How flexible manufacturing systems affect tooling and machining enterprises

By: Albert N. Link and Perry D. Quick

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Abstract:

This paper[1] presents the empirical results from an extensive study of the use of elements of flexible manufacturing systems (FMS) by enterprises in the US tooling and machining industry. Important managerial implications regarding the use of FMS technology in industrial settings are drawn from the lessons learned in the study.

Keywords: flexible manufacturing systems (FMS) | tooling and machining industry

Article:

1. Introduction

There has been great interest in recent years in new manufacturing technologies and techniques. This interest has come about and been maintained for a number of reasons, two of which are the continuous decline in the competitive position of many US industries in world markets and the success of Japan and other rival nations in these areas.

Manufacturing experts and other observers believe that flexible manufacturing systems (FMS) can improve productivity and the global competitiveness of manufacturing sectors, especially that of the USA. There is an abundance of anecdotal evidence to support the claim that FMS can lead to lower production costs, increased labor productivity, and improved international competitive advantage [1-4].

Surprisingly absent from this literature are in-depth industry studies regarding the subtleties surrounding the adoption of and benefits from FMS technology. The numerous empirical studies that do exist focus almost exclusively on explaining inter-firm differences in the timing of the adoption of the technology [5-7]. Although interesting in their own right, these investigations are often too narrow in scope for one to draw meaningful managerial prescriptions.

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The purpose of this paper is to present the empirical results from an extensive study of the use of FMS technology by enterprises in the US tooling and machining industry. After describing the nature of this industry in Section 2, selected statistics are presented in Section 3 to illustrate the extent to which this technology is used in this industry and to describe the benefits received by the adopters. Managerial inferences from this analysis are set forth in Section 4.

2. The tooling and machining industry and the sample of enterprises

The US Standard Industrial Classification distinguishes between tooling and machining. Tooling, or more commonly the tool and die industry (SIC 3544), includes enterprises that produce special tools and fixtures that are used with machine tools, hammers, die-casting machines and presses. Machining (SIC 35995 within SIC 3599) includes machine shops doing contracted work for others.

The US tooling and machining industry comprises relatively small enterprises. US Census of Manufacturers data for 1987 show that 57% of the 7300 establishments within SIC 3544 have fewer than 10 employees; 94% have fewer than 50 employees. For SIC 3599, 69% of the 21500 establishments have fewer than 10 employees and 97% have fewer than 50 employees.[2]

Enterprises in this industry were selected for study for several reasons.

1. Because of their fundamental involvement with many aspects of the manufacturing sector, the tooling and machining industry is at the core of the US industrial economy.
2. The potential for the extensive application of elements of an FMS exists for all tooling and machining enterprises, regardless of their size, owing to both financial and competitive pressures, and to a decreasing supply of highly skilled labor.[3]
3. The National Tooling and Machining Association (NTMA), the industry association of tooling and machining enterprises, expressed an interest in this study and a willingness to assist in the data collection effort.

In 1990, the year in which the study was conducted, the association had approximately 3000 members. With the assistance of NTMA's president and staff, a random sample, stratified by size, of 300 enterprises was selected for a mail survey.[4] Of the 300 members surveyed, 128 returned completed or partially-completed survey instruments. Of the 172 non-responding enterprises (as determined from follow-up telephone interviewers), 67 did not return the survey because it did not apply to their operations (presumably these enterprises did not use FMS), 54 were unwilling to participate in the study, 12 stated that they would return the instrument but never did, and the contact person in the rest could not be reached on two attempts.

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[2] See refs. (8, 9) for detailed overviews of the US tooling and machining industry.

[3] A 1990 survey (10) of tooling and machining enterprises indicated that over 80% of these managers believed that it would be 'very difficult' or 'somewhat difficult' to fill positions for precision machinists, tool makers, die makers, and mold makers over the next five years.

[4] Details about the size distribution of enterprises within the sample of 3000 and the sub-sample of 300 are available upon request. The survey instrument is also available.

The 128 enterprises that returned completed or partially-completed instruments formed the basis for this study. The size distribution of sample enterprises closely parallels the size distribution of the tooling and machining industry as a whole. Specifically, 85% of the sample enterprises had fewer than 50 employees, and only 7% of the enterprises had 100 or more employees.

3. The use of flexible manufacturing systems in enterprises

3.1. Use of the technology

Although there is not a standardized definition of a flexible manufacturing system, there is much agreement as to the elements that constitute such a system and how they interface. The definition used in this study closely parallels that used for other purposes by the US Department of Commerce (1985) [9]. For this study:

A flexible manufacturing system (FMS) is a computer-controlled grouping of work stations and material-handling devices designed to adapt automatically to design, model, or style changes. An FMS may contain a number of elements, including numerically-controlled (NC) or computer numerically-controlled (CNC) machine tools, industrial robots, material handling devices, and computer-aided manufacturing (CAM) technologies.

On the basis of this definition, 63 of the 128 enterprises have at least some aspect of their production operation controlled by elements of an FMS. As shown in Table 1, most enterprises that use the technology have between 10% and 75% of their operations so controlled. The median response was 25-50% of production operations controlled by elements of an FMS.

Table 1. Extent of operations controlled by FMS technology (n = 128)
Survey question: *Using [our] definition of a flexible manufacturing system, approximately how much of your production operation is controlled by elements of an FMS?*

	Number	Percentage	Cumulative percentage
0%	65	50.8	50.8
up to 10%	8	6.3	57.0
10 to 25%	16	12.5	69.5
25 to 50%	16	12.5	82.0
50 to 75%	14	10.9	93.0
75 to 100%	8	6.3	99.2
100%	1	0.8	100.0

Of the five specific FMS elements mentioned in our survey definition, 9 enterprises use only one element, 36 use two, 16 use three, and only 1 enterprise out of 62 responding to this survey question uses four elements. Of these 62 enterprises, nearly 97% use CNC machine tools and nearly 73% use CAM technology.

Not only do tooling and machining enterprises differ in the extent of their production operations controlled by elements of an FMS (Table 1), but they also differ in the extent to which they utilize the technology that is in place. As shown in Table 2, one-third of the enterprises reported that elements of an FMS are used in less than 25% of all possible application areas. The median

FMS user appears to use the technology in close to 50% of the possible application areas in production.

Table 2. Extent of use of FMS technology among enterprises using elements of an FMS (n = 63)
Survey question: *Our enterprise uses elements of an FMS in approximately — percent of all possible application areas in production.*

	Number	Percentage	Cumulative percentage
up to 10%	8	12.7	12.7
10 to 25%	13	20.6	33.3
25 to 50%	14	22.2	55.6
50 to 75%	13	20.6	76.2
75 to 100%	13	20.6	96.8
100%	2	3.2	100.0

Several statistical tests were performed on these sample data. Larger enterprises that use elements of an FMS do so in greater variety than do smaller enterprises that use the technology. The correlation coefficient between enterprise size (as measured by number of employees) and the number of elements of an FMS in use is 0.43 (significant at the 0.01 level).

Data were collected on the year in which the enterprise first adopted an FMS element. On average, these enterprises have been using FMS technology for 7.2 years (range of 1 year to 15 years). The correlation coefficient between the number of years an enterprise has used FMS technology and the number of elements it currently uses is 0.24 (significant at the 0.10 level). This finding suggests that, over time, FMS users have increased the variety of elements that they employ. This conclusion is not inconsistent with the positive relationship between enterprise size and usage under the assumption that enterprises grow over time, nor is it inconsistent with the increasing need for enterprises of all sizes to adopt technology in order to remain competitive in globally competitive markets.

3.2. Factors influencing the adoption of the technology

To determine the extent to which outside information influences a tooling and machining enterprise's decision to adopt elements of an FMS, 11 potential information sources were identified (with the assistance of the NTMA staff). As shown in Table 3, over 91 % of the 47 responding enterprises agreed that information (1) from industrial shows, exhibits, and demonstrations and (2) from the trade press or from magazine articles was the most influential in their decision to adopt the technology. This finding is especially interesting when compared to the empirical studies of technology adoption that conclude that the diffusion of a new technology follows a logistic pattern. Many researchers (e.g. [11]) infer that the rate of adoption increases over time as firms realize that their competitors have adopted the technology. However, 60% of the enterprises studied reported that they disagreed or strongly disagreed that information about other tooling and machining enterprises using an FMS aided their decision to adopt the technology.

Shown in Table 4 is the distribution of the number of information sources used. There is a fairly uniform distribution for enterprises that were aided by at least 3 and as many as 9 sources. This

pattern may suggest that there is a critical threshold number of information sources necessary to elicit an FMS investment commitment.

Table 3. Information sources that aided the decision to adopt elements of an FMS (in percentages; $n = 47$)
Survey question: *Our decision to adopt elements of an FMS was aided by:*

	Strongly agree	Agree	Disagree	Strongly disagree	No opinion
information from consultants	4.3	14.9	55.3	14.9	10.6
information about our competitors using an FMS	6.4	38.3	42.5	8.5	4.3
information from the government	0	0	63.8	19.2	17.1
information from our customers	10.6	61.7	27.7	0	0
demands from our customers to adopt the technology	14.9	59.6	23.4	0	2.1
information from FMS vendors	12.8	59.6	16.9	4.3	6.4
information from other vendors	2.1	59.6	29.8	0	8.5
information from industrial shows, exhibits, and demonstrations	27.7	63.8	4.3	2.1	2.1
information from trade associations and professional societies	8.5	63.8	12.8	4.3	10.6
information from the trade press or from magazine articles	16.9	74.5	0	2.0	6.4
accounting systems that showed the advantages associated with this new technology	4.3	25.5	53.1	4.3	12.8

Table 4. Distribution of number of information sources ($n = 47$)
For each enterprise, the total number of information sources used was determined by summing over the above responses for which a 'strongly agree' or 'agree' response was given. The distribution of the number of information sources used is:

	Number	Percentage	Cumulative percentage
1 source	0	0	0
2 sources	0	0	0
3 sources	4	8.5	8.5
4 sources	7	14.9	23.4
5 sources	5	10.6	34.0
6 sources	10	21.3	55.3
7 sources	5	10.6	66.0
8 sources	6	12.8	78.7
9 sources	4	8.5	87.2
10 sources	2	4.3	91.5
11 sources	4	8.5	100.0

In an effort to determine the relationship between enterprise size and the use of alternative information sources, a correlation coefficient was calculated between the number of employees and the number of utilized sources. The coefficient is 0.008, which is statistically insignificant. Size *per se* does not influence the number of information sources used as part of this technology adoption decision.

Note, in Table 3, that no enterprise strongly agreed or even agreed with the statement that information from the US government aided in their adoption decision. Perhaps the US government does not provide information on advanced technologies, or, if it does, perhaps it is uninformative. However, in another question (not shown but available), 39 of 59 responding enterprises (66%) stated that the government's reinstatement of the 10% investment tax credit would provide a strong incentive to adopt more elements of FMS technology; 31% stated that it would provide a mild incentive.

Finally, FMS technology users were asked to evaluate possible barriers to greater adoption of elements of an FMS. As shown in Table 5, cost is the strongest barrier. Ranking just behind this is the cost of training personnel and the cost of system integration. The relatively high ranking of cost as an adoption barrier explains the receptiveness of FMS technology users to government loan programs. Of 59 enterprises, 48 reported in another question (not shown but available) that a direct government loan or loan guarantee by the government would provide either a strong (29 enterprises) or a mild (19 enterprises) incentive to adopt additional elements of FMS technology. Of the 13 items listed, the item reported most frequently as not a barrier was information on the benefits of FMS technology.

Table 5. Barriers to the adoption of additional elements of an FMS (in percentages; $n = 46$)
Survey question: *What to you see as barriers to greater adoption of elements of an FMS?*

	Strong barrier	**Mild barrier**	**Not a barrier**
Cost of:			
hardware	41.3	47.8	10.9
system integration	19.6	60.9	19.6
other installation	6.5	41.3	52.2
part design and programming	13.0	50.0	37.0
other software	17.4	60.9	21.7
training	28.3	54.3	17.4
Lack of information on:			
hardware	15.2	39.1	45.7
system integration	21.7	50.0	28.3
other installation	13.0	37.0	50.0
part design and programming	19.6	39.1	41.3
other software	8.7	52.2	39.1
training	19.6	54.3	26.1
benefits of FMS	6.5	30.4	63.1

3.3. Benefits to users of FMS technology

Of the 63 enteprises that use FMS technology, 56 provided information about the competitive benefits that they receive from using these elements. As shown in Table 6, the competitive benefits that scored most highly were those associated with the production process (product quality, engineering tolerance, more productive use of direct labor, ability to respond to market changes, faster throughput, shorter turn-around time, ability to customize). Less highly regarded, but still of significant benefit, was the effect of adoption on price. There was less agreement regarding the benefits of using less labor and almost no net agreement on the benefit of having lower inventories. Quantifying these responses (strongly agree as 4, agree as 3, no opinion as 2,

disagree as 1, and strongly disagree as 0) and correlating them with enterprise size produced an insignificant coefficient.

Table 6. Competitive benefits from using elements of an FMS (in percentages; $n = 56$)
Survey question: *Our adoption of elements of an FMS has resulted in our enterprise improving our competitive position in:*

	Strongly agree	Agree	Disagree	Strongly disagree	No opinion
price	37.5	50.0	10.7	0	1.8
product quality	48.2	50.0	1.8	0	0
engineering tolerance	37.5	57.1	3.6	0	1.8
ability to customize products	37.5	46.4	5.4	0	10.7
ability to respond to market changes	30.4	60.7	3.6	0	5.3
faster throughput, shorter turn-around time	44.6	46.4	7.2	0	1.8
more productive use of direct labor	37.5	57.1	5.4	0	0
using less labor	26.8	53.6	16.0	1.8	1.8
having lower inventories	10.7	33.9	35.7	1.8	17.9

Table 7. Summary benefits from using elements of an FMS (in percentages; $n = 54$)
Survey question: *As a result of our adoption of elements of an FMS we:*

	Strongly agree	Agree	Disagree	Strongly disagree	No opinion
acquired new customers	33.3	42.6	16.7	0	7.4
increased our sales	31.5	53.7	9.3	0	5.5
improved our profitability	22.2	63.0	9.3	1.9	3.6

Table 8. Management changes in response to the adoption of elements of an FMS (in percentages; $n = 51$)
Survey question: *As a result of our adoption of elements of an FMS, we found it desirable to make the following management changes:*

	Strongly agree	Agree	Disagree	Strongly disagree	No opinion
more supervisory personnel were hired	2.0	17.6	64.7	9.8	5.9
production workers were moved to non-FMS areas within the enterprise	3.9	11.8	64.7	7.8	11.8
communication channels were improved among workers	7.8	31.4	41.2	2.0	17.6

In addition to benefits directly related to production, over 80% of the 54 respondents said that their use of FMS technology increased their sales and improved their profitability. Over 75% noted that their customer base expanded (see Table 7). An additional benefit from FMS technology, as shown in Table 8, is that few management changes are needed as a result of adopting the technology. In fact, nearly 40% of the enterprises noted that their communication channels among workers improved after the adoption of elements of an FMS. Apparently, FMS

technology does not demand new supervisory personnel or a reallocation of production personnel.[5]

4. Inferences from the study

To the extent that the lessons learned in this study of the tooling and machining industry can be generalized to other industries, there are four important managerial implications regarding the use of FMS technology in industrial settings.

First, non-users of FMS technology should not rely on a single information source when contemplating the decision to adopt. Multiple information sources would be useful, and these information sources are readily available – information is not an adoption barrier to overcome.

Second, the cost of FMS technology is a significant barrier to overcome in both the initial adoption decision and the decision about more extensive use of the technology.

Third, FMS technology users can expect myriad benefits, especially as related to their production process. Improved production leads to increased sales and heightened profitability. Relatedly, adopters should not expect cost benefits primarily in terms of savings of labor from the technology.

Finally, if the technology is well understood prior to its introduction, perhaps through an efficient use of information sources, few, if any, organizational changes will be needed when the technology is introduced.

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[5] Regarding the findings in Tables 7 and 8, there is no statistical correlation between enterprise size and any of the categorical responses.

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