I. STRATEGIC, ECONOMIC AND FLEXIBILITY ASPECTS

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MANUFACTURING TECHNOLOGY POLICY AND DEPLOYMENT OF PROCESSING INNOVATIONS

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Abstract

This is a report of a study on the evolution of manufacturing technology policy during the deployment of domestic advanced manufacturing systems in thirty-four plants and two panels of data collection separated by one year. Changing firm environment was significantly correlated with pioneering product introduction business strategy ($p < 0.05$). More importantly, it was found that manufacturing technology policy is significantly ($p < 0.05$) associated with pioneering business strategy. Further, findings indicate that fine-tuning or modest adjustment in this policy (versus doing nothing or drastic change) was significantly ($p < 0.05$) associated with the maximum levels of reported utilization of these new systems in a subsample of second panel, complete data cases ($n = 21$). This curvilinear relationship between the absolute value of changes in technology policy and performance measure did not hold for the percentage of target cycle time achieved nor uptime, although results concerning performance are considered preliminary at the time of this writing. Advertising this processing technology tends to be inversely related to the radicalness of the technology incorporated into the system ($p = 0.076$) during the deployment period tracked thus far. That is, firms installing more radical systems tend to become very cautious about sharing information about the project once installation begins.

Keywords

Technology management, modernization, manufacturing, technology policy, computer-integrated manufacturing, organizational change.

1. Introduction

Technology policy has been previously defined as the long-range plan for incorporation of new materials, introduction of new products, and adoption of new processing technologies into a firm (Ettlie and Bridges [9]). The theory that a very aggressive technology policy is associated with the adoption of radical technology in process and product has generally been supported by empirical findings (Ettlie and Bridges [9], Ettlie [6], Ettlie et al. [10]). A number of other authors have also substantiated the link between strategic issues concerning technology and organizational outcomes such as innovativeness and effectiveness (Foster [13], Maidique and Patch [21], Cooper and Schendel [4], Cooper [5], Birnbaum [2]).

There have also been a more limited set of studies that have examined the connection between individual characteristics of managers and policy concerning technologies with rather consistent results (Hayes and Abernathy [18], Miller et al. [24]). For example, Ettlie [6] found for fifty food processing firms that the more aggressive a company's technology policy, the higher key managers rated themselves on innovation intentions ($r = 0.28$, $p < 0.05$). The latter was measured using a scale developed by Ettlie and O'Keefe [11], and correlates significantly with standardized, accepted measures of individual creativity and change values.

The issue under consideration here is the role that technology policy plays in the deployment of advanced manufacturing technology. The continued refinement of the technology policy concept is essential to this type of study, but perhaps not the most significant challenge. The investigation of the causes and effects of manufacturing technology policy in high-tech domestic plants represents a formidable research agenda. For example, there are 20 000 robots in use in U.S. plants at the time of this writing, and one report concludes that there are 400 flexible manufacturing systems world-wide (Farnum [12]), with probably 60 of those being large domestic systems, disregarding small flexible manufacturing cells which are clearly an adoption trend.

2. Manufacturing technology policy

Manufacturing technology policy is defined as the long-range plan for modernization of the productive core of an organization and its key interface and support functions such as engineering and materials handling or logistics. This definition assumes that in all organizations there is a tendency for gradual change over time to close performance gaps (March and Simon [23]), and that in manufacturing organizations, some equipment is always in need of replacement because of obsolescence, absence of repair parts, and wear-out or breakdown. Therefore, firms vary on the degree to which they aggressively pursue state-of-the-art, radical departures from existing technologies of processing to replace their existing plant capacity in the manufacturing core.

The definition of manufacturing technology policy also needs to be distinguished from several other related concepts. First, it is expected to be distinct from the concept of *innovation strategy*, which in at least one formulation by Freeman ([14], p. 171) focuses on R&D strategy integrated with business unit strategy. Thus, firms can be either offensive, defensive, imitative, etc., in Freeman's terms for their products and services. Obviously, other construct definitions of innovation strategy are possible.

The other distinction that needs to be made is that of technological versus *administrative innovation.* The latter refers to changes in strategies and structures and practices that may or may not be related to technological changes in the operations or design core of an organization. Clearly, an innovation administrative practice would be one that is new to the world, and could apply to manufacturing technology policy, and here the issue of how one measures administrative innovation is important. To the extent that measures of administrative and policy innovation are related, these two concepts may, indeed, be quite similar.

The organizing thesis of this research assumes that manufacturing technology policy occupies a central position in a causal model of deployment strategies for computer-integrated manufacturing and can, therefore, be very useful in predicting outcomes such as overall success or failure. The thesis is that *modest flexibility at the policy level of analysis, i.e. manufacturing technology policy, over the duration of a major deployment effort, is crucial to the success of the program.* This also assumes that the strategies in place, which give rise to operating policy, remain relatively stable and unchanging over this same period. Not coincidently, it also follows that structural adaptations will vary considerably and follow from more modest policy fine-tuning during the deployment period. This organizing thesis and framework is summarized in fig. 1.

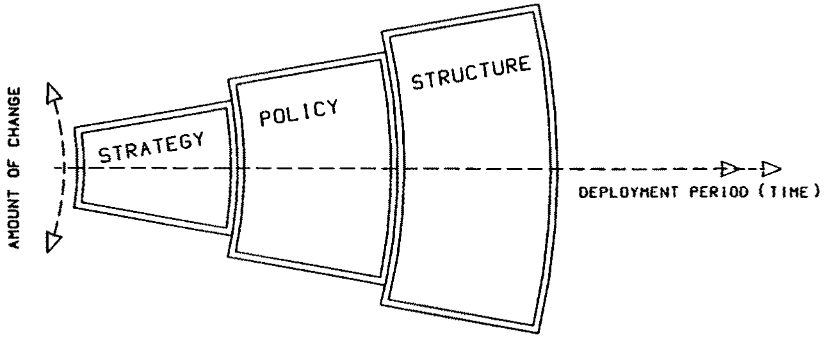

Fig. 1. Organizing framework.

The causes of these modest policy changes vis-a-vis technology and their substance and impact on outcomes is the focus of this line of research. This thesis of fine-tuning policy within the context of stable strategy for business is founded in part on results of empirical studies of radical technological change in organizations which show the benefits of flexibility during deployment (e.g. Mann and Williams [22], Graham and Rosenthal [15]), and the general trends of the strategic planning literature that attempts to show the benefits of cohesive, consistent strategies in organizations.

Any policy of an organization, regardless of its functional base, is assumed to be sequentially activated and derived from corporate strategy (What business are we in?) and business strategy (How are we going to compete in that business?). Therefore, the first two propositions of the study involve replication of any number of other studies on strategy that hypothesize an environment-business strategy connection (Hambrick [17]), and a subsequent business strategy-manufacturing technology policy connection (Swamidass [28]).

PROPOSITION 1

Business strategy is contingent on firm environment; e.g. rapidly changing environments are associated with pioneering product business strategies, etc.

PROPOSITION 2

Technology policy follows from strategy. Pioneering product business strategy is associated with an aggressive manufacturing technology policy, etc.

3. The evolution of manufacturing technology policy

The focus and thesis of this research is on the modest changes or evolution in manufacturing technology policy during deployment programs for computer-integrated manufacturing technology. This fine-tuning of the policy associated with the technology changes in the manufacturing core is hypothesized as being essential to the success of these ambitious programs. Both the extent of change and the substance of these changes are crucial to understand if this theory is to be tested and refined. What is more, the methods used to plan may also be affected by these gradual changes.

First, concerning the extent of change in manufacturing technology policy, regardless of the degree to which this policy is aggressive or not, one expects a nonlinear relationship with project success. Too much change at the policy level will be disruptive, but inflexibility, in the face of the typical uncertainty and new information created during the deployment period, is also dysfunctional. There is an optimum level of directional change to fine-tune and take into account information inputs from members of the focal change team. They must be able to have an impact on policy to ensure commitment and technically accurate solutions to problems that crop up during the early stages of the learning curve with a new process.

PROPOSITION 3

There is a curvilinear relationship between the amount of change in manufacturing technology policy and the success of a computer-integrated manufacturing (CIM) program. Modest, fine-tuning changes are associated with the greatest success, while no change and radical shifts in policy are associated with lower success.

Second, concerning the substance of the changes in manufacturing technology policy, it is expected that the type of changes in policy will be dependent in part on the starting point level of aggressiveness of this policy and the profile of technology policy that initiated the CIM project. Although the overall aggressiveness and extent of formalization of manufacturing technology policy (degree to which it is documented) is likely to remain stable during deployment, much like business strategy, the degree to which this policy and the outcomes with CIM are made public is likely to vary considerably across companies and plants.

4. Advertising modernization

If the Allen-Bradley, world contractor assembly plant (Knill [20]) and IBM, Lexington, Kentucky typewriter plant experiences are any indicators, then being in the automation supply business promotes showcase factory-of-the-future deployment strategies. On the other hand, the experiences of many other firms mounting equally challenging systems integration projects suggests that keeping the wraps on these programs until the last possible moment is a planned strategy (e.g. GE Bromont in Quebec). Although these examples seem to illustrate the extremes in strategic posture, they actually allow these firms to maximize the strategic benefit of automation projects. In the one extreme, the showcase optimizes the strategic marketing objective of the firm, in the other extreme, it allows the plant to maximize strategic integration of manufacturing strategy with business and corporate strategy. In either case, there will be modest pressure to sustain enthusiasm by increasing the pro-activity and aggressiveness of the business unit's manufacturing technology policy.

In some cases, firms have decided to showcase an installation as an afterthought (e.g. Allen-Bradley) when manufacturing strategy shifted during the course of deployment, which is rather rare. In other cases, showcase installations are used in a much more limited fashion for more narrow sets of objectives. For example, the GE dishwasher line in Louisville is only open for very restricted audiences representing friendly manufacturing firms, and is not generally available to the public like the GM Orion plant in Pontiac, Michigan. Larger firms pick some automation projects to showcase and not others. Most firms do not have this luxury.

There are at least two plausible explanations for why plants would become more protective of information concerning an automation project. First, there might be performance problems. If publicized, this might present the project in a bad light and result in a premature evaluation of the radical shift in technology (Hage [16]). Second, the project may become more detailed in its specification as it unfolds and, if considered a radical shift and potentially a leapfrog on competitors, there will be a strategic advantage in keeping the project proprietary for some years even after the learning curve has run its course. This does not rule out the possibility that the case will evolve into a showcase, but it seems that most firms will delay this decision until the last possible moment, pending outcomes with the new system. If performance does warrant advertising and if the firm wants to sell the technology, it will likely become a showcase. This assumes that performance and system radicalness are unrelated.

Based on this framework and case history tendences, the following two final propositions are offered for testing.

PROPOSITION 4

The more radical the technology incorporated into a new manufacturing system, the less likely the firm is to advertise the outcomes of the project during the deployment period.

PROPOSITION 5

The better the performance of a new system, the more likely a firm will be to advertise the system.

There is one plausible, rival hypothesis here that ultimately needs investigation, although it is not addressed in this study. A few firms appear to be pursuing a strategy that maximizes internal showcase activity, but drastically reduces external exposure for many years after a program is started. There are not many known cases of this trend because of the very nature of the strategy itself, but it is a tendency worth watching.

5. Method

The overall study design called for three longitudinal panels of data collection in domestic plants of durable goods manufacturing. Preliminary results are available from the first and second panels of data collection for this report.

SAMPLE

A national sample of announcements of firms purchasing advanced manufacturing systems was selected primarily using published sources such as *Metalworking News*, *Automation News*, and several robotics and newspaper publications. Industry sources and suppliers were also used to identify candidate cases of new technology systems being installed during the study period. In order to be eligible for the study, a firm was required to have committed resources for the purchase of a system, although not necessarily to have installed equipment yet. In the first panel, a total of 39 (66%) of the 59 eligible plants participated in interviews at plants, with a total of over 100 personnel interviewed by the author and associates primarily in the fall of 1984 and a few in early 1985. The second panel data was collected in the same way in 1985 and 1986 on 34 of the 39 cases. Eighteen (67%) of the 27 plants eligible for questionnaires mailed back at least one survey from cell personnel, and a total of 57 (67%) of the 85 questionnaires distributed were returned completed. Of the primary respondents, most were middle managers (53%).

The majority (26, or 67%) of the cases were flexible manufacturing systems defined in very broad terms – multiple machine, materials handling intensive, and computer-integrated systems. In addition, five (13%) were flexible assembly systems and three (8%) were robotic cells. No attempt was made in this study to systematically categorize these systems by the degree to which they were tended, partially tended, or untended. However, the sample was segregated by flexible manufacturing system and all other cases, and correlations show no significant change. Industry comparisons were also done by major grouping (2-digit SIC), as well as size of firm and plant, with no major effects detected. The exception was the tendency for larger firms to be unionized. However, unionization was not correlated with any other factor, so it was deleted from the analysis. Median system cost was $3.6 million, but 10 (28%) of the plants spent less than $1.0 million at the time of the first panel data collection.

Participating plants were operated by primarily large firms, with the vast majority (34) having more than 500 employees, and covering all the major manufacturing categories of transportation equipment, fabricated metal products, and electrical or other equipment. Plant sizes tended to be smaller, however, with over 40% having less than 500 employees. All regions of the country were well represented in the sample.

Complete data for both the first and second panel at this writing were available for 34 of these 39 plants. Two plants have been declared ineligible because they have closed, and one has matured to the point where no significant change is ocurring. Two plants have yet to provide complete panel-two data. It is important to note that this sample does not represent all durable goods manufacturers, but rather a more select set of organizations already introducing advanced manufacturing processing change.

6. Measures

Scales were developed from interview data to measure variables of interest, and indicators used (one question each) for two more factors. Two variables were measured using judges' evaluation of interview data, so that a total of nine entries appear on the correlation matrix in table 1. Where available, Cronbach alpha and inter-rater reliabilities are reported on the diagonal of the correlation matrix, as indicated. Questionnaire data are not discussed in this report. Both interview schedule and questionnaire are available from the author. Summation scales were used in all cases.

Table 1

Descriptive statistics and correlation coefficients

Variables	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8a)	(8b)	(8c)
Time 1 (n = 39)												
(1) Environment (n = 38)	2.66	1.19	( )									
(2) Business strategy	2.31	0.69	0.29**	( )								
(3) Manufacturing technology policy	15.03#	3.51	0.14	0.44*	(0.69)							
(4) Technology radicalness	1.95	0.69	0.03	0.20	0.18	(0.77)$						
Time 2 (n = 34)												
(5) Business strategy	2.35	0.77	0.22	(0.79*)	0.34**	0.14	( )					
(6) Manufacturing technology policy	15.03	3.17	0.30**	0.57*	(0.81*)	0.01	0.43*	(0.46)				
(7) Item D from (6): Advertise manufacturing technology policy	3.88	1.27	0.08	0.01	0.19	−0.25	0.14	0.44*	( )			
(8) System performance												
a: Cycle time (percent of target obtained) (n = 17)	0.94	0.12	0.09	0.15	−0.35	−0.21	0.08	0.03	0.21	(0.53¢)		
b: Uptime (n = 23)	0.85	0.13	0.01	−0.10	0.51*	−0.36**	0.02	0.42*	0.40**	0.22@	(0.56¢)	
c: Utilization (n = 21)	0.62	0.23	−0.14	0.16	0.44**	0.02	0.25	0.18	−0.01	−0.55**@	0.29ç	(0.45¢)

* $p < 0.01$ (one tail).

** $p < 0.05$ (one tail).

@ $n = 15$.

ç $n = 19$.

$ For an independent engineering panel of six judges, there was a 77.2% agreement with the author on the radical category.

¢ Kendall Tau correlations, Judge ranking and indices for nine cases ($0.05 < p < 0.10$).

\# Mean = 14.88 without missing cases estimated.

Manufacturing technology policy is the firm or business unit long-range plan for modernization of the productive core. Four, five-choice, Likert-type items resulted from the reliability analysis with a Cronbach alpha of 0.69 for panel one, and with a Cronbach alpha of 0.46 (n = 34) for panel two data. With the exception of the last item which was new for this study, these questions replicate earlier scales for this construct: (1) a long tradition of being first to try out new equipment and mathods; (2) actively engaged in recruiting technical personnel; (3) strongly committed to technological forecasting; and (4) advertise new processing technology to customers. Although the reliability of the scale is highest in the second panel with just the first and third items (0.71), all four items were retained for comparability because of the relatively high test-retest coefficient of $r = 0.81$ ($p < 0.01$) in table 1. The decrease in the Cronbach alpha for second panel data is assumed to be due to the fine-tuning of this policy during deployment.

There is also a question on the interview schedule that asks whether or not the firm or SBU (strategic business unit) had a written technology policy. This was coded "3" for written, proprietary policy, "2" for written policy, and "1" for no written policy. It was assumed that the higher the scores on this scale, the more strategic and valued the technology policy because, thus coded, it was significantly correlated (first panel) with reported "plans in the books" for system investments for the next three years, $r = 0.25$ ($p < 0.07$, $n = 39$).

System performance was measured using three indicators, which were all significantly intercorrelated, but for which only a very limited sample was actually available in panel two data. Cycle time was defined as the percentage of cycle time target achieved, and data for 17 cases were available. Uptime was the amount of time (two shifts) available for production (n = 23); utilization was the amount of time under cycle control (two shifts), for which 21 cases provided data.

Validation of these first three scales was accomplished by correlated case scores and, where available, with an industry expert ranking on FMS. This independent judge assigned scores of 1 (failure), 2 (poor), 3 (average), 4 (good), and 5 (excellent) to nine of the cases with available outcome data. The resulting Kendall correlations were Tau = 0.53 ($p < 0.06$) for cycle time; Tau = 0.56 ($p < 0.05$) for uptime; and Tau = 0.45 ($p < 0.08$) for utilization. This is a good indication of adequate construct validity for this type of research.

While utilization and uptime were directly related (table 1), cycle times did not follow this pattern. Given the small sample of complete data cases available at the time of this writing, tests of propositions involving performance measures are considered preliminary and should be interpreted with great caution.

Environment and business strategy were measured by category responses after the formats in Hambrick [17], which follows the Miles and Snow theory of prospector-analyzer-defender business trategy, and growth to maturity categories for environment. The business strategy categories are various graduations on the degree to which new product development is central to the posture of the firm or

SBU, and the product-process dependency assumption (Ettlie [7]) can be tested using these self-report categories based on Hambrick's work. That is, product development business strategy follows from environment which, in turn, stimulates an aggressive technology policy. Correlation between first and second panel scores was $r = 0.79$ ($p < 0.01$).

Radicalness of technology incorporated into each system was determined by a panel of judges ranking using the following protocal: (1) radical technology is a rare event, e.g. typically only 10% of all new products introduced each year are new to the world (Booz, Allen and Hamilton, Inc. [3]); (2) radical technology incorporation involves new science (science indicators approach) that is a demonstrable departure from existing practice, e.g. cutting of metal bars with saws versus lasers; (3) new technology that is radical is risky to adopt because of lack of precedence in use and the outcome of use is uncertain (Hage [16]); and (4) radical technology requires new skills and attitudes to deploy, and a learning curve effect is observed when it goes into use. For the radical category alone, and for a panel of six engineers, there was a 77% agreement with the author on codification. In addition, and before cases were presented, these six engineers agreed on five additional criteria for the protocol: (1) level of integration of the system; (2) flexibility; (3) machine intelligence; (4) robustness or degree to which the system meets performance goals under adverse conditions; and (5) number of new features incorporated into the system. Eight of the 39 cases were coded as radical technology systems in the first panel.

7. Results

The descriptive statistics for the variables of interest appear in table 1. Note that, *on average*, there is virtually no change in the scores for business strategy and manufacturing technology policy from the first to the second panel of data collection. However, when one examines table 2, which summarizes the absolute and new values of changes in the manufacturing technology policy scale items, it is clear that there is movement on this scale. In particular, the advertising of the new technology to customers and the active campaign to recruit new technical personnel are noticeably active over the one-year panel. The former is discussed in greater detail below.

With respect to the latter, several managers' comments indicate possible reasons for shifts on this item. With respect to the decreases in aggresive recruiting, managers said that they had enough new people now, and just training them and assimilating them into the firm and on the advanced manufacturing technology (AMT) project were more important. In some cases, managers noted the scarcity of good manufacturing engineers and the high cost of, especially, newly graduated engineers as a deterrent to further investment in recruiting. Finally, some firms are apparently moving, for various reasons, to greater emphasis on internal development of personnel.

Table 2

Manufacturing technology policy one-year panel comparisons

Scale items (5-point Likert)	Absolute value of changes (n = 34)	Positive changes/ negative changes
A. We have a long tradition and reputation in our industry of attempting to be first to try out new methods and equipment . . .	10	+6/ − 4
B. We are actively engaged in a campaign to recruit the best qualified technical personnel available in engineering or production . . .	17	+9/ − 8
C. We are strongly committed to technological forecasting . . .	14	+7/ − 7
D. We advertise our new processing technology to our customers . . .	23	+10/ − 13
MAD (Mean Absolute Deviation)	16	+32/ − 32

Overall, the general thesis of this study that fine-tuning of manufacturing technology policy against a foundation of very stable business strategy is sustained by these preliminary data. Although no structural variables were included in this analysis, the model predicts that they would exhibit even greater change (fig. 1). However, testing this part of the theory is beyond the scope of this paper.

The correlation matrix which represents the preliminary data analysis for the variables also appears in table 1. Written technology policy was eliminated from this matrix because it was only significantly correlated with one variable, the panel one manufacturing technology policy, $r = 0.30$ ($p < 0.05$).

Propositions 1 and 2 are supported by these results. First, a very competitive, new product environment is significantly correlated with a pioneering business strategy, $r = 0.29$ ($p < 0.05$) for panel one data and $r = 0.22$ ($p = 0.12$) for panel one environment and panel two business strategy. Second, the correlation between business strategy and manufacturing technology policy for panel one was $r = 0.44$ ($p < 0.01$) and for the panel two cross section $r = 0.43$ ($p < 0.01$). The correlation between panel one business strategy and panel two manufacturing technology policy was $r = 0.57$ ($p < 0.01$), which exceeds the correlation between manufacturing technology policy (panel one data) business strategy (panel two) correlation of $r = 0.34$ ($p < 0.05$). However, the difference in the latter two coefficients might be due to the stability of the measures rather than the underlying causal relationship (Rogosa [26]).

Table 3

Curvilinear tests for changes in manufacturing technology policy and three system performance measures

System performance	Absolute value of the change in manufacturing technology policy				
	Simple correlation (Pearson r)	Eta	Second-order regression test		
			$R^2_{(R)}$	$R^2_{(F)}$	F
Cycle time ($n = 17$)	−0.19	0.70	0.037	0.091	0.840
Uptime ($n = 23$)	0.06	0.26	0.003	0.007	0.069
Utilization ($n = 21$)	0.38**	0.70	0.15	0.32	4.72**

** $p < 0.05$.

In order to test proposition 3, the cases available for each performance measure were tested for curvilinear effects against the amount of absolute change in the manufacturing technology policy measure. The latter appear in table 2. The results of these two tests of comparing the simple Pearson correlation with eta and the second-order regression test appear in table 3. Table 2 results show that the greatest change in manufacturing technology policy occurs in advertising to customers, and to a lesser extent in aggressive recruiting campaigns for technical personnel.

Proposition 3 is sustained by the results (table 3), but only clearly for utilization. All three eta's (0.70, 0.26 and 0.70) are substantially larger than the corresponding r's (−0.19, 0.06 and 0.38) for cycle time, uptime, and utilization, respectively. However, only the utilization measure of performance is statistically significant, with an $F = 4.72$ ($p < 0.05$) on the second-order regression test for curvilinearity with the absolute value of changes in manufacturing technology policy. That is, this performance measure is maximized in the most restricted sample ($n = 21$) for fine-tuning versus no change or drastic change in manufacturing technology policy. Over 30% of the variance (R^2) in utilization is accounted for by the absolute change measure and its square in the curvilinearity test using regression. The results are in the predicted direction for the other two measures of cycle time and uptime, but neither test was statistically significant for these restricted samples.

Open-ended question reports during interviews add more interesting information to this trend in manufacturing technology policy data. First, many plants are tactically and strategically automating to the factory walls and attempting to eliminate islands of automation as quickly as possible. Automation of assembly is a clear trend, where the last direct labor in most shops still resides. Second, there is still tension between corporate and plant planning of automation system specifications and justification. In some instances, the need for engineering planning is sufficient to justify plant personnel expertise. In other cases, plant personnel are not seen as justified. Third, and finally, the emergence of the high-tech versus low-tech solution to production problems, e.g. integrated systems with sensors and closed-loop control versus just-in-time manufacturing with cells, is evident in many comments by managers as a key issue in this strategic planning cycle.

Proposition 4 is weakly supported by these results. The result just fails to be statistically significant at the 0.05 level. The correlation between panel two technology advertising scores and system radicalness (panel one data) was $r = -0.25$ ($p < 0.076$). Firms do tend to become more conservative in their advertising during the course of the deployment if they are incorporating more radical technology into the system being installed. Several excellent case histories in the project are illustrative of this trend, but due to the very nature of the variable, they cannot be related because the managements of these plants now want complete secrecy. Other direct reports during interviews indicate that for the aggressive modernization programs, managers want to achieve the stategic benefits of this technology.

Proposition 5, which predicts that successful plants advertise their new system, was weakly supported at this stage of the panel data collection. The correlations between advertising the technology to customers and the three performance measures was $r = -0.21$, $r = 0.40$ ($p < 0.05$) and $r = -0.01$, for cyle time, uptime, and utilization, respectively. Note that performance using cycle time and utilization measures was not significantly correlated with system radicalness ($r = 0.21$, $r = 0.02$, respectively), but performance as measured by uptime was inversely and significantly correlated with radicalness, $r = -0.36$ ($p < 0.05$). Perhaps it is premature to evaluate this hypothesis, even in a preliminary fashion.

8. Discussion

Based on the preliminary results of two panels of data collection on nearly three dozen cases of the deployment of AMT, some tentative conclusions can be summarized. First, environment and business strategy are consistently and significantly correlated. That is, competition tends to appear to drive new or improved product introduction. Second, business strategy is consistently correlated with manufacturing technology. That is, new and improved product introduction is associated with a more aggressive technology policy or the maintenance of an aggressive technology policy which stimulates innovation in the manufacturing core.

Over the deployment period, fine-tuning of manufacturing technology policy is rather typical and significantly correlated with some tentative measures of system performance. However, these measures are unlikely to capture a comprehensive index of performance, especially with respect to the degree of integration and human resources accounting achieved in these plants with these programs.

Nonetheless, extreme changes in technology policy are associated with lower performance. It is the fine-tuning of policy, apparently good to begin with, that seems to succeed. This interpretation tends to support the general wisdom notion that factory-of-the-future programs need extreme planning investments well beyond the normal investments in equipment and software.

The dimensions of manufacturing technology that appear to require the greatest attention for fine-tuning are recruitment of professional personnel in engineering and manufacturing, and advertising the new processing technology, especially to customers. In particular, results indicate that firms will become more secretive about the modernization project during deployment if they truly believe that they have the distinct capability of achieving strategic advantage through manufacturing technology and with a radical shift in processing capability. This does not preclude eventual showcase status for the project after sufficient time, when the marketing benefits can also be added to the return on investment of the project and performance levels have stabilized at acceptable levels.

With respect to the second dimension where fine-tuning occurs, recruiting of technical personnel, there appears to be two reasons for the evolution of manufacturing technology policy. First, after an intensive recruiting period, many firms do find the people they need for projects, and subsequent, intense activity is confined to replacement of team members. Second, many firms cannot find the people they want, especially if the plant to be modernized is located in a remote part of the country. Therefore, these business units often evolve to a position of a combination of developing in-house personnel and hiring new personnel.

Performance and technology radicalness were not found to be significantly related at this stage of the study; nor were there consistent relationships between system performance and advertising technology to customers.

The recent Kellogg example is an illustrative case that substantiates this trend. Tours of the Kellogg facility in Battle Creek, Michigan have run longer than for any other firm, since 1906. Tours are now discontinued because of a $500 million modernization project in high-technology cereal-making. Company spokesmen have indicated that they were fearful of industrial spies present in the tours (Ann Arbor News [1]).

The risk of these new projects cannot be ignored. It is real. Just enough information leaks on disastrous failures and low-level system utilization, serving to remind even the casual observer that this risk is at the heart of the innovation process. For example, Sykes [29] reported recently on Frank Riley's presentation in Bridgeport, Connecticut that "AT&T spend $30 million for a robot assembly plant in Shreveport, Louisiana, but they did not understand the technology" and "they had to go offshore".

Although the evidence is not overwhelming, what data are available suggest that on the average more firms are classifying their high-tech manufacturing projects as proprietary. The expense and risk of sharing information prematurely is evidently forcing a greater number of firms into this posture. This may be a barrier to widespread scientific investigation of this phenomenon during the next strategic planning period in domestic manufacturing.

Although two of the propositions tested here concern policy and performance relationships, the general model allows only for an *indirect* connection between these types of variables or indicators. That is, the policy-outcome connection is generally thought to be mediated by structural-type changes, which are expected to be greater in their magnitude and larger in their direct impact on performance. The development of the remainder of this model and its testing, as mentioned earlier, are beyond the scope of this paper.

9. Future research

Although there are some potentially interesting conclusions in this paper about fine-tuning manufacturing technology policy, this effort represents just one path to pursue that might reduce a useful input into the planning process in organizations. Among other things, substantive themes in manufacturing strategy require that such issues as product focus in plants (Skinner [27]), the relationship between product and process (Hayes and Wheelwright [19]), or the relative emphasis on certain aspects of manufacturing practice and policy such as quality, cost and delivery (Richardson et al. [25]) should be incorporated into a comprehensive model that relates new technology, or the maintenance of technology-strategy relationships. That is, the role of innovation in manufacture is still largely an unresolved puzzle. This situation is a consequence almost exclusively of the appearance of viable and reliable flexible manufacturing and assembly systems that are not being integrated into plant and business unit operations and administration.

Up until this point, the strategic potential of flexible automation has been debated and studied as a way of coping with new products, new markets and new customers. However, there are clearly alternatives to this strategic emphasis in manufacturing, given the technologies that are now available to serve production and design. Flexibility could be used to reduce inventory and other costs by enhancing the effective delivered quality of a productive unit. Flexibility can be used to foster and serve manufacturing R&D through experimentation. Flexibility could be exploited to master the make-buy decision and tradeoffs between reliable source and delivered quality. There are obviously many other strategic alternatives that could be proposed. The point is, we have a great deal to learn about the nature of new design and production technologies from the standpoint of their implications for business unit strategy.

A number of firms we are aware of are actually running and operating their flexible systems as if they were business units within the plant. Little, if anything, is known about the efficacy of this strategy; but this trend and the other opportunities that are presented in the above discussion suggest that there is hardly a functional interface in the modern manufacturing firm that is not changed by these new integrated, flexible production systems.

In the past, it was also assumed that mid-volume, mid-range part variety was the appropriate application region for flexibility in manufacturing. This, however, defines flexibility in far too narrow terms. There are several known examples of installed systems that exploit other dimensions of flexibility, including rapid change-over, flexibility to more easily incorporate design changes, and material flexibility. What is more, flexible assembly is now just coming into its own in domestic manufacturing, and "super cells" of fabrication, production and assembly are now within easy reach of many firms.

Does scheduling methodology affect strategy? Most likely it does. We have yet to explore this relationship fully. When we have new tools available, they open up new strategic options as well. Most would agree that we have not yet fully exploited all the technology we now have installed with equal cleverness in scheduling and planning. This is especially true in plants that have not embraced group technology for flexible automation or cellular manufacturing and assembly.

The economic performance in both short planning periods and return on investment is also an area where technology and strategy intersect. This issue, along with artificial intelligence, has brought literally hundreds of researchers closer to production technology in the past few years, and is a preoccupation for another order of magnitude larger number of practitioners. It is probably fair to speculate that there is a relationship between the firms that will be nominated for leadership distinction in the next decade and their progress toward an effective accounting and justification for computer-integrated technology. This capture of benefits and costs makes the final link between corporate and manufacturing strategy possible, not only on a quarterly basis, but on a weekly scheduling basis as well. It is possible that a revolution in our thinking in this area could also change how we view other organizations such as suppliers, potential joint-venture partners, and buy-out candidates.

There is a scenario well known to many of us directly involved in the planning for modernization whereby top management makes it very clear that they want technology that works, but technology that will not be obsolete in two years. They want flexibility, but they also want to make deliveries and so on. The nature of these tradeoffs is not well understood, especially when it comes to actually applying what we know to the complexities and politics of the decision-making process.

We live in an exciting age. As fewer people produce more in firms, we will all move to a position of a greater stake in and, hopefully, a greater understanding of strategy in a productive unit. It is the vision of these strategies that still separates the best and the also-rans in our industries. And it is the elusiveness of this vision that makes it a fascinating challenge.

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Footnote

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