind large firms in their use of new technologies and in their productivity. However, many studies have also shown that small businesses create most new jobs and are increasing their share of added value, not only in labour-intensive industries but in modern sectors too. This paradox can be explained because, traditionally, researchers have tended to use analysis methods developed for large firms, and research has been more often limited to the characteristics of effective firms. If, however, the methods are adapted to the complexity of small businesses, and the businesses themselves are analyzed on the basis of what they actually do, then the results will be much different" (Julien, 1995).

Research on the adoption of new technologies by small and medium-sized enterprises has increased in recent years and the importance of AMT for small manufacturing firms is now commonly acknowledged. For example, Acs and Audretsch (1993) speak about a new line that has recently emerged in economics literature regarding the source of innovative activity and technological change. Central to the new learning is that small firms, as well as large enterprises, play an important role in innovative activity. Therefore, management of technological change has become one of the critical determinants of organizational performance, if not of survival, for small and medium-sized enterprises in the manufacturing sector (Preece, 1995).

However, many questions remain open: "this is due to the inherent complexity and heterogeneity of the small business universe, and to the large number of factors that potentially affect the adoption of a new technology, or the progress of a technological development. Hence, the strategies adopted depend on the industrial sector, the economic/technological conjunction, the opportunities that arise, and the previous actions of the firm" (Raymond et al., 1996).

A first issue for debate concerns the real motives which push SMEs to adopt AMT. The need for a strategic perspective has been emphasized in the literature, even though it is not clear whether all, or even most, large companies are as articulated and forward-looking in their manufacturing and technology strategies as would be required. Meredith's studies (1987) have demonstrated that SMEs tend to seek different competitive advantages from AMT adoption than do the larger firms therefore, emphasis is placed on different strategic considerations. In their study, Harvey et al. (1992) say that the SME's strategic outlook is generally limited to short-term time horizons hence, their decisions tend to be based more on short-term operating realities: "in an effort to address the causes of operating problems, the small manufacturer adopts one kind of AMT. If he is successful, the operating situation improves and management learns something new about what AMT can do for the company. Criteria used to decide on adopting AMT are modified, resulting in further adoption of AMT . . . The results do not in any way disprove the so-called "strategic model" of technology adoption. We believe it likely that, when it comes to small companies, we are more likely to find this kind of adaptive hands-on approach to new technology adoption than a more cerebral strategic analysis".

A second issue for debate concerns the economic, technical and organizational factors which, according to other authors, can either enable and/or hinder the adoption and implementation of AMT among SMEs. As illustrated in the work of Lefebvre et al. (1996), "there are more barriers to adopting sophisticated technology in SMEs than in larger firms due to the usually large capital investment and skilled manpower involved in the implementation and operation of such technologies. Further, the potential benefits derived from the adoption of AMT's are sometimes difficult to fully realize and, in the absence of internal expertise, serious doubts can be raised regarding the realization of such benefits. Finally, the financial, technical and even social uncertainties generated by AMT adoption, if incorrectly assessed, can be very detrimental to SMEs as they can rarely rely on organizational slack to act as a buffer".

However, other studies have demonstrated that this is not always true: "instead of being constrained by less resources, our study provides some evidence that smaller firms are not necessarily as constrained as once thought, and may be responding to global competition through AMT" (Mechling et al., 1995).

In reality, it is recognized that technical or economic factors are not the most critical ones for SMEs. In her work, Kelley (1993) states that "more than technical or economic factors, an organisation's internal resources and the availability of external sources of assistance are major factors in explaining why AMT adoption has been slow among small firms generally and more rapid in certain sectors and countries in which customer-supplier linkages are particularly strong". Analogously, Lefebvre et al. (1996) state that intangible assets such as skills of workers, influence of customer and vendors, strategic motivation focused on process improvement and customers, are the critical determinants of advanced manufacturing technology adoption in SMEs.

The lack of qualified workers has long been identified as one of the major problems plaguing smaller firms which do not have the formal selection, training, compensation and human resource management practices generally found in larger firms (Corsten and Lang, 1988; Snell and Dean, 1992).

The actual level of management commitment to technology adoption is another critical organizational factor discussed in the literature. Munro and Noori (1988) found that larger firms exhibited more commitment to manufacturing automation. In contrast, Dimnik and Richardson (1990) assert that not only were the smaller firms in their sample more automated than larger firms, but that their managers were more aware of opportunities for automating than larger plant managers. They attribute this to the managers at larger plants being more preoccupied with implementing top management decisions.

Lastly, many authors recognize that inter-organizational ties (dependency on customers and on various information networks including close contacts with technology vendors) play an important role in the adoption and implementation process of small firms. For example, small subcontracting firms are strongly influenced by their customers when they acquire innovative technologies. Systems suppliers and consultants often give small firms the chance to overcome the lack of internal expertise (Zairi, 1992). The role of networks in small firm competitiveness has been well highlighted by Malecki and Tootle (1996). They say: “contact networks as a means of obtaining external information are a well accepted aspect of firm behavior. For large firms, formal ties, such as strategic alliances and joint ventures, are common, but for small firms more flexible, informal connections are the norm. In addition, semi formal flexible manufacturing networks have evolved as a means for firms to identify similar and compatible firms for cooperative activities”.

* * *

Building on existing theory about AMT adoption and implementation in small firms and on the author’s experience, three variables – perceived advantages, internal constraints and external context – were identified as the main reasons that could explain the AMT adoption and implementation practices of small firms. The relationships of these variables with the process of AMT adoption and implementation are shown in the research framework in Figure 1.

‘Perceived advantages’ refers to the potential benefits that AMT may offer to small firms. As seen above, these can be grouped into two categories: tangible or direct benefits and intangible or indirect benefits or opportunities. The first are mainly operational savings related to the internal efficiency of the organization. The latter concern the impact of AMT on business processes and relationships and are mostly tactical and competitive advantages. Clearly, greater managerial understanding of the relative advantages of AMT will increase the likelihood of the allocation of the organizational, financial, and technological resources necessary to implement AMT.

‘Internal constraints’ is defined as the availability of the organizational resources required for AMT adoption and implementation. As previously seen, several factors (organizational, financial, technological) can inhibit technology adoption and inhibitors probably play a critical role in the context of small organizations.

‘External context’ refers to the influence of the outside environment on the AMT adoption and implementation process of small firms. Some elements of the external context which one would expect to be particularly influential are competitive pressure, customer focus, technology suppliers and networks of relationships.

Internal constraints is expected to influence the adoption, the implementation and the evaluation of AMT. External context is expected to influence both the adoption and implementation of AMT while perceived advantages is expected to play a critical role in the adoption decision.

3. Research methodology

The organizations involved in this study are all firms operating in the machine tool industry in Italy which have adopted a CAD-CAM system in the last few years. According to the Annual Report of UCIMU (the Italian Machine Tool Producers Association), the Italian machine tool industry is

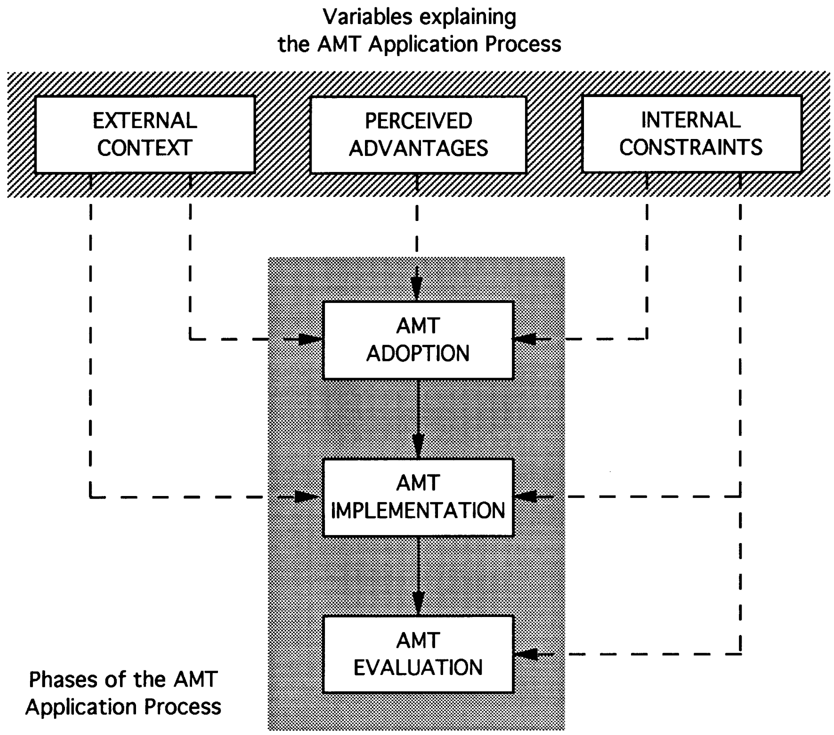

Fig. 1. Proposed small business AMT adoption and implementation model.

in fourth place in the world behind Japan, Germany and the U.S.A. It comprises about 450 firms and employs 28,120 people. Most firms are small. Ninety per cent of the firms active in 1993 had an average turnover of 15 million dollars, 85% of these employed less than 100 people. Ninety two per cent of the producers are concentrated in the North of Italy. These producers produce 94% of the national turnover and 93% of all exports in the industry. Twelve per cent of the firms are located in the Veneto region (North-east Italy) (UCIMU, 1994).

This study was carried out on fifty four machine tool producers in the Veneto region. All these firms are active in both the domestic and international markets (on average, they export 70% of their overall production). On the international markets they compete with the large-scale Japanese, German and U.S. producers. As regards their competitive profile, these firms have benefitted from a tradition of specialist production and from their particular ability to meet the specific requirements set by customers. This has meant that even the smallest firms with a low turnover have been able to become leaders within particular niches, at both the European and world levels (Booz Allen & Hamilton Inc., 1991).

The firms were selected from the list of UCIMU members. Initial contacts were made by telephone. After preliminary discussion with a representative of the company, concerning the aims and objectives of the research project, twenty-six firms agreed to participate in the research.

The main data collection method was face-to-face structured interviews with managers of the small organizations. Two interview guides (questionnaires) were developed, based on the author's experience and on the literature, and were used in field interviews to ensure the constancy and reliability of inquiry procedures at all sites. One of the two questionnaires was used with senior management about issues such as: the overall strategy of the organisation, the basis of competitive advantage, the company's performance in relation to the dimensions of competitiveness, reasons for implementing the particular technology, their role in planning and implementation of the technology and the benefits of the technology to the organisation. The focus of the second questionnaire was on exploring issues concerning planning, implementation and management of AMT implementation. It was used with engineering managers, manufacturing managers, and marketing managers.

All interviews were tape-recorded and all sessions were transcribed before the data were analyzed. To enhance the validity of the answers, summaries of the major findings of each interview were verified by the participants after the end of each interview session.

Given the objectives of the research, a multiple-case study approach was chosen as being the most suitable for this study for several reasons. First, it was obvious that a complex organizational phenomenon such as the adoption of CAD/CAM could be better understood if the context of the action were also studied. The utilization of multiple cases would allow for cross case analysis, which could significantly enhance investigation of the research hypothesis. Second, since the literature did not reveal a set of valid measures to assess the variables of interest, it was problematic to use survey techniques. To ensure that the case study yielded testable, relevant and valid results, Eisenhardt's (1989) list of case implementation steps was followed. Copies of the interviews are available on request from the author.

Figure 2 summarises the key characteristics of the twenty-six companies involved in this research. As previously said, these firms were selected because they had recently made a significant investment in advanced production technologies. Because all the firms in the sample felt that the ability to design and produce highly specialized, custom-built products is crucial for competitive success, a large amount of the skills and resources of the firms are focused on design and new product development activities. Hence, examination of the problems incurred by the introduction of advanced production technologies has concentrated upon CAD-CAM technology which, potentially, can play an important supporting role in design activities.

Examination of Figure 2 reveals that the research sample is made up of small manufacturing firms. All of which conform to EU norms

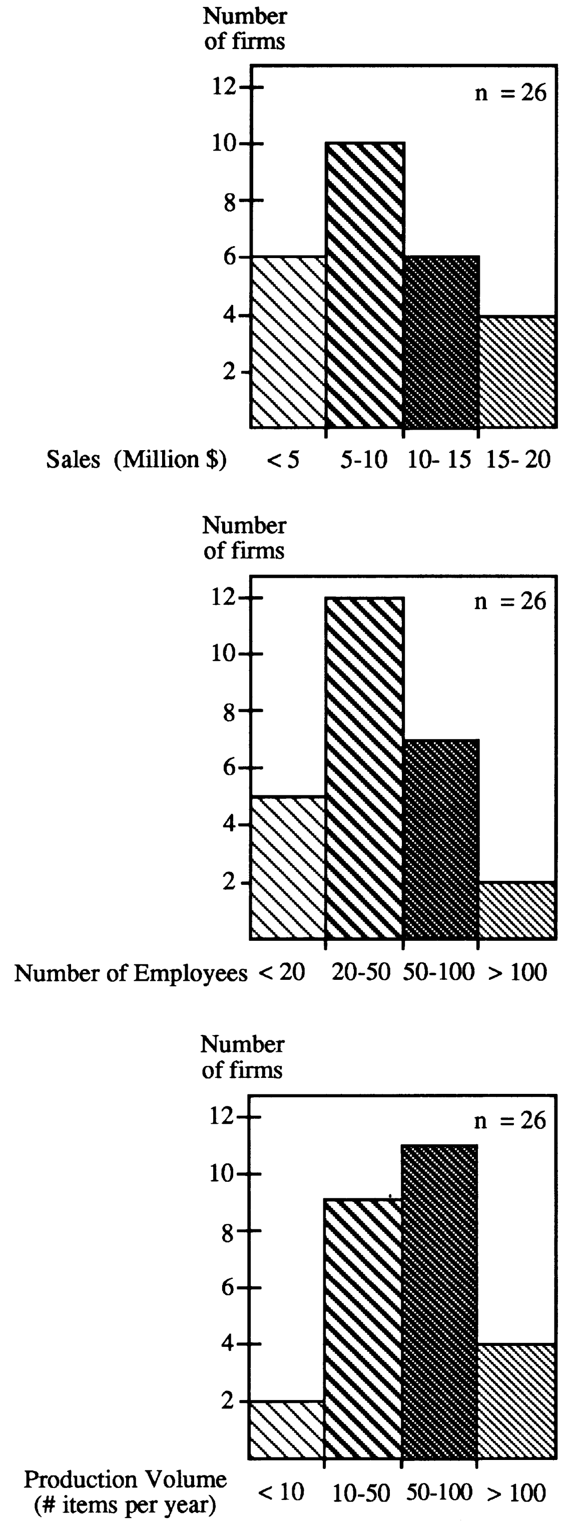

Fig. 2. Main characteristics of firms in the research sample (1995).

and standards for the definition of small and medium firms. Furthermore, from a variety of standpoints, the sample is representative of the situation of small firms operating in the machine tool industry in the Veneto region:

– *size*, the average size and financial data of the firms in the sample are similar to those of the whole industry;
– *territorial*, the firms in the sample are distributed evenly over the area;
– *type of product*, both firms which make small products, with a good level of standardization and relatively high volume of production and firms which design and produce a few, much more complex products per year, are presented in the sample;
– *competitive strategies*, firms who operate both in national and international markets are included in the sample.

TABLE I
Perceived benefits associated to CAD-CAM adoption

Rank	Score*	Benefit
1	69.2	Reduced time-to-market
2	65.3	Improved quality of drawings and project
3	57.6	Improved design flexibility
4	50.0	Increased simplification and standardization of product
5	42.3	Improved customer image
6	38.4	Improved management of project changes
7	38.4	Savings in estimators' labour
8	34.6	Savings in drawing and design labour
9	26.9	Higher employee morale
10	19.2	Support innovativeness
11	15.3	Automated management of bill of materials and routings

* Score for a benefit represents the percentage of respondents who rated the benefit as either important (3) or very important (4).

4. The relevance of perceived advantages on CAD-CAM adoption

A list of potential benefits associated with the adoption of CAD-CAM systems was drawn from the literature (Plonski, 1991; Primrose et al., 1985; Senker, 1985; Stark, 1988; Pandya and Satyre, 1996) and was included in the questionnaire. Moreover, it was possible for managers to add other benefits which had emerged as being important for the adoption decision. Managers of the companies were asked to indicate the level of importance of each benefit on a five-point scale which ranged from 0, negligible, to 4, very important.

To assess the relative importance of the various perceived advantages, the percentage of respondents who rated them as either important or very important (i.e. 3 or 4 on the scale) was calculated. This was done because since we were interested in discovering whether each factor was pervasive and significant, a frequency measure was used, instead of conventional averaging. The resultant ranking is given in Table I.

As Table I shows, most of the reasons given by the firms for adoption of CAD-CAM fall into the strategic area and not into that which is more closely linked to efficiency. Adoption of CAD-CAM systems means, firstly, shortening times, improving quality, improving the firm's image in relation to technological innovation and improving its ability to respond to market demands. This agrees with competitive profile of those firms which see the ability to design and produce products with a high degree of customization as being very important for success. Hence, from this point of view, the fundamental aim of design is that of attaining close integration with the market, or rather, aiming at overall efficacy in the firm's response to external demand. This means an increased ability to differentiate and/or customize the product, to diversify production and to improve the quality of products.

Alongside these motivations, the desire to develop policies for standardizing and simplifying the product is a further element that pushes the firm into investing in a CAD-CAM system. Indeed, this aspect was emphasized by the firms as being one of the priorities for the near future. All these firms are faced with growing international competition which has led them to question their traditional method of operating (characterized by higher levels of customization of their products than that offered by their competitors) and has increased the importance of other factors especially those related to cost reduction.

Given this, it is clearly crucial that when products are designed, both the physical and management characteristics of the production system must be take into account, that is, designed in such a way as to manage to combine efficacy in the response to customer demands with efficiency of operations carried out within the firm. Consequently, design activities must concentrate more upon aspects such as standardization of components, reduction in the number of parts required and modular structure of the product.

5. The relevance of internal constraints in CAD-CAM adoption, implementation and evaluation

Much time was dedicated during the interviews with company managers to examine the internal constraints faced by the firms in the CAD-CAM adoption and implementation phases.

Analogously to the above, a list of factors (drawn from the literature) which were expected to play a critical role in CAD-CAM adoption, implementation and evaluation was given during the interviews. Moreover, it was possible for managers to add other problems which they had encountered. Managers of the companies were asked to indicate the level of severity of each factor using a five-point scale ranging from 0, no problem, to 4, extreme problem.

To appreciate the relative severity of the various internal constraints, the percentage of respondents who rated them as either major problem or extreme problem (i.e. 3 or 4 on the scale) was calculated. The ranking which emerged is shown in Table II. The right hand column of Table II indicates the phase of the CAD-CAM introduction process in which that particular factor seemed to be most critical (i.e. A = adoption; I = implementation; E = Evaluation).

The constraints in Table II may be sub-divided into three classes: organizational, financial and technical. Examination of Table II reveals that the firms found that the main constraints on the adoption, implementation and evaluation of CAD-CAM were those of an organizational nature connected to the difficulty of fully understanding the effects of automation on all aspects of the organization. Four of the five most severe constraints are of an organizational nature. These results are similar to those obtained by other authors who have done research in similar fields (Senker, 1985; Plonski, 1991; Beatty, 1992).

TABLE II
Severity of internal constraints on CAD-CAM adoption, implementation and evaluation

Rank	Score*	Factor	Phase**
1	76.9	Personnel training	I
2	69.3	Management support	A/I/E
3	65.3	New professional skills	A/I
4	65.3	Project costs	A
5	57.6	User involvement	A/I/E
6	50.0	Project management	I/E
7	46.1	Integration with existing systems	A/I
8	42.3	Resistance to change	I/E
9	34.6	Technology standards	A/E
10	30.7	Changes in organizational structure	I
11	26.9	Database development	I

* Severity score for a factor represents the percentage of respondents who rated the constrain as either a major roblem (3) or an extreme problem (4).
** A = Adoption, I = Implementation, E = Evaluation. This column indicates the phase(s) of the introduction process in which that particular factor seemed to be most critical.

Organizational constraints

A first area of concern is that of human resources management. The interview findings clearly demonstrate that the installation of CAD-CAM systems creates a demand for additional skills. Consequently, finding new technical-engineering skills on the labour market and training personnel were mentioned as being two rather important problems which concern firms who adopt these new technologies.

However, the organizational dimension does not only concern human resource management in terms of education, training and specialisation. Many firms highlight the fact that implementation of a CAD-CAM system requires organisational re-planning, that is, there is a need for re-assessment and re-organization at both the structural and managerial levels in order to be able to respond to the important changes these systems bring about in structural relations between the various departments of the firm.

Changes to the organizational structure have been explicitly recognised as being one source of resistance to change which emerged, to differing degrees, in many the firms in the sample. Any changes in management responsibilities that are associated with using the new forms of automation were not always unreservedly accepted by the decision makers involved. Resistance to such changes appeared at various levels within the firm especially where technological changes called into question the role and the power of professional workers who are particularly tied to the pre-innovation system.

As well as resistance to change, management support was also indicated as a critical factor by participants. Management should show its commitment to making the technological application successful. This commitment must include an allocation of resources which demonstrates upper management's priorities. Commitment also involves follow-up actions to show continuing interest and to ensure that the implementation plan is being followed.

Lastly, project definition and planning appears as another important factor for the success of the implementation process. Formulating clear objectives from the outset, drawing up a formal work plan, setting precise *milestones* for a formal check on results obtained, bench marking the current state, the presence of a strong and motivated project leader, the existence of an interfunctional work group with a clear hierarchy of responsibility and with a holistic view of the questions discussed are all elements which the firms underlined and emphasized.

Financial constraints

The difficulty of estimating the financial needs of the CAD-CAM investment is considered to be important by the firms interviewed, even though not the most important factor (see Table II). CAD-CAM adoption does not seem to be perceived as a large- scale financial investment for the firms. Managers state that the assessment of purchasing and installation costs almost never plays a critical role in the adoption phase. Instead, one major reason for concern is the assessment of integration costs and subsequent enhancement costs, whose estimation is much more complex for the firms. These costs remain high despite the fact that the cost of hardware (though not of software) has been falling in recent years. Moreover, technological obsolescence, a major problem for these systems, sets in very fast, and the technological hiccups which often make interfacing different machines and systems difficult, render the adoption of these technologies even more risky and create difficulties for management which wishes to fully understand the costs really incurred by these systems.

Technical constraints

Although technical factors were never at the top of the list of elements which may inhibit CAD-CAM adoption and implementation, some firms emphasised two elements as being important for them. More specifically, firms' main worry was how well the new system would be able to be integrated (at the level of hardware and software) with already existing systems. Probably, despite the enormous efforts made in recent years to achieve a high degree of standardization, these systems still have problems communicating with each other.

Furthermore, this problem is often exacerbated by the inappropriateness of the existing technology standards. In other words, the firms studied highlighted the difficulties of transferring technology that had been developed for other industries, which may be characterized by different structure, logic and competitive variables; such a transfer may well require the reformulation of specific details and standards for application.

Internal constraints and implementation evaluation

As indicated in the framework of Figure 1, the variable 'internal constraints' was expected to influence the evaluation phase of the application process. Indeed, some of the factors shown in Table II were crucial for the development of careful and accurate post-implementation audits.

This ex-post evaluation is an important moment within the process of introducing these technologies, not only because it allows the effective costs and benefits that derive from the investment to be evaluated, but also because it offers a series of indications and suggestions, i.e. guidelines, that could be useful for future projects.

Given these considerations, the interview guides contained a series of questions which aimed, principally, to investigate the level of satisfaction in the firms following the adoption of the CAD-CAM system.

TABLE III
Degree of satisfaction with CAD-CAM system.

Response	Percentage
Very dissatisfied	0
Moderately dissatisfied	11.5
Satisfied	42.3
Moderately satisfied	26.9
Very satisfied	19.3

TABLE IV
Benefits achieved from CAD-CAM implementation

Benefit	(1)	(2)
Reduced time-to-market	19.2	80.0
Improved quality of drawings and project	11.5	66.6
Improved design flexibility	0	–
Increased simplification and standardization of product	7.6	100
Improved customer image	0	–
Improved management of project changes	0	–
Savings in estimators' labour	34.6	88.8
Savings in drawing and design labour	46.1	100
Higher employee morale	0	–
Support innovativeness	0	–
Automated management of bill of materials and routings	11.5	33.3

(1) Percentage of firms who performed a rigorous quantitative evaluation of the performance improvement due to CAD-CAM implementation in relation to each benefit.
(2) Score represents the percentage of those respondents who performed a rigorous quantitative evaluation and rated the improvement as either high achievement (3) or very high achievement (4).

As indicated in Table III most of the opinions were favourable, and agreed that the introduction of CAD-CAM had, in general, improved the firm's performance. However, these are qualitative evaluations, based more on the subjective opinions of the personnel interviewed rather than on objective data. Closer inspection of the responses revealed phrases such as: I think, we feel, we believe, it is probably higher, somewhat reduced, and so forth.

Indeed, it proved very difficult to get the interviewees to be more precise, by comparing expected and real benefits, in their assessment of the real success of the implementation. CAD-CAM implementation success was measured by company personnel assessing the degree to which the systems' implementation objectives had been achieved. Companies indicated the level of achievement of these objectives using a five-point scale ranging from 0, nil achievement, to 4, very high achievement.

As Table IV shows, it was often impossible to gather quantitative data about the actual advantages which had lain behind the decision to adopt the CAD-CAM system and which could have been used to quantify the real improvement in services obtained.

Questioned about why they were not performing rigorous post-implementation evaluations, the participants all answered differently. However, three general themes ran throughout the responses.

First, evaluation was not possible because key measurements were either not recorded or did not exist before the implementation process had begun. In other words, "before" data could not be compared with "after" data.

The second major theme focused on the perception that the ever-changing nature of the business and the impact of technology on the organization, made it cumbersome to perform rigorous follow-up evaluations. In addition, the difficulty of measuring things which are in part intangible, resurfaces in attempts to evaluate these systems.

Last, and perhaps even more important aspect, is connected to the organizational internal constraints. Post-implementation evaluation is a significant task in itself. A large number of people have to be involved, managers have to do a great deal of collating, writing, and project planning. It follows that the task should be properly planned, with a sufficient amount of time and resources allocated to it, and should be carried out with full involvement of those concerned. These resources were not available in most of the cases examined.

6. The relevance of external context in CAD-CAM adoption and implementation

A list of elements of the external context (drawn from the literature) which were expected play a critical role in the CAD-CAM adoption and implementation was given during the interviews. Managers of the companies were asked to indicate the level of importance of each factor using a five-point scale ranging from 0, negligible, to 4, very important.

To appreciate the relative importance of the different external elements, the percentage of respondents who rated them as either important or very important (i.e. 3 or 4 on the scale) was calculated. The resulting ranking is shown in Table V. The right hand column of Table V indicates the phase of the CAD-CAM introduction process in which that particular factor seemed to be most critical (i.e. A = adoption; I = implementation).

TABLE V
External influences on the CAD-CAM adoption and implementation

Rank	Score*	Factor	Phase**
1	100	Informal contact	A/I
2	92.3	System suppliers	A/I
3	84.6	Customer focus	A
4	73.1	Consultants	A/I

* Score for a factor represents the percentage of respondents who rated the factor as either important (3) or very important (4).
** A = Adoption, I = Implementation. This column indicates the phase(s) of the introduction process in which that particular factor seemed to be most critical.

Examination of Table V shows that the external context plays an important role in either facilitating or impeding the adoption of CAD-CAM systems.

Many organizations cited customer focus as an important influence on AMT adoption. Changes in customer preferences, the demand for more choice and flexibility and reduced time-to-market are example of elements that firms saying pushed them to adopt CAD-CAM technology. They felt that the CAD-CAM system would be able to offer the opportunity of achieving this customer focus through such things as reducing the time taken to deal with enquiries, offering of more services, improved product quality and reliability of products.

The availability of information about the new technology was the factor which was seen as being the most crucial both in the adoption and implementation phases of CAD-CAM systems. Any uncertainties were not only related to the characteristics and performance of the system that was to be adopted, but also to the real potential for innovation within the specific structural characteristics of each firm. Many firms have experienced considerable uncertainty about whether, and how best, to deploy CAD-CAM technology. This lack of in-house technical expertise has, therefore, pushed the firms to search beyond the organization's boundaries for the information they need to overcome the gap.

The following types of information channels commonly relied upon by managers were identified from a list of items respondents were asked to rate: direct contacts with sales representatives of equipment vendors and distributors, consultants, informal contact with managers and engineers in other companies.

Suppliers provide technical support, user-training, collaboration and elaboration of new solutions through synergic exploitation of diverse technological knowledge, information about new products and about competitors. This means that the choice of supplier with whom to set up a relationship is a very delicate one and, it appears, that such a choice is based on criteria such as the guarantee of continuity in updating the product acquired, the success of previous installations and the assistance offered during installation.

Consultants were usually involved in personnel training programmes and organisational re-planning rather than in strictly technical matters. Two types of reason cause a firm to turn to external consultants. On the one hand, the process which leads to innovation may require crucially important skills which are often so highly specialised that making them available in house cannot really be justified. The second reason, which is becoming more and more important, is that an increasing proportion of innovation is cross-sectorial, linked, that is, to the horizontal spread of informatization and automation in the firm. This means that, in order to exploit innovative opportunities to the full, entrepreneurs have to be able to monitor a far broader range of activities than in the past. This requires knowledge and specialisation that may be very different from those that are usually developed within one, individual industry.

"Know-how trading" (a term coined by von

Hippel, 1988) in the form of informal exchanges of information through conversations with manager and engineers outside the establishment (i.e. in other companies) was another common external resource cited by the respondents as a important way of learning about the CAD-CAM system.

7. Discussion and conclusions

The paper, so far, has identified the main factors which explain the CAD-CAM adoption and implementation practices of a group of twenty-six small firms operating in the machine tool industry in Italy. Given that only firms which had already made some technological change were analyzed, these empirical findings are not surprising.

Now, in order to better understand how these small firms adopt and implement new technologies, it is important to analyze the variety of small firms' behaviour in relation to technological innovation. Cluster analysis were used to identify those factors which most differentiate the firms. The final objective was to identify different groups of firms characterized by distinct profiles of innovation management.

To carry out the statistical examination, a matrix was set up containing the values assigned by the twenty-six firms to each factors of the three variables identified in the research model (i.e. perceived benefits, internal constraints, and external context). Since 11 factors were identified for the 'perceived advantages' variable, 11 factors for the 'internal constraints' variable and 4 factors for the 'external context', the matrix is made up of 26 rows and 26 columns.

Table VI shows that 6 of 11 factors discriminate significantly between clusters for the first variable (perceived benefits), 8 out of 11 for the second (internal constraints) for a total of 14 factors out of the initial 26. None of the factors of the 'external context' variable discriminate significantly between clusters.

The results of cluster analysis illustrated in Table VI allow the research sample to be broken down into three technology management profiles.

A first group is composed by 5 organizations which we could call *Myopic Firms*. These are the small firms that introduced a CAD-CAM system without having fully recognized the need for it and without owning the necessary resources to integrate the technology. As a result, they have not understood the relative strategic advantages of the technology, the potential benefits of CAD-CAM system do not materialize and, hence, they are not willing to spend resources to enhance their investment. The lack of internal technical and

TABLE VI
Cluster analysis of research variables

Factors	G1* (n = 5)	G2 (n = 15)	G3 (n = 6)
Perceived advantages (mean importance)			
Reduced time-to-market	1.2	4.0	4.0
Improved quality of drawings and project	1.3	3.7	3.8
Improved design flexibility	1.1	3.5	3.7
Increased simplification and standardization of product	0.8	3.1	3.6
Improved customer image	0.9	4.0	3.7
Savings in drawing and design labour	1.9	2.6	2.0
Internal constraints (mean severity)			
Personnel training	4.0	3.8	1.9
Management support	4.0	3.3	0.9
New professional skills	3.8	3.4	1.8
Project costs	4.0	3.0	1.5
User involvement	3.7	2.9	1.2
Project management	3.2	3.2	0.7
Integration with existing systems	3.8	2.8	0.8
Resistance to change	3.7	3.0	1.4

* G1, G2, G3 are groups obtained from the cluster analysis. Variables discriminate significantly between groups at $p < 0.05$. Mean score for each group on a scale of 0 to 4.

organizational skills hinders exploitation of imported technology and financial constraints, which are particularly marked in this type of firm, slow down the purchase of complex and sophisticated systems. The systems introduced are, in the majority of the cases, stand-alone systems with low levels of integration with those of other departments. Basically, they are used as a technical drawing tool for the purpose of saving drawing labour.

These firms are characterized by company policies which are not based on well-defined strategies: a non-growth approach and a day-by-day management, based on intuition, prevail; their principal objectives are satisfactory profit and short term survival. Planning is of little importance to these companies. Technology importation is not supported by the firms' ability to identify and specify its own demand for technology. The decision to adopt and implement a CAD-CAM system appears mostly as a "quick-fix", overnight solution to business difficulties, a decision often based on the direct or indirect influence of larger customers or on the basis of emulating their closer competitors (a "everyone does it" mentality).

A second group of 15 small enterprises, called the *Aware Firms*, is characterized by a different technology management profiles. These organizations are aware of the potential benefits of the technology, but have not allocated the organizational resources and/or technical expertise really required to integrate the system into the organization. Consequently, they have experienced many problems in introducing the CAD-CAM system.

These firms have recognized the strategic benefits that may accrue from the introduction of a CAD-CAM system which will allow them to respond better to demand (differentiated needs, time based competition, particular qualitative requirements as to product, such as reliability, adaptability and modularity). Also, their strategic outlook is not bounded by short-term horizons and short-term operating realities. Their decisions are based on a clear understanding of their customers' requirements and on the need to develop products to match those wants. Their relative success in the markets allows for financial constrains to be less critical than those of the myopic firms and the CAM-CAM systems introduced are more elaborate than those adopted by these latter firms.

The main reason behind this missing link between the acknowledgement of the importance of the benefits associated with the CAD-CAM system and the appropriate allocation of resources for the implementation process lies in not having developed a formal technological strategy. In other words, the decision-making process of these aware firms is characterized by the absence of alignment between technological choices, organizational structure and the firm's overall strategy.

In these cases, the decision to invest in a CAD-CAM system was initially taken by the entrepreneur or by a "charismatic" figure within the firm, someone who believed in the important role of technology as an element of success in competition. The basic hypothesis which, more or less consciously, guided the choices in these cases is that technology is, in itself, a good thing and gives results, thus improving performance.

As a result, these firms have paid little attention to the setting-up of in-house technical expertise and organizational competency. This lack of experience in technology project definition and planning has lengthened the adoption and implementation process and made it difficult to take full advantage of the benefits of the CAD-CAM system. This situation has pushed them to depend strongly on external technological support. Such firms rely heavily on inter-organizational ties (see section 6) which are a crucial support for the management of technical change and for enabling the small firm to overcome its shortcomings.

The third group of 6 small enterprises, named *Skillful Firms*, comprises those organizations which have recognized the relative advantages of the CAD-CAM system and have allocated the required resources to support the adoption and implementation of the technology.

The structural characteristics and strategic goals of these firms are better defined than those of the firms in the other two groups. These firms' strategies are based on long-term planning with greater emphasis laid on technological innovation and on customer focus. The development of technological core competence as well as collaboration with other firms, mainly regarding technological information, are important features of these firms.

The organisational structure that supports such innovative activity is characterised by a better balance both between entrepreneurship and management, and between technological know-how and managerial skills. The decision-making process regarding technology adoption has paid careful attention to the nature of the changes required by CAD-CAM implementation and has been able to recognize how important it is for the strategic choices of the firm and the organizational structure to be congruent with the constraints imposed by the firm's technological choices.

Consequently, technology adoption here was evaluated very carefully, available necessary resources were dedicated to the implementation process, both users and managers were involved and help was asked for from systems suppliers and consultants concerning those questions that could not be adequately resolved by experts within the firm, the project was carefully defined and planned, integration of the CAD-CAM system with other already introduced systems was evaluated.

The main characteristics of the three technology management profiles are shown schematically in Table VII.

Having outlined the main factors which could explain CAD-CAM adoption and implementation practices in a sample of twenty-six small firms and identified three different clusters of firms characterized by different technology management profiles, we shall now examine one issue: the influence of the external context on the technology introduction process and the relevance of success.

As previously stated, none of the factors of the 'external context variable discriminate significantly between clusters. However, examination of the data given in Table V has revealed that the influence of the outside environment played an important role in the CAD-CAM adoption and implementation process in all the small firms in the sample.

When specifically asked about this, firms stressed the fact that, nowadays, internal innovation is a "relationship process", that is, it fundamentally derives from the system of relationships that the firm has with other actors. The main "engine" for innovation and the diffusion of technology seems to be located within the customer-buyer-supplier relationship. In the Veneto region, these relationships have, historically, been facilitated by the type of relations that have been developed within districts (Belussi,

TABLE VII
Distinctive characteristics of the three technology management profiles

	Myopic firms	Aware firms	Skillful firms
Perceived advantages	Operating benefits	Strategic benefits	Strategic benefits
Internal constraints	Absence of internal technical and organizational skills; Marked financial constraints	Little attention to setting up in-house technical expertises and organizational competency; Modest financial constraints	Good level of in-house technical expertises and organizational competency
External context	Influence of customers and competitors in the adoption phase	Critical role of inter-organizational ties in the adoption and implementation process	Support of the external actors important but limited to specific issues
Type of CAD-CAM system	Stand alone system	Partly integrated system	Integrated system
Competitive strategy	Non growth approach, day by-day management	Strategic outlook based on long-term horizon and customer focus	Strategies based on long term horizons, great emphasis on customer focus and technological innovations
Decision making process	Quick-fix approach	Recognition of the role of technology for success but absence of a formal technological strategy	Recognition that the strategic choices of the firm and the organizational structure have to be congruent with the technological choices

1992). Horizontal relationships between producers (associations, commercial agreements, strategic alliances – the least common) have also allowed, and still allow, firms to deal with difficult, intensely innovative, phases. In other words, the predisposition of the individual entrepreneur to innovate is only a precondition, in practise, innovation takes place within a context which is characterized by the existence of a capillary system of relationships with numerous, different, actors.

Relations with other actors represent an exchange of knowledge and, hence, a way of obtaining qualified and specialist services and information the cost of which is borne by the firm and is in some way incorporated within the transaction, thus is, in some senses, a variable cost. Learning from this type of relation is, essentially, learning by doing.

Nowadays, the learning by doing method appears, however, to be relatively slow and inefficient in the face of the rapidity, and the radical nature, of current changes. What would appear to be needed today is a model of learning by learning. Such a change could, however, only take place under certain conditions and would, in any case, require both a change in entrepreneurial culture (which change does, however, already appear to be taking place, helped by the passage of generations) and, a greater integration between research institutions, education and training organizations and manufacturing firms. This integration should be a priority in order to encourage a flow of technical-scientific knowledge, of information and of resources between the various actors. The creation of supportive networks to provide "real services" to the firms was particularly emphasized. Such networks can be of different kinds: they may consist of companies alone, or of companies and education, training, consultancy or other supportive organisations.

References

Acs, Z. J.and D. B. Audretsch, 1990, *Innovation and Small Firms*, Cambridge, MA: MIT Press.

Acs, Z. J. and D. B. Audretsch, 1993, 'Innovation and Firm Size: The New Learning', in M. Dodgson and R. Rothwell (eds.), *International Journal of Technology Management, Special Publication on Small Firms and Innovation*, pp. 23–35.

Adam, E. E. and P. M. Swamidass, 1989, 'Assessing Operations Management from a Strategic Perspective', *Journal of Management*, **15**(2), 181–203.

Adler, P. S., 1988, *Managerial Challenges of CAD/CAM Integration*, Standford University: Industrial Engineering and Engineering Management Department.

Beatty, C. A., 1992, 'Implementing Advanced Manufacturing Technologies: Rules of the Road', *Sloan Management Review* **33**(4), 49–60.

Beatty, C. A., 1993, 'Critical Implementation Decisions for Advanced Manufacturing Technologies', *International Journal of Technology Management, Special Issue on 'Manufacturing Technology: Diffusion, Implementation and Management'* **8**(3/4/5), 189–196.

Belussi, F. (ed.), 1992, *Nuovi modelli di impresa. Gerarchie organizzative e imprese rete*, Milano: Franco Angeli.

Bessant, J., 1993, 'The Lessons of Failure: Learning to Manage New Manufacturing Technology', *International Journal of Technology Management, Special Issue on 'Manufacturing Technology: Diffusion, Implementation and Management'* **8**(2/3/4), 197–215.

Booz Allen & Hamilton Inc., 1991, *Analisi dell'evoluzione della domanda di macchine utensili, automazione e robotica in alcuni setori portanti dell'economia italiana*, Milano: UCIMU.

Chen, I. J. and M. H. Small, 1996, 'Planning for Advanced Manufacturing Technology', *International Journal of Operations and Production Management* **16**(5), 4–24.

Corsten, H. and O. Lang, 1988, 'Innovation Practice in Small and Medium-sized Enterprise: An Empirical Survey of the Member States of the European Community', *Technovation* **2**, 143–154.

Davis, D. D., 1986, *Managing Technological Innovation: Organizing Strategies for Implementing Advanced Manufacturing Technologies*, San Francisco: Jossey-Bass Publishers.

Decks, J., 1976, *The Small Firm Owner-manager-Entrepreneurial Behavior and Management Practice*, New York: Holt, Rinehart and Winston.

Dimnik, T. and R. Richardson, 1990, 'Flexible Automation in the Auto Parts Industry', *Business Quarterly* **54**(4), 46–53.

Eisenhardt, K. M., 1989, 'Building Theories from Case Study Research', *Academy of Management Review* **14**(4), 532–550.

Ettlie, J. E., 1986, 'Implementing Manufacturing Technologies: Lessons from Experience', in Davis D. Donald (ed.), *Managing Technological Innovation: Organizational Strategies for Implementing Advanced Manufacturing Technologies*, San Francisco: Jossey-Bass Publishers.

Gerwin, D., V. Kumar and S. Pal, 1992, 'Transfer of Advanced Manufacturing Technology from Canadian University to Industry', *Technology Transfer* (Spring-Summer), 57.

Goldhar, J. K. and M. Jelinek, 1983, 'Plan for Economies of Scope', *Harvard Business Review* **61**(6), 141–148.

Goldhar, J. K. and M. Jelinek, 1985, 'Computer Integrated Flexible Manufacturing: Organizational, Economic and Strategic Implications', *Interfaces* **15**(3), 94–105.

Harvey, J., L. A. Lefebvre and E. Lefebvre, 1992, 'Exploring the Relationship Between Productivity Problems and Technology Adoption in Small Manufacturing Firms', *IEEE Transactions on Engineering Management*, **39**(4), 352–358

Hayes, R. H. and D. A. Garwin, 1982, 'Managing as if Tomorrow Mattered', *Harvard Business Review* **60**(3), 67–77.

Julien, P. A., 1995, 'New Technologies and Technological Information in Small Businesses', *Journal of Business Venturing* **10**(6), 459–475.

Julien, P. A., M. F. Estimé and G. Drillon, 1993, *Les petites et moyennes entreprises: Technologie et Compétitivité*, Paris: OCDE.

Kelley, M. R., 1993, 'Organizational Resources and the Industrial environment: The Importance of Firm Size and Firm Linkages to the Adoption of Advanced Manufacturing Technology', in M. Dodgson and R. Rothwell (eds.), *International Journal of Technology Management, Special Publication on Small Firms and Innovation*, pp. 36–68.

Lefebvre, L. A., E. Lefebvre and J. Harvey, 1996, 'Intangible Assets as Determinants of Advanced Manufacturing Technology Adoption in SME's: Toward an Evolutionary Model', *IEEE Transactions On Engineering Management* **43**(3), 307–322.

Malecki, E. J. and. D. M. Tootle, 1996, 'The Role of Networks in Small Firm Competitiveness', *International Journal of Technology Management* **11**(1/2), 43–57.

McDaniel, J. R., 1989, *Managing Automation: A Study of the Adoption, Implementation and Evaluation of Advanced Manufacturing Technology*, Ph.D. Dissertation, University of Massachusetts.

Mechling, G. W., J. W. Pearce and J. W. Busbin, 1995, 'Exploiting AMT in Small Manufacturing Firms for Global Competitiveness', *International Journal of Operations and Production Management* **15**(2), 61–76.

Meredith, J., N.L. Hyer, D. Gerwin, S.R. Rosenthal and U. Wemmerlöv, 1986, 'Research Needs in Managing Factory Automation', *Journal of Operations Management* **6**(2), 203–218.

Meredith, J. R., 1987, 'The Strategic Advantages of New Manufacturing Technologies for Small Firms', *Strategic Management Journal* **8**, 249–258.

Meredith, J. R. and N. C. Suresh, 1986, 'Justification Techniques for Advanced Manufacturing Technologies', *International Journal of Production Research* **24**(5), 1043–1057.

Munro, H. and H. Noori, 1988, 'Measuring Commitment to New Manufacturing Technology: Integrating Technological Push and Marketing Pull Concepts', *IEEE Transactions on Engineering Management*, **35**(2), 63–70.

Noori, H., 1990, *Managing the Dynamics of New Technology*, Englewood Cliffs, NJ: Prentice-Hall.

Pandya, K. V. and F. Satyre, 1996, 'Factors Affecting Decision Making in the Implementation of Manufacturing Technology', *International Journal of Technology Management* **12**(2), 163–180.

Panisset, B. D., 1988, 'Measuring the Implementation', *Production and Inventory Management Review* **29**(2), 40–52.

Parthasarthy, R. and P. S. Sethi, 1992, 'The Impact of Flexible Automation on Business Strategy and Organizational Structure', *Academy of Management Review* **17**(1), 86–111.

Paul, H. and B. Suresh, 1991, 'Manufacturing Strategy through Planning and Control Techniques of Advanced Manufacturing Technology', *International Journal of Technology Management* **6**(3), 233–242.

Plonski, G. A., 1991, 'Comparing CAD Implementation in Engineering Firms in Brazil, Canada and the United States: the Need for 'Engimation', in David Bennett and Carl Lewis (eds.), *Achieving Competitive Edge*, Proceedings of the OMA-U.K. Sixth International Conference, London: Springer-Verlag, pp. 269–274.

Preece, D., 1995, *Organizations and Technical Change*, London: Routledge.

Primrose, P. L., G. D. Creamer and L. Raymond, 1985, 'Identifying and Quantifying the Company-wide Benefits of CAD within the Structure of a Comprehensive Investment Programme', in E. Rhodes and D. Wiels (eds.), *Implementing New Technologies*, Oxford: Basil Blackwell.

Ramamurthy, K., 1995, 'The Influence of Planning on Implementation Success of Advanced Manufacturing Technologies', *IEEE Transactions on Engineering Management* **42**(1), 62–73.

Raymond, L., P. A. Julien, J. B. Carrière and R. Lachance, 1996, 'Managing Technological Change in Manufacturing SMEs: A Multiple Case Analysis', *International Journal of Technology Management, Special Issue on the 5th International Forum on Technology Management* **11**(3/4) 270–285.

Rosenthal, S. R., 1984, 'Progress Toward the Factory of the Future', *Journal of Operations Management* **4**(3), 203–229.

Sambasivarao, K. V. and S. G. Deshmukh, 1995, 'Selection and Implementation of Advanced Manufacturing Technologies: Classification and Literature Review of Issues', *International Journal of Operations and Production Management* **15**(10), 43–62.

Schroeder, D. M., C. Gopinath and S. W. Congden, 1989, 'New Technology and the Small Manufacture: Panacea of Plague?', *Journal of Small Business Management* **27**(7), 1–10.

Senker, P., 1985, 'Implications of CAD/CAM for Management', in E. Rhodes and D. Wiels (eds.), *Implementing New Technologies*, Oxford: Basil Blackwell.

Snell, S. A. and J. W. Dean, 1992, 'Integrated Manufacturing and Human Resource Management: A Human Capital Perspective', *Academy of Management Journal* **35**(3), 467–504.

Son, Y. K., 1992, 'A Comprehensive Bibliography on Justification of Advanced Manufacturing Technologies', *The Engineering Economist* **38**, 59–71.

Stark, J., 1988, *Managing CAD/CAM*, Singapore: McGraw-Hill.

Takanaka, H., 1991, 'Critical Success Factors in Factory Automation', *Long Range Planning* **24**(4), 45–63.

Tidd, J., 1991, *Flexible Manufacturing Technologies and International Competitiveness*, London: Pinter.

UCIMU, 1994, *Annual Report*, Milano: mimeo.

von Hippel, E., 1988, *The Sources of Innovation*, New York and Oxford: Oxford University Press.

Voss, C. A., 1992, 'Successful Innovation and Implementation of New Processes', *Business Strategy Review* (Spring), 29–44.

Weill, P., D. A. Samson and A. S. Sohal 1991, 'Advanced Manufacturing Technology: An Analysis of Practice', *International Journal of Technology Management, Special Issue on 'Manufacturing Strategy* **6**(3/4), 335–353.

Zairi, M., 1992, 'The Role of Consultants in AMT Implementation', *Journal of General Management* **18**(1), 63–73.