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WINDOWS OF OPPORTUNITY:
Creating Occasions for Technological Adaptation in Organizations

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Abstract

This paper examines the introduction and ongoing adaptation of technologies that support productive operations. The authors suggest that ongoing improvement of new process technologies by user organizations is limited by increasing routinization that occurs with experience. Evidence from three manufacturing and service organizations indicates that there exists a relatively brief window of opportunity to explore and change new process technology following initial implementation. Afterwards the technology and its context of use tend to congeal, often embedding unresolved problems into organizational practice. Further adaptation is difficult unless discrepant events provide new windows for revisiting previous choices and assumptions. Implications for conceptualizing and managing technological change in production environments are discussed.

"Here is Edward Bear, coming downstairs now, bump, bump, bump, on the back of his head behind Christopher Robin. It is, as far as he knows, the only way of coming downstairs, but sometimes he feels that there really is another way, if only he could stop bumping for a moment and think of it..."

(Milne, 1926)
ADAPTATION OF TECHNOLOGIES IN USE

New technologies are almost never perfect upon initial introduction. As Sahal (1982:7) stated, once introduced, "new technologies are afflicted by a wide variety of teething problems." Deployment of a given technology within a specific context of application reveals numerous opportunities for improvement that were not apparent before introduction, but that are needed to meet users' needs, objectives, or changing circumstances (Rosenberg, 1982; Dutton and Thomas, 1985). The modifications that follow can affect the technology, its physical context, or even users' basic assumptions and patterns of use (Leonard-Barton, 1988).

Unfortunately, however, we know little about the dynamics that underlie the modification of technologies-in-use. The objective of this paper is to provide an empirically grounded and theoretically informed conceptualization of how technologies change once introduced into specific user environments. Our research examined two questions. (i) What is the pattern of technological adaptation in organizations -- do users' modifications describe a continuous and gradual accumulation of minor improvements, or is adaptive effort and attention applied only intermittently, in a discontinuous fashion? Similarly, do organizations continue to adapt new technologies until most problems are addressed, or do adaptive efforts cease before that point? (ii) To the extent that general patterns of technological adaptation are observed, what organizational forces can be found to explain them?

These questions are central to understanding the process of technological change -- and to appreciating how organizations change through their use of new technologies. Users' modification of existing technologies is critical for several reasons. First, users' discovery of and adaptation to problems in operation is an important force for shaping technological evolution and guiding R&D activity (von Hippel, 1982; Dutton and Thomas, 1985). Second, within the user context, modification of existing technologies and procedures for using them is a major determinant of operating efficiency and effectiveness (Enos, 1958; Hollander, 1965; Dutton and Thomas, 1984). Third, modifications made to technologies-in-use often change the organizations and the
individuals deploying them. As Van de Ven (1986:591) has pointed out, once in use, new technologies "not only adapt to existing organizational and industrial arrangements, but they also transform the structure and practices of these environments." Thus, we suggest that only by understanding how technology is altered once it is put into use can we begin to build more complete theories of technological change in organizations.

For the sake of brevity, we will use the term "technological adaptation" to refer to adjustments and changes made by users and aimed at improving the usefulness or usability of the technology in that setting. Subsumed in this definition are three important points. First, changes are adaptive in the sense that they respond to misfits or problems revealed through use. Second, while modifications may address physical aspects of the technology itself (e.g., hardware components or software routines), they may equally well address users' procedures, assumptions, or relationships (such as, maintenance practices, operators' knowledge, or intra-firm communication patterns). Third, adaptations are situated -- they relate to use of technology in a given context and application, they stem from the active involvement of users in that context, and they are frequently embedded in local organizational routines, behaviors, or assumptions. It is this situated quality of technological adaptation that renders the phenomenon difficult to study, yet also critically important for improving both our theories of technological change and the practice of managing technology (Brown and Duguid, 1991).

**EXISTING LITERATURE**

Existing literatures contain conflicting implications about technological adaptation over time. Research on experience or learning effects has associated incremental improvements in the production process with the cumulative volume of production (e.g., Conway and Schultz, 1959; Alchian, 1963). This approach assumes that adaptation occurs in a regular, ongoing fashion. Indeed many theorists suggest that such "progress can be thought of as a continuous process of adaptation" (Dutton and Thomas, 1984:244). Ample empirical work supports the association
between improvement and cumulative output (see Muth, 1986). However, such studies aggregate results from many machines, often of different ages. Further, analyses aggregate many sources of improvement in the production process, including adaptation of existing machines, introduction of new technologies, andexploitation of economies of scale. Therefore, it is impossible to unravel the dynamics of adaptation around a given technology in a specific setting. In addition, with few exceptions (e.g., Argote, Beckman and Epple, 1990; Adler and Clark, 1991), behavioral explanations for observed trends have not been explored.

Studies of innovation trends also make important assumptions about the modification of technologies over time at an aggregate level. For example, Dosi (1982), Abernathy and Utterback, (1975), and Tushman and Anderson (1986) argue that modifications to an existing technical base are made on an ongoing basis. Thus, long periods of continuous but gradual change are observed in most technologies, wherein existing users play a major role by suggesting or creating minor improvements in response to problems encountered over time. By contrast, disruptive or “radical” changes that break from existing assumptions and practices are seen as extraordinary and rare events (Abernathey and Clark, 1985; Tushman and Anderson, 1986). By aggregating changes from many users and many sources, these studies capture overall trends but do not explore the pattern of modifications made by specific users situated in particular organizational settings.

Another important theme in the innovation literature is more prescriptive. This view suggests that, because many problems emerge only after a technology has been in use for a considerable period of time, adaptive problem solving in user organizations should be a gradual effort. Rogers (1983) stated that when organizations try to rush the introduction process, they fail to identify and correct problems that later hamper productive use of the technology. Thus, “too-rapid implementation of the innovation ... can lead to disastrous results” (Rogers, 1983:364). Rosenberg (1982) argued that “learning by using” following initial installation of new equipment is a long-term process because “the underlying problems may not even declare themselves for a few years” (1982:137). Similarly, Hughes (1971:152) suggested that “trying to force the pace” of improvement and adaptation would be counterproductive because “the greatest uncertainties
connected with [new technologies] arise from problems that may not show up until the [technologies] have been in operation for a few years.”

Building on these observations, other scholars argue that adaptive change should be a continuous activity. For example, Leonard-Barton (1988:28) suggested that organizations introducing new technologies need to develop “ongoing dedication to the process of change.” This theme has been enthusiastically embraced by practitioners; recent popular works describe “continuously improving” organizations and exhort managers to undertake continuous change around new technologies as in other arenas (Goldratt and Cox, 1986; Imai, 1986; Senge, 1990).

As attractive as this notion of continuous technological adaptation is, it is not fully convincing. An important problem is that the underlying assumptions have not yet been integrated with theories of human behavior. Indeed, comparison with behavioral theory at the level of organizations, groups, or individuals, presents several unresolved conflicts. For example, a well-established concept in organizational theory is that organizations use experience to create routines that simplify their information-processing needs (March and Simon, 1958). Because such routines determine which environmental cues are considered salient and the manner in which information about events is disseminated, increasing experience may cause the organization to overlook or ignore many problems or misfits between a technology and its setting (Kiesler and Sproull, 1982). Groups in organizations develop similar tendencies toward routine behaviors. Over time, they become increasingly unlikely to recognize and respond to new kinds of problems (Kelley and Thibaut, 1954; Katz, 1982; Hackman, 1990). At the individual level, it has been shown that people’s arousal, attention, and motivation to engage in effortful problem solving is not constant over time. Specifically, active problem solving and information processing appear to drop sharply as soon as tasks become familiar or manageable (Langer and Imber, 1979; Kruglanski and Fruend, 1983). With increasing exposure, observers tend to “chunk” activities into larger units that convey less information than fine-grained observations (although a sudden surprise can sometimes reverse the process) (Newtson, 1973). Familiarity also breeds routinized response patterns; once activities are well entrenched, even superficial resemblance to a known stimulus is sufficient to trigger a
familiar response (Luchins, 1942). Taken together, these behavioral insights suggest that the effort and attention required to discover and respond to new problems in the use of a given technology may be unevenly applied over time.

This paper confronts the conflicting characterizations of technological adaptation that emerge from these different conceptual perspectives, and develops a more integrative theory that takes into account both technological and behavioral aspects of the adaptation process. The study described here examined users’ adaptations to individual process technologies installed in specific organizational settings. The next section of the paper describes the study and our research methodology. The following section presents the results of our exploratory process analysis of technological adaptation in three organizations. The fourth section examines some emergent hypotheses using cross-sectional data from one of these organizations.

Based on our findings, we conclude that experience with a new technology often serves to constrain, rather than amplify, adaptive behavior. The period immediately following initial introduction of new technology emerges as a critical time for users to frame the new technology and to define its role. Ongoing change appears to be a highly discontinuous process, with users’ effort and attention moving only intermittently from normal operations to experimentation and adaptation. We end by suggesting ways in which these patterns can be managed so as to exploit opportunities for ongoing technological adaptation.

**RESEARCH STUDIES AND METHODS**

Research Studies and Sites

In generating an exploratory theory of technological adaptation we were interested in examining the implementation and use of process technologies in production settings. We had previously been involved in a number of field-based studies of technological change in the production process, and we drew on three studies to explore empirically our research questions. Following Leonard-Barton (1990:251), we specifically selected the studies so as to vary the nature
of the technology, the type of users, and the context of technological adaptation for greater generalizability. Each of the three studies chosen encompassed the same phenomenon—changes in the process technology of a single organization—where the technology clearly constituted a primary means by which production work was accomplished for an organization or department. This follows Pettigrew’s (1990:275) suggestion for selecting field sites, that the phenomenon of interest be transparently observable. The sites were matched on four dimensions to ensure comparability across technologies and organizations (Leonard-Barton, 1990:253): (i) The technologies studied had passed the test of technical and organizational feasibility, hence failure of technological adaptation would not be due to either technical failure or user rejection. (ii) The technologies studied altered the work in some obvious although not radical ways, hence failure of technological adaptation would not be due to the fact that users were unaware of any change in their process technology. (iii) The technologies were open-ended in the sense that users (with or without assistance) had the means to make changes, hence failure of technological adaptation would not be attributable to an inability of users to manipulate their technologies. (iv) The focus of the research was consistent across the three studies, that is, all investigated new technologies from the time of initial installation of a new version or generation of process technology through to its full and regular use.

The first study investigated the introduction of new capital equipment in BBA, a leading manufacturer of precision metal components. The study examined projects in eight factories in Europe and the United States. The second study examined the introduction of computer-aided software engineering (CASE) tools into SCC, a U.S. software consulting firm engaged in the custom development of computer-based information systems. These tools, once implemented, become the primary means through which productive work, writing software, is accomplished in SCC. The third study investigated the introduction of user-customizable software in an information

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1 Names of all organizations have been disguised.
systems support department at Tech, a technical research university. The study examined technical changes made by users as they customized their computer work environments.

The research sites, thus, represent a range of technologies, organizational contexts, and users. The technologies studied are used to produce physical products (in BBA), software (in SCC), and services (in Tech). Further, the studies examine organizations with very different priorities and practices. At SCC, where hours spent on software production translate directly into fees billed to clients, the dominant objective is the maximization of production for current revenues. Priorities are more mixed at BBA, where factory personnel are directly responsible for identifying and implementing process improvements as well as producing parts. At Tech, innovation and novelty are central concerns, and many users regard these as more important than current output or productivity. Indeed the technology examined at Tech, user-customizable software, is specifically designed to allow continuous adaptation during use. Most users at Tech are technically trained, and many of those interviewed were involved in the initial development of the technology they were using.

We deliberately sought variety in our selection of settings to enrich the range of insights and to enhance generalizability (Van de Ven and Poole, 1990:316). Examined together, the three studies encompassed a range of process technologies—from metal shaping equipment to graphics software—increasing the likelihood that any patterns of adaptation we find across the technologies are intrinsic to the generic process of technological adaptation rather than consequences of a specific implementation approach or a particular technology. Van de Ven and Rogers (1988:633) note that inclusion of multiple innovations increases the reliability of the research. The three settings studied also span geographic locales (U.S. and Europe), hence controlling for the ethnocentricity of many U.S. based studies of technological change. This diversity reduces the danger of our findings being merely an artifact of American management practices, and increases the reliability of our findings (Downs and Mohr, 1976; Van de Ven and Rogers, 1988; Leonard-Barton, 1988).
Research Methods

All three of the studies from which we drew data for our research were in-depth, field studies. Hence, they included open-ended discussions with respondents, ensuring that the concepts and patterns we generated from this data were grounded in the experiences and terminology of users (Glick, 1990:302). Two of the studies were longitudinal, thus capturing the situated and processual investigation of technological adaptation as it unfolded over time, without researchers or participants knowing the outcomes of the process being studied (Van de Ven and Rogers, 1988:640). The third study was a cross-sectional analysis that triangulated between the initial, formal specifications of the technology, and the expectations and sense-making of people experiencing the technology months or years later. The multiple data collection and analysis techniques employed in the three studies furnished a rare opportunity to explore the introduction and use of process technologies both cross-sectionally and longitudinally. We briefly describe the methods of the three research studies below, before discussing the analytical technique we utilized to explore the phenomenon of technological adaptation across these data sets.

Research Site and Method at BBA

BBA is a European-based manufacturer of precision metal components; it is a world market leader in market share and product quality. BBA is organized geographically, with operations in different countries run as separate divisions with local management. The study was carried out in three major divisions--Italy, West Germany, and the United States--and involved eight different plants (Tyre, 1991; Tyre and Hauptman, forthcoming). Four to eight projects were studied in each plant, for a total of 48 process technology introductions. Process technologies included metal turning and precision machining equipment, assembly and inspection systems, thermal treatment and metal forming equipment, and handling systems. For reasons of data availability and recall, the projects were selected on three criteria: (i) they were undertaken during the last four years and reached completion before or at the time of the study; (ii) they represented an investment of more than $50,000 per project; and (iii) they involved personnel who were available for participation in
the study. These projects were studied using three types of data: description and experiences were obtained from retrospective, semi-structured interviews; evaluations of project features and outcomes were gathered through written questionnaires; and historical and contextual data were collected from company and plant archives. Respondents, comprising project managers, operating and technical personnel, and plant and division managers, were interviewed before and after completing a questionnaire. Interviews lasted from one to four hours and occurred between zero and 18 months of completing the introduction project. These interviews were supplemented by multi-participant discussions and project documentation.

Research Site and Method at SSC

SCC is a multi-national software consulting firm that builds customized software applications for client firms across various industries such as financial services, manufacturing, retail, and government. The software developed by SCC typically consists of large, transaction-processing application systems that clients use to support their major administrative activities. SCC's operations are organized by project, with project teams varying from around ten to over a hundred personnel, and projects extending from a few months to a number of years in duration. SCC recently constructed and deployed process technology--known as Computer-Aided Software Engineering (CASE) technology--in all its projects to automate the software development production process. The research constituted an in depth field study over eight months (Orlikowski, forthcoming). Five application projects (four large and one small) were selected for detailed analysis. The selection process ensured exposure to the introduction and use of the technology in all major phases of the systems development production process (requirements analysis, conceptual design, detailed design, implementation, and testing). Data was collected via on-site observation of participants, unstructured and semi-structured interviews, documentation review, and informal social contact with the participants. Participants spanned SCC's hierarchic levels from the most junior consultants and programmers, to senior project managers. Other key informants were identified and sought out both within and outside SCC, such as the director of
research and development, senior recruiting officers, sales directors, major client managers, and former SCC employees. Over a hundred and twenty interviews were conducted, each lasting an average of an hour and a half.

Research Site and Method at Tech

Tech is a technical research university in the northeast U.S. and it includes a department responsible for providing a variety of technical and administrative computing services to the university. In function, this department's activities resemble those of a corporate information systems department. A number of groups within this department--administration, education, operations, systems development, user services, and video applications--rely heavily on computer software applications, such as electronic mail, graphics, spreadsheets, and word processing, to perform their various duties. The study focused on how various users (managers, secretaries, technical specialists, support staff) in these groups customized new versions of their software tools (Mackay, 1990). The research methodology included a mixture of retrospective and longitudinal methods, employing interviews, questionnaires, and automatic records of customization activity. Three sets of open-ended interviews were conducted with 51 users over a period of four months, beginning shortly after installation of the new technology. Interviews explored users' customization strategies, how they made customization decisions, and the factors that facilitated or hindered customization. Questionnaires were filled out before and after interviews and included questions on the level and type of customization activities undertaken. The computer system was programmed to automatically capture data on participants' customization activity, and this data was used to generate patterns of customization by participant and by group over time, as well as to highlight critical instances of customization activity. These key events were used in conjunction with a critical incident technique (Chapanis, 1969) which allowed probing of participants' specific customization activities during interview sessions.
**Exploratory Research Method**

We re-analyzed the data from these research studies using the interpretive lens of our research questions on technological adaptation. Data analysis proceed in four phases, the first three constituting within-study analyses, and the fourth consisting of a cross-study analysis. First, we re-analyzed the data we had collected across the three sites, searching for patterns around the introduction, adaptation, and use of the process technology. Second, we examined the identified patterns for evidence of whether technological problems had been resolved or not. We were particularly interested in instances where adaptation activity ceased before problems with the use of the new technology were resolved. Third, we searched for the underlying reasons that would account for the termination of adaptation activity and the persistence of technological problems. As Eisenhardt (1989:542) suggests, this step of deriving the underlying reasons for relationships is critical to establishing the internal validity of the findings. On the basis of this exploration, we identified the pattern of technological adaptation that best described each site. We were also able to articulate and categorize a number of organizational forces that appeared to influence these patterns. Finally, we compared the patterns and organizational forces we observed across the three sites and identified similarities and differences. The cross-study patterns and forces that emerged are strengthened by the fact that evidence from one study was corroborated by evidence from the others (Eisenhardt, 1989:541), and that these findings were generated from data collected by multiple investigators using multiple data collection methods (Eisenhardt, 1989:546).

**RESULTS**

**Overview of Central Findings**

A striking finding across the three research sites was that adaptation efforts appeared to fall off abruptly after a short initial introduction period. Put another way, the initial period appeared to represent a finite window of opportunity during which users found it relatively easy to make
changes to new technologies-in-use. Conceptually, the pattern of adaptation we observed can be represented by a time plot, as shown in Figure 1.

![Figure 1](image)

Significantly, this pattern did not appear to be the result of an intended decision process that decreased resources for adaptation efforts once problems associated with the new technology were solved or reduced to the point of diminishing returns. Instead, even when serious problems persisted, we found that adaptive problem solving subsided after a relatively short initial spurt. In some cases, events prompted later, but also short-lived phases of adaptation (represented by Phase II in Figure 1). In essence, experimentation and adaptation in each phase were aimed at making the system operable, but not optimal, in a given production setting. There was an assumption that optimization could be a second step. As one developer from SCC explained:

[The technical staff] do not want to release stuff until it is perfect. But we would rather they give us something to walk with, and then they can enhance it later to give us a racing car. But right now we need basic transportation.

However, once the system was operable, perceived incentives for further improvements and optimizations decreased dramatically. At that point attention shifted to other, more pressing considerations -- mainly getting everyday work done. This transition had a self-reinforcing character; the more the user made use of the system to support production work, the more familiar and settled he or she became with existing patterns or routines. Therefore, time and experience did not appear to support further learning or ongoing adaptation, but rather to impede these processes.

This pattern was echoed in each of operating environments studied. Experimentation was more likely to occur and significant changes more apt to be implemented prior to or immediately following introduction than at any later time, despite ongoing problems or additional insights that might be gained over time. For example, analysis at Tech charted the level and nature of changes made over time by users of customizable software. It revealed that the level of customization activity fell off abruptly shortly after initial implementation of new software (or after the release of a new version of that software). In particular, data showed that exploration or experimentation as a
means of learning about the technology virtually ceased after the first few weeks following initial implementation.

Similarly, at SCC, a large amount of adjustment and modification took place immediately following initial installation of CASE tools into a new site to fit the software to the particular client organization. These adjustments were accomplished by technical support members, who had designed and constructed the CASE tools. Following initial adaptation of the tools, applications personnel responsible for the actual production of new applications software were brought onto the project. Once these applications personnel began using the CASE tools as process technology, they insisted that the technology be stable and reliable. In order to facilitate their task, applications personnel halted further changes to the tools. Only under extreme conditions (such as a breakdown in the software) were refinements tolerated and scheduled.

Even when project participants recognized the need for ongoing process modifications and incorporated that into their schedules, opportunities for change narrowed over time. This occurred at BBA despite increasing insight and experience among users and developers. For instance, in the case of a very innovative metal shaping machine, users and developers both acknowledged the need for adaptation based on accumulated shop-floor experience. The new equipment was installed in the factory under a development contract stating that machine concepts as well as tooling would be adapted further to fit emergent local requirements. But users did not move fast enough to identify needed changes. The further away in time the technology was from the lab, the more difficult it became to revisit basic decisions made during the development process. By the time a plan for reconfiguration was developed, changes proved impossible to implement. Developers had already replicated the machine based on their original design, and the factory had begun to integrate the machine into the larger production process.

In those cases where "windows of opportunity" were reopened after initial implementation, they were generally triggered by some discrepant or surprising events. These are shown in Figure 1 as later phases or waves of adaptive activity.
In the following section, evidence from all three environments studied is presented to articulate and illustrate key organizational forces that shape the pattern of adaptation. Data are segmented into four sections, each of which corresponds to one of the four major organizational forces that emerged from our exploratory analysis. These forces include: (i) the tension between production requirements and adaptive activities, (ii) the constraining effect of habits and procedures once they are developed, (iii) the modification of expectations based on experience, and (iv) the erosion of enthusiasm and team membership over time.

Organizational Forces Influencing Technological Adaptation

i. Production Requirements Versus Adaptation Opportunities

Data from all three studies suggest that one of the most powerful forces behind the failure of continuous ongoing modification is the misfit between the requirements for production and those for adaptation. Because of this misfit, productivity demands quickly chase out opportunities for identifying and solving new problems once technology is put into use. At SCC, for example, both applications personnel and technical support members were acutely aware that making changes to the tools or experimenting with different technology options meant time away from producing application systems. Since software was produced on-site to tight client specifications and timeframes, SCC could not afford to let schedules slip. According to an SCC manager, once software production begins, "We push ourselves too hard. And the problem is that as a result we don’t have time to learn how to do something new, or develop new tools."

Such problems are perhaps predictable at SCC, given its intensive focus on short-term productivity performance. More surprising is that similar patterns emerged at Tech. Despite users' stated preference for ongoing innovation and refinement, these same users were unlikely to adapt operational systems once they were set up unless forced to do so by external events. According to one typical user, "I hate to stop [working] long enough to get set up [with new features]." Another commented that making changes is something one does when one has "leisure time."
In part, these comments reflect the conflict between the certainty required by the production process, and the uncertainties involved in making changes to the system. Users engaged in production were understandably risk-averse, as there was always a significant risk that a seemingly straightforward adaptation would balloon into a major project. Further, users recognized the potential to make a mistake that would cause greater problems than the one they were trying to fix. In addition, these comments reflect users’ conviction that near-term production requirements left them no time to pursue further changes. Implicit in this conviction is the belief that simply extending the timeframe for implementation would solve their problems. However, our data suggest that this is not the case. As we discuss below, we found that when users took a longer time to complete the introduction of the new technology, further barriers to adaptation often arose.

**ii. Patterns of Use Congeal and Become Constraining Over Time**

In all three operating settings, users adapted themselves fairly quickly to the introduction of the process technology. They established norms and routines for using the technology shortly after their initial experiences with it. These patterns of use supported productivity goals but constrained further exploration and adaptation. This proved to be a major barrier to ongoing change, apparently stunting the “learning” process that many managers expected to occur.

In SCC, CASE technology was introduced to leverage the technical skills of its personnel. Indeed as users gained experience with CASE tools their productivity increased, but so did their dependence on the technology in its current form. Users therefore resisted ideas for improvements or adjustments to their tools because these threatened to destabilize developed capabilities. When such changes were occasionally introduced, users often tried to ignore them by bypassing the new versions to work with the original system.

The constraining effects of increased experience were also pronounced at BBA. For instance, in the case of one novel grinding machine, productivity benefits were predicated on the integration of the new equipment into an existing automated processing line. However, initial integration problems forced project engineers to install a temporary manual “workaround.”
Although the manual workaround was inefficient, operators quickly learned to depend on it for particularly demanding jobs. Later, when the grinder was finally fully repaired, users clung to the system they had become accustomed to, and prevented engineers from dismantling the "temporary" workaround system. Because of this, the new grinder's capabilities for efficient, high-precision machining were never fully developed and exploited.

The same tendencies surfaced among software users at Tech. Once functions became habitual or automatic to users, they were extremely resistant to change. This was illustrated by the fact that when new software versions were installed, users very often simply retrofitted the new versions to mimic functions of the familiar, original version.

iii. Expectations Adjust to Fit Experience

In many of the projects studied, expectations regarding the performance capabilities of a new technology changed over time. Specifically, expectations were amended to fit actual achievement. Therefore, as time went on, "problems" often disappeared from view not because the technology was improved, but because standards were lowered or interpretations amended.

For example, one project at BBA involved the introduction of an advanced precision grinding machine. The original objective of the project, according to both development engineers and original project documentation, was to develop the capability to machine all five "faces" of a particularly complex metal part. Indeed the plant manager had explained that "grinding all five faces was the key objective in this project," more important than the productivity improvements expected from the machine. Developers had demonstrated full-radius grinding in the lab, but they had not been able to test whether the machine would hold required tolerances under actual plant conditions. Therefore the project team agreed to continue development in the factory. A key engineer was assigned to work on five-face grinding.

But as time wore on development was blocked by the very success of the project on other criteria. Within several months the new machine was operating at speeds up to six times those of the equipment it had replaced, even without the addition of five-face grinding. Production
personnel found they had sufficient slack to run complex parts through additional grinding machines to complete all five faces.

Users soon reconstructed the original project objectives to fit this new reality. Several of those interviewed denied that full-radius grinding had ever seriously been considered as a key project objective. As one engineer commented, “We only tried doing all five faces on this machine as an experiment. It was sort of an add-on that did not work.” The supervisor in charge of the machine was even more adamant. When he was interviewed some 18 months after installation, he stated that the machine “is now doing exactly what we purchased it for -- we are getting the (excellent) productivity improvements.”

**iv. Enthusiasm Degrades and Teams Dissolve Over Time**

Another barrier to ongoing adaptation was that when projects bogged down, the teams involved tended to dissolve and lose direction. For instance, one project at BBA involved the introduction of a novel thermal-forming approach for producing complex metal parts. The lead project engineer explained that,

Our approach was to create a team consisting of a manufacturing engineer, a service technician, and a skilled operator to put the machine into production. But the slow rate of production start-up was a problem. Each time the machine went down, we had to disband the team and send the people to other activities while we waited for new parts or tools. We got the people back in when we received the new tools, then sent them out when the new tools broke. That really hampered our learning. And, you do not always get the team members back. We strove to keep the group together, but sometimes individual people became involved in other, more urgent projects that were not dragging on as much.

According to another BBA engineer, “Engineers are always excited at the beginning of a project. But, after a while, they lose enthusiasm for doing all of the detailed changes that spell the difference between success and failure in an innovation project.” Similarly at SCC, once projects reached a stage where the CASE technology had been installed and applications personnel began using the technology to do their production work, many of the technical support personnel requested assignment to other projects with “more interesting” work. These tendencies blocked implementation of detailed process technology changes requested by managers during projects.
Renewed Opportunities for Technological Adaptation

The data presented above suggest that ongoing adaptive change becomes increasingly difficult as process technologies become more thoroughly embedded and routinized in the user environment. Regular use of the technologies we studied was not consistent with the kind of mental and physical effort required to develop and implement new ideas. Yet, paradoxically, routine use was also necessary for ongoing adaptation; it provided the raw data that, if utilized, led to new insights about improved use of technologies. Several examples serve to illustrate the possibility of "reopening" the window of opportunity to change the process technology and its context of use.

At Tech we found that only when some unusual event disrupted normal operating patterns did users make changes to software. Examples of disruptive events that opened new windows for change included urgent and unusual requirements that could not be met with the existing system. In one case, an experienced user was given a special assignment that required him to process greatly increased amounts of data in a very short time. To cope with the crisis, he created a new set of rules that automatically sorted, labeled, and routed his electronic messages. Once the special assignment was completed, he discovered that these new rules significantly improved his effectiveness even under normal circumstances.

A more subtle way in which opportunities for change occurred in Tech was when normal workflow and thought patterns were interrupted by outsiders' questions. For instance, when a visitor asked whether their electronic mail system succeeded in routing their messages reliably, some non-technical users expressed surprise and concern. They had never thought the technology might not work correctly and they then began to worry about this new possibility. As a result of this interruption, they began to undertake new experiments with their technology.

These examples suggest one reason why such periodic opportunities to regroup and reconsider routine operations must be separated, at least in part, from daily operations. Daily operations entail application of established routines. But in order to review and evaluate
accumulated experience, users need to reframe their roles and their relationship with the technology. At Tech, one of the participants described her adaptation patterns regarding a recurrent problem in her text editing software. She first noted the difficulty of actively identifying the problem: she was reluctant to stop work in the middle of a job to document the problem when it occurred, yet at other times the problem was invisible. However, once she forced herself to focus on the issue, she realized that fixing this one problem would provide the insights needed to attack other recurring software problems she encountered in her work and to better understand the problems other system users were facing. This user's comments demonstrate that the costs of change only appeared worth bearing once they were evaluated in a broadened context. Thus, it was only through an expanded framing of the issue that she attempted to adapt an existing, and basically serviceable, process technology.

By contrast, the organizations we studied typically failed to create opportunities to reframe, analyze, and synthesize their experiences. At SCC, for example, one senior consultant commented that once projects were finished “we are never asked to reflect on the problems we’ve had... No one asks how are these tools used after their time so we can fine-tune the process or correct and eliminate the problems.”

Where opportunities to explore and reframe existing technology did arise, these were almost always by chance. For instance, in one of the examples described above, a new machine installed at BBA was plagued with problems for more than two years because users were unable to reconfigure the technology on the shop floor. As the factory-level project leader explained:

We wasted a huge amount of time ... We would make some small adjustment but then, due to difficulties at a more basic level, something else would happen or a tool would break... The whole process accomplished very little until we were able to rethink some of the early choices and assumptions.

Significantly, the opportunity to “rethink” early choices came about only once a new group of divisional managers took over and made the troubled project an initial focal issue of their tenure.
TRIANGULATION

The above findings are surprising in relation to much of existing theory. Established views in innovation theory suggest that extended timeframes are needed to deal with the problems that emerge as users gain experience with new process equipment. This view is reflected in Rogers' (1983) admonition that too-rapid implementation can seriously harm results. Yet our evidence suggests that results are likely to suffer when introduction efforts are extended over too long a period of time. Problems that are not addressed during a relatively brief initial period may later be ignored or even become embedded in habitual organizational practices.

We were able to validate this interpretation by using cross-sectional data that had been collected for another purpose at BBA, but were relevant to the questions examined here. Naturally these data, which came from the same set of observations used to derive our theory, cannot be used to test that theory. Rather, analysis of quantitative data is used here as a way of examining the robustness of the qualitative results, reported above (Jick, 1979).

Variable Definition and Measurement

Data on project characteristics and outcomes were collected through a written questionnaire supplemented in each case by semi-structured interviews (see above). Quantitative measures (described below) were developed for each of the following: time to introduce, project outcomes and project attributes.2

Time to Introduce: This measures the elapsed time in months between installation of the technology in the factory and the point when participants considered the project complete. Completion was defined as the point when the new technology was up and running as a regular part of the production system; it was not necessarily the point when all problems were solved.

Project Outcomes: Two project outcomes were measured. Technical success was an aggregate scale of three interview and questionnaire items (scale alpha =.86). Items measured

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2 Further details on variable definition and measurement are provided in Tyre and Hauptman (forthcoming).
were (1) achievement of technical project goals, (2) reliability of the new equipment, and (3) the usefulness of the technical solutions implemented. In collecting data on technical success, we emphasized that we were interested only in users' assessments of the final results achieved, not whether the introduction process had proceeded in a smooth, efficient, or predictable manner. **User learning** is an aggregate scale of five questionnaire items (scale alpha = .83). Items measured were (1) amount of attention to operator training, (2) amount of attention to training of engineers/technicians, (3) amount of new know-how required to use the new equipment, (4) “This project was a big learning experience for me” (agree -- disagree), (5) “This was an exciting experience because I was exposed to many new ideas” (agree -- disagree). All items were 1-to-5 scales.3

**Project Attributes:** In order to control for the size of the project and the newness of the technology (which would be expected to affect both time to introduce and project outcomes) three project attributes were measured. **Technical novelty** measures the newness of technical features and designs, while **operating novelty** measures the newness of the operating approach (in terms of the conversion technology or the degree of process integration involved) for the plant or company. Both variables are aggregate scales of five questionnaire items (scale alpha = .90 and .86, respectively). **Project size** is based on the total investment represented by the project (in constant U.S. dollars).

**Organizational Response Mechanisms:** Variables relating to the organization’s problem solving efforts around the new technology were also measured. For present purposes, two of these are relevant. **Early user involvement** measures the intensity of users’ preparatory search efforts aimed at finding and solving problems prior to installation. Early involvement was measured by four interview and questionnaire items detailing the involvement of factory personnel in proposing and developing the technical features of the new equipment or system (scale alpha = .67). **Ongoing developer involvement** measures the intensity of joint search across organizations

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3 Measures of user learning were collected for only 31 of the 48 cases (i.e., for projects undertaken in Germany and Italy, but not in the U.S.). Given our qualitative data, we had no reason to expect bias from this division.
subsequent to installation. Data on developer involvement came from four interview and questionnaire items describing the role of personnel from outside of the factory and the importance of their contributions during the start-up process (scale alpha = .79).

**Triangulation Results**

Summary statistics and correlations are shown in Table 1. On a zero-order basis, time to introduce was inversely associated with technical success ($r = -.53, p < .01$) and directly associated with user learning ($r = .33, p < .10$). This suggests that, as expected, shorter (not longer) time to introduce the technology is associated with greater technical success.\(^\text{4}\) It also indicates that shorter times might also be associated with somewhat less successful projects in terms of user learning achieved. The latter finding was not expected, based on the results reported above. However, correlations were somewhat suspect because it was also noted that time to introduce, technical success, and user learning are all associated with other variables--notably, both project attributes and response mechanisms. Therefore, it is also possible that correlations are due to common causes, rather than to the direct effects of time to introduce on project outcomes.

![insert Table 1 here](image)

A path analytic approach was chosen to investigate this issue (Prescott, Kohli and Venkatraman, 1986). Analysis began with two sets of ordinary least squares regressions (Table 2). The first set regressed time against project attributes and response mechanisms, with the latter assumed to be exogenous variables.\(^\text{5}\) In the second set of equations, each outcome variable

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\(^4\) It might be argued that causality runs in the other direction: when projects are successful (for whatever reason), participants tend to declare the project complete sooner than when the project is not successful. This reasoning was not compelling to us. Technical success was deliberately defined in terms that are conceptually distinct from the time required to attain that success (current reliability and usefulness, achievement of goals; not ease of introduction or how soon reliable operation was attained). Further, while time to introduce was derived from records kept during the introduction period, success was assessed well after completion of the project per se.

\(^5\) Initially, all exogenous variables were included in each analysis. Later, in order to conserve degrees of freedom, variables were deleted from analysis when they had no significant effect on a given outcome measure in any version of the model. Deletions had no significant impact on coefficients of the retained variables.
(technical success and user learning) was regressed against exogenous variables and time. Regressions all explained a significant amount of variance ($R^2 > .27$; $F > 4.70$). Standardized beta values were then used to represent path coefficients (Figure 2).

The usefulness of the path analyses was confirmed by the fact that direct plus indirect effects of exogenous explained most ($>.90$) of the relevant correlations for most variables (Table 3). Further, results provide additional insight into the effects of variation in time to introduce. By comparing path coefficients relating time to each outcome variable with the zero-order correlation results, it is possible to separate the direct effects of time from the spurious effects due to common causes (Pedhazur, 1973). In fact, we find that the spurious effect of time on technical success is essentially nil (direct effect of -.55, compared to a correlation of -.53). Thus, time appears to have a direct, negative effect on success (i.e., shorter introduction times are associated with greater success) that is independent of its correlation with other explanatory variables. Time is also an important mediating variable between exogenous variables and technical success; as shown in Table 3, indirect effects of exogenous variables (technical novelty, operating novelty, early user involvement, and ongoing developer involvement) via their influence on time are all stronger than the direct effects of these variables.

The second path analysis further suggests that, while introduction time was negatively and significantly correlated with user learning, a significant portion (26%) of the association was due to common causes (direct effect $= .24$ ns, compared to $r = .33$, $p < .10$). Further, Table 3 shows that
the direct effects of operating novelty, project size, and early user involvement are considerably stronger than the indirect effects of these variables via time.

In sum, quantitative data from BBA support the findings that emerged from our qualitative analysis of the same setting. Such triangulation, or convergence of multiple methods on the same result, strongly decreases the possibility that our findings are the result of mere methodological artifact (Jick, 1979).

**DISCUSSION**

The results of our investigation suggest that process technologies tend to congeal with ongoing use fairly rapidly after introduction. We found that adaptation ceased or became considerably more difficult the longer the technology had been in operation. This leads us to posit that users’ first experience with new technologies provides a limited and valuable occasion for observing, exploring, and changing the technology and the way it is used in the organization.

We found several pressures that may help to explain why process technologies tend to congeal relatively soon after implementation. First, while many problems do not surface until the technology is put into full and regular use, by that point it is often too late to deal fully with these issues due to the need to maintain the steady pace of production. Indeed, it is striking that this “production imperative” appeared not only in those environments dominated by immediate productivity concerns, like the consulting firm, but also within innovation-prone groups in a university setting.

Second, users over time gain proficiency with a given set of procedures for applying a new technology. However these procedures, once developed, constrain further experimentation or adaptation. We found that established routines created “competency traps” (Zucker, 1977; Levitt and March, 1988) that blocked adaptation and creation of potentially superior approaches.

Third, while experience confers greater knowledge and insight, it also obscures the sharp focus on objects and events that comes with novelty. In particular, as time goes by, expectations
adjust to fit reality. We found that issues that were once viewed as problems became accepted as normal practice by users who still encountered difficulties, but had learned to live with them.

Finally, as the time spent on the introduction lengthens, project teams tend to lose momentum and coherence. We found that apparently underutilized team members were pulled off to other tasks, and the initial enthusiasm of remaining participants waned.

We also examined whether new opportunities for adaptation arose after the initial period of implementation. We found that once use of the new technology had become routinized, opportunities for change were sometimes created—but not often. In a few cases, discrepant events arose that disrupted normal routines and enabled users to evaluate their accumulated experience. Based on their findings, these users revised basic choices about the technology and their relationship with it. However in many cases, users who were faced with new problems or unusual events did not manage to change their assumptions and interactions with technology. Changes to technology were often regarded by users as unnecessary annoyances. In many of these cases, users simply retrofitted a new version of the technology to resemble familiar, existing processes.

In a few instances, however, new revisions did create the chance to reevaluate the utility of learned routines in light of new possibilities. Our data suggest that the explanation for these different responses may lie in the way that discrepant events were framed for users in each situation. Exploiting new opportunities to explore existing technologies appeared to require not just a break in local production routines, but also an appreciation of the larger benefits that could accrue to ongoing experimentation. This was demonstrated by one participant’s experience when confronted by a bug in an existing piece of software. The decision to step out of normal operating routines required reframing everyday problems in a broader context.

Yet in none of the three organizations we studied was there evidence that managers paid conscious attention to framing unusual events or problems as opportunities for change. Instead, such opportunities appeared to arise due to chance occurrences or crises that forced users to rethink their assumptions about technology or its context of use. Occasions to revisit these assumptions after implementation, therefore, were rare.
Implications for Theory

These findings suggest new ways of thinking about the organizational forces underlying technological adaptation in the user context. In particular, we found that experimentation is both enhanced and constrained by users' experience, with the result that adaptation is not a smooth, ongoing process, but a discontinuous one. Users' initial attempts to use the new technology provide an important window for change. It is a window in the sense that, for a time, users have a clear view of the new technology as a discrete artifact. Initial experiences yield new insights about the technology and its relationship to the context of use. Later, users' views are obscured by integration of the technology into a complex production system, and by the habitual behaviors that sustain it. The initial introduction period also represents a window because, during this limited time, users (often assisted by technical experts) can reach into the technology to change it. Once the new technology is assimilated into the larger production process, change threatens to disrupt the habits and procedures that support productive work. The production process and the specific technology used to support it congeal, and the window for change is closed. Only if discrepant events provide the opportunity to step out of normal routines will there be occasions to modify the technology and its relationship with the user context.

This suggestion is significant because existing theory proposes that adaptations to technology in use occur, or should occur, more or less continuously. For instance, empirically-derived learning curves in manufacturing are generally interpreted as "a continuous improvement in [the firm's] input-output ratio as a consequence of a growing stock of knowledge" (Dutton and Thomas, 1984). While some studies have noted that apparently regular performance improvements may be the cumulative result of discrete events (such as the introduction of improved product designs or equipment), they simultaneously assume that adaptive effort and attention are applied continuously. Our research suggests that a closer look might reveal that adaptive efforts occur only occasionally (for instance, in response to unexpected events), and that such occasions normally give way to periods of relatively static operation.
This perspective is consistent with the widely-accepted notion that significant change in organizations occurs discontinuously (e.g., March and Simon, 1958; Hedberg, 1981; Gersick, 1991). Many examples exist in organizational life where intermittent, discrepant events are created or used as opportunities to reframe experience and revise current practice. These include quarterly reporting periods (Kiesler and Sproull, 1982), executive retreats where participants are encouraged to rethink existing programs, the entry of new senior managers (Tushman, Newman and Romanelli, 1986) or new employees (Louis and Sutton, 1991) that provokes different modes of thinking about problems within the organization, and, in group activities, natural breakpoints that enable revision of established group behaviors (Gersick, 1988; Hackman, 1990).

Our work finds parallels in these ideas but also diverges from them in important ways. In most of the works cited above, convergent or incremental adaptation is described as a continuous process and is differentiated from significant revisions that occur episodically (Gersick, 1991). Our findings imply a new perspective on what constitutes a revision or "significant" change. In particular, they suggest that the significance of a technological change must be assessed with reference to the procedures and assumptions of specific users, not simply related to current practice at the organizational level. For example, from the point of view of Tech, a leading technical research institution, users' adaptation of computer-interface software was a trivial, incremental matter. For those users, however, changes in the interface altered the way that productive work was executed; it literally reconfigured their relationship to the technology. A perspective that views these changes as significant within a specific time and place, therefore, offers new insights about the problems of technological change in organizations.

Indeed our findings suggest that the traditional, deep cleavages in innovation theory among radical innovation, incremental change, and operation may be a considerable detriment to understanding the way that technologies actually evolve in organizational settings. A specific modification may be experienced as a routine adjustment or as a highly disruptive change, depending on whose perspective is taken. Simple labels that obscure this multifaceted nature of technological adaptations may be seriously misleading.
Our findings also help to extend ideas on the management of attention as a factor underlying technological or organizational change. Some theorists have suggested that radical technological change or other environmental “jolts” can serve as opportunities for generating new insights and behaviors, but that taking advantage of such opportunities requires careful management of perceptual and motivational processes (Meyer, 1982; Dutton and Jackson, 1987; Eisenhardt, 1989). Van de Ven (1986) has further suggested that the management of any innovation is characterized by “the human problem of managing attention, because people and their organizations are largely designed to focus on, harvest, and protect existing practices rather than pay attention to developing new ideas.” Our work shows that the problem of managing attention is at least as salient for introducing and using a given technology on an ongoing basis. Indeed the importance of managing attention becomes even greater when the need for new ideas is not signalled by a loud alarm, such as a major jolt, but rather emerges from continued use of an existing technology.

Therefore we argue that the management of non-cataclysmic organizational events, such as the introduction and use of productive tools in the work environment, calls for careful management of attention and perception. Indeed, we propose that effectively utilizing technology involves both taking advantage of the initial window of opportunity provided by introduction of the technology, as well as creating occasional “jolts” or surprises after use of the technology has become routine. The need to “trigger the action thresholds of individuals to appreciate and pay attention to new ideas, needs, and opportunities” (Van de Ven, 1986:596), we argue, must be seen as a central challenge for the management of technological adaptation, equally or more so than for the management the initial innovation process.

**Implications for Action**

These findings, while tentative, have potentially major implications for the management of technological change in the production process. Traditional prescriptions suggest that managers must not rush the implementation of new process technologies because problems and their
solutions take a long time to unfold. By contrast our work indicates that managers should develop strategies to encourage rapid testing, ramp-up, and modification following initial installation. Further, once the technology is institutionalized, a provocative suggestion is that managers find ways periodically to "reopen the window" for ongoing change. This might be done by taking users out of their regular operating environment to provide a new perspective for reviewing experience and developing ideas (Tyre, 1991b). Alternatively, managers might create discrepant or unusual challenges to periodically renew users' relationship with the technology (Newtson, 1973; Chanowitz and Langer, 1983).

Yet it is important to note that discrepant events do not guarantee that new windows for change will be opened. For example, users at Tech often ignored new versions of software. When such exogenous changes were evaluated within the perspective of existing, production-oriented routines, they appeared to be useless distractions, likely to cause more harm than good. However, this is not the only perspective that users might employ. Research at the individual (Langer, 1983; Langer and Piper, 1988) and organizational (Dutton and Jackson, 1987) levels shows that how an event is framed or introduced helps to determine whether it is interpreted within existing routines or used to create new ways of understanding. Likewise, managers may be more likely to turn discrepant events into windows for change when they frame unexpected events as noteworthy and potentially informative.

Our work also challenges popular notions that the disjuncture between development and use of technologies can be mended merely by involving users in the development process, or by moving developers into the user context along with their innovations. Our work suggests that simply throwing people over the wall between development and production -- or even dismantling the structural boundaries between these activities -- will not ensure a smooth technology transition. This was illustrated by patterns of adaptation at Tech, where many technically-oriented individuals who had helped to develop new systems still showed rapid decreases in innovative activity once they began to use these systems to support productive work. Differences in context and requirements also create boundaries between development activities and production operations.
Therefore, one implication of this study is that cross-functional teams do not provide a panacea; managers must also create discrete windows for adaptation and change, and encourage teams to exploit them.

Suggestions for Further Research

Examples from our research suggest that we should regard windows for change as opportunities only, not as guarantees of reflection and adaptation by users. But what factors enable organizations to exploit such opportunities? Some factors that might prove important include the human resource strategies that shape users' actions (Orlikowski, 1989; Osterman, 1991), the composition and formation of problem solving teams (Ancona and Caldwell, 1989; Bettenhausen and Murninghan, 1985) and the involvement of external experts (Tyre, 1991a,b). Managerial interventions may also play a role in helping people step out of routine behavior. If so, the timing of such interventions is likely to be important. Windows for change are more likely to be opened at natural breakpoints in organizational activity (Hackman, 1990), such as at formal completion of a project (Orlikowski, 1988), or when taking on new roles or work assignments (Kiesler and Sproull, 1982; Mackay 1990). Language and imagery may also be important factors in framing organizational events as occasions for reviewing and revising routines (Eveland, 1986; Dutton and Jackson, 1987; Langer and Piper, 1988). Much research is needed to test these ideas and to better understand the managerial behaviors that would encourage users to capture the discoveries they make during the introduction and use of a new technology.

A Final Note

Our findings on the pattern of technological adaptation are remarkably consistent across three different companies with divergent industry, technology, and managerial characteristics. This suggests that, while variations in organizational systems and contexts may affect the rate at which new technologies congeal, the forces identified here are likely to be present in many productive organizations. Further, these patterns may apply to a wide range of process innovations, not only
technological ones. New operating procedures may congeal with existing routines before they are fully explored, and new environmental challenges may cease to arouse special attention long before appropriate adjustments have been made.

A simple anecdote serves to illustrate this point. During the drafting of this paper, both authors coincidentally moved households. In the process of gathering and packing their possessions, both authors found that the window for change in everyday life is remarkably narrow. At the start of previous moves, both authors had made solemn resolutions to be better organized at home. Yet when they began packing this time, each discovered that any box that had not been unpacked within approximately two weeks following the previous move had remained untouched. It had simply become part of the landscape, or been lost in the rubble of a back closet, or had become a constant but low-level irritation that was never severe enough to act upon. Consequently, this time both authors have resolved to attack the problem of unpacking and organizing immediately following installation in their respective new residences. Even when the technology is as simple as boxes of books in a room, we have found that patterns of behavior congeal all too rapidly.

ACKNOWLEDGEMENTS

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REFERENCES


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——— (1991b) "Managing Technological Change in Manufacturing," Technology Review (October).

——— and Hauptman, Oscar (forthcoming) "Effectiveness of Organizational Response Mechanisms to Technological Change in the Production Process," To appear in Organization Science.


Figure 1: Pattern of Technological Adaptation over Time

Level of Adaptive Activity related to New Technology

Phase I
Phase II

Time since Introduction of New Technology
Figure 2: Determinants of Project Success--Path Analyses

- Technical Novelty
- Operating Novelty
- Early User Involvement
- Ongoing Developer Involvement
- Project Size

Time to Introduce

Technical Success

User Learning
Table 1: Summary Statistics and Correlations

\[ N = 48 \ (Variables \ used \ in \ Path \ Analysis \ I) \]

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard Deviation</th>
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<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
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<td>.51</td>
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<td>-</td>
<td>- .25</td>
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<td>12.0</td>
<td>6-54</td>
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<td>-</td>
<td>-</td>
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<td>(4)</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>(6)</td>
<td>Ongoing Developer Involvement</td>
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<td>4.8</td>
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<td>-</td>
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\[ N = 31 \ (Variables \ used \ in \ Path \ Analysis \ II) \]

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Table 2: Determinants of Time to Introduce, Technical Success, and User Learning

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<th>Path Analysis I: Dependent Variables</th>
<th>Path Analysis II: Dependent Variables</th>
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<td>Time to Introduce</td>
<td>Technical Success</td>
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<td>Ongoing Dev. Involvement</td>
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<tr>
<td>Time to Introduce</td>
<td>--</td>
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</table>

R² | .54 | .35 | .27 | .47 |
DF | 43 | 42 | 27 | 26 |
F  | 14.9 | 6.1 | 4.7 | 7.7 |
P  | < .001 | < .001 | <.01 | < .001 |

Coefficients are standardized.

*** p < .01; ** p < .05; * p < .10
Table 3: Decomposition of Path Analytic Results

**Path Analysis I**

<table>
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<tr>
<th>Bivariate Relationship</th>
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<th>Direct Effect</th>
<th>Indirect Effect</th>
<th>Total</th>
<th>Spurious</th>
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<td>.02</td>
<td>-.38</td>
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<td>.20</td>
<td>.33</td>
<td>.53</td>
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<td>Ongoing Dev. Involv. Tech. Success</td>
<td>.08</td>
<td>.01</td>
<td>.18</td>
<td>.19</td>
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**Path Analysis II**

<table>
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<th>Bivariate Relationship</th>
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<th>Indirect Effect</th>
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<tr>
<td>Operating Novelty - User Learning</td>
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<td>-.08</td>
</tr>
<tr>
<td>Early User Involv. - User Learning</td>
<td>.45</td>
<td>.31</td>
<td>-.13</td>
<td>.18</td>
<td>.27</td>
</tr>
</tbody>
</table>

**Notes:**
Total = Direct Effect + Indirect Effect
Spurious = Correlation - Total