# A Dynamic Theory of Expertise and Occupational Boundaries in New Technology Implementation: Building on Barley's Study of CT Scanning

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# A Dynamic Theory of Expertise and Occupational Boundaries in New Technology Implementation: Building on Barley's Study of CT Scanning

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**In this paper, we develop a theory to explain why the implementation of new technologies often disrupts occupational roles in ways that delay the expected benefits. To explore these disruptions, we construct a dynamic model grounded in ethnographic data from Barley's widely cited (1986) study of computed tomography (CT) as implemented in two hospitals. Using modeling, we formalize the recursive relationship between the activity of CT scanning and the types and accumulations of knowledge used by doctors and technologists. We find that a balance of expertise across occupational boundaries in operating the technology creates a pattern in which the benefits of the new technology are likely to be realized most rapidly. By operationalizing the dynamics between knowledge and social action, we specify more clearly the recursive relationship between structuring and structure.●**

The purpose of new technology, though often unstated, is to improve the effectiveness of the work done in organizations. Attempting to capitalize on such gains, however, often disrupts boundaries between professional and functional groups (Zuboff, 1988; Barley, 1996) and demands that they interact in new and different ways (Sproull and Keisler, 1986). For example, computer-aided design and manufacturing (CAD/CAM) systems, developed to shorten development cycle times (Liker, Fleischer, and Arnsdorf, 1992; Wheelwright and Clark, 1992) and improve product quality (Adler, 1990a, 1990b), require new modes of communication and information sharing between design and manufacturing engineers. Similarly, successful use of less-invasive surgery techniques requires that surgeons rely more on information provided by nurses and technicians than they did with previous techniques (Pisano, Bohmer, and Edmondson, 2001).

Unfortunately, many organizations struggle to create the necessary new patterns of interaction between groups and consequently often fail to reap the benefits of the new technologies they introduce (Robey and Boudreau, 1999). For example, efforts to implement CAD/CAM have been slowed by power differences between the design and manufacturing communities, the complexity of representing manufacturing problems, and the historical differences in computer skills between these two functional groups (Adler and Helleloid, 1987; Robertson and Allen, 1992). Similarly, efforts to use less-invasive surgery techniques founder when doctors are unable to change the ways in which they interact with nurses in the operating room (Galloway et al., 1999; Edmondson, Bohmer, and Pisano, 2001). Even though it is now recognized that the implementation of new technologies has mixed outcomes that arise from a variety of technical, cultural, and political problems in working across boundaries (Barley, 1986; Sproull and Keisler, 1986; Orlikowski, 1992), the existing literature offers few insights concerning how to manage the disrupted relations more effectively across occupational or functional boundaries when implementing new technologies.

The mainstream literature in organization studies offers two basic perspectives from which to view the impact of new technologies on organizations. Those taking an objectivist stance start with the physical properties of technology and use them to guide the search for ways those properties influence behavior. Over time, however, to maintain such an "imperative" view of technology (Khandwalla, 1974) in the face of increasingly contradictory findings, researchers from an objectivist tradition have augmented their theories with additional variables on which technological outcomes are contingent, including organizational size, task complexity, and amount of centralization (e.g., Woodward, 1965; Blau, Heydebrand, and Stauffer, 1966; Hickson, Pugh, and Pheysey, 1969). Alternatively, those favoring a more subjective view (Manning, 1977; Feldman and March, 1981; Prasad, 1993) have focused on a different causal path, attending to how the properties of new technologies evolve as they are used and modified by people in the course of day-to-day activity. There is little reason to expect, this view suggests, that the introduction of new technology will produce regular changes in patterns of behavior (Sproull and Kiesler, 1986).

More recent studies of new technology implementation suggest that neither approach is adequate, for the simple reason that both capture important aspects of the phenomenon in question (Barley, 1986; Poole and DeSanctis, 1990; Orlikowski, 1992). Building on the structuration framework of Giddens (1984), this line of research suggests that causality runs in both directions: technology influences the patterns of human activity, and the technology changes as it is modified in the course of day-to-day activity (Barley, 1986; Orlikowski, 1992). Consequently, this view holds that the technology in use can be understood only as the transient outcome of an ongoing and recursive interaction among actors, the technologies they use and modify, and the social context in which such interactions take place. Applying the structuration perspective to understand how technology influences patterns of behavior has made scholars more aware of dynamics that were often obscured by more static theoretical perspectives. In particular, empirical studies of new technology taking this recursive perspective have revealed previously unnoticed dynamics in organizations that call into question mono-causal theories that preceded a structuration approach (e.g., Barley, 1986; Orlikowski, 1992). But although a recursive conceptualization of technology and social action has been instrumental in critiquing existing theories, it has not been as useful in moving forward to develop new ones.

One of the first studies informed by a recursive conceptualization of technology and organizational action was Barley's (1986) careful documentation and analysis of the introduction of CT (computed tomography) scanning in two Massachusetts hospitals, which clearly revealed the mutual evolution of technology and social action. Since its publication, Barley's study has been widely cited as a convincing rejection of both the technological imperative and more subjective accounts. Barley did more, however, than present data; his analysis of those data yielded several novel propositions concerning the variety of patterns he observed. Most notably, he concluded his analysis by suggesting that the autonomy of technologists, or what he called "decentralization" of decision making, varied significantly within and across the sites where the new technology was deployed. He ventured that the distribution of expertise across the occupational groups interacting with a given technology might have substantial explanatory power "to explain how distributions of expertise can be accommodated differently in daily interaction" (Barley, 1986: 107). Despite the prominence of Barley's inquiry in the organizational literature, however, few scholars have built on his substantive insights to develop a more general account of the relationship between new technology and behavior in organizations.

The dilemma is not unique to Barley's analysis. Following his study, the literature on the connections between technology and social action has grown to include several population-specific (Barley, 1986; Sproull and Kiesler, 1986; DeSanctis and Poole, 1994; Orlikowski, 1992), or "substantive analyses" (Glaser and Strauss, 1967), of technology implementation. Although, as Glaser and Strauss argued, the progressive consolidation of substantive analyses into more formalized, general categories is a key step in developing theory that spans multiple inquiries, few scholars of technology implementation have made such an attempt to provide a more general account of the influences between new technology and social action. Until such theories are produced, it will be difficult to test empirically our understanding of the impact of new technology to improve theory or provide useful advice to practitioners.

The scarcity of attempts is likely due to the difficulty of operationalizing the recursive conceptualization at the heart of a structuration approach. Whether it be placing similar observations under a single category or hypothesizing that one category influences another over time, developing theory that spans multiple episodes requires that categories and hypotheses emerging from each substantive analysis be, to some degree, abstracted and formalized. But Giddens' (1984) description of the duality of structure, that it is both a medium and an outcome, provides theorists with little guidance in making such abstractions or formalizations. Likewise, merely identifying that there is a mutual influence between technology and social action falls short of specifying the relationship between technological and social factors over time. Until we are able to identify and represent specific instances of new technology, social action, and the ways in which they recursively interact, it will be difficult to apply insights emerging from studies of specific episodes of technology implementation beyond the contexts in which they were derived.

To break this impasse, in this paper, we develop a new approach to analyzing interconnections among new technology and social action. Our approach integrates three ongoing themes in social and organization theory. First, we acknowledge the importance of focusing on the activity (Suchman, 1987; Lave, 1988; Weick, 1979) or the work (Barley and Kunda, 2001) in which the technology is used and the relations between actors are played out. Second, we focus on the accumulations of knowledge, both the type and amount (Bourdieu, 1980; Carlile, 2002), possessed by the actors involved and the power this affords them. Third, we examine the recursive dynamics (Giddens, 1984) between the activity and the relative accumulation of knowledge developed by the actors involved. To combine these three themes into an approach for understanding the dynamics that arise from introducing new technology, we draw on system dynamics (Forrester, 1961; Sterman, 2000) to create a context-specific representation of actors' accumulations of expertise, their relations, and outcomes generated over time. We apply this analytic approach to Barley's (1986) ethnographic study of CT-scanning technology to develop a more systematic account of what determined the different social patterns he observed over time. Our work focuses on the activity of CT scanning, the types of and relative amounts of expertise that are of consequence to doctors and technologists, and the recursive relations between doctors and technologists and how their accumulated expertise affects their using the technology over time. Our analysis thus picks up where Barley's left off, formalizing just how "relative expertise" matters in explaining the variety of patterns he observed.

## DATA AND ANALYTIC APPROACH

In his article, Barley (1986) detailed the efforts of two Massachusetts hospitals to implement computed tomography (CT, today called CAT) scanning. He observed day-to-day operations and shadowed doctors and technologists both before CT scanning was introduced and for nearly nine months after it became operational. Barley's distillation of doctor-technologist interactions into "scripts" revealed the roles (Goffman, 1959)—and the changes in those roles—that doctors and technologists adopted with one another as they used the new CT machine over time. He thus documented how the new technology, implemented similarly at two hospitals that he called Suburban and Urban, led to significantly different patterns of social interaction. We first summarize Barley's study and findings and then describe how a focus on activities, accumulations, and recursion can reveal the consequences of "relative expertise" when using the new technology.

### Barley's Ethnography

**Suburban.** Suburban launched its CT area by hiring one CT-experienced radiologist and two technologists experienced with CT scanning. Two technologists unfamiliar with CT were also transferred from other areas of the radiology unit. Barley divided his observations of Suburban into two phases, based on the distinctive characters of the interactions between doctors and technologists before and after a change in staffing. Phase 1, Negotiation of Discretion, was characterized by role-clarifying interactions and scripts labeled Unsought Validation, in which technologists provided justification for actions that the doctor confirmed as appropriate; Anticipatory Questioning, in which technologists asked operationally oriented questions; and Preference Stating, in which the doctor stated his preference for scanning procedures, often volunteering a rationale. In this phase, the interactions became increasingly collaborative as technologists grew more facile with the CT equipment and the doctor grew more adept at asking for what he wanted. Barley (1986: 91) wrote:

As the technologists demonstrated responsibility and competence, the radiologist began to grant them greater discretion. By the end of the third week a tentative climate of joint problem solving arose to create an atmosphere that more closely resembled the ideal of complementary professions working in concert.

Phase 2, Usurping Autonomy, began in the fourth week, when five radiologists inexperienced with CT began rotating through the scanning area. As technologists tried to interact with the inexperienced doctors, the scripts evolved into Clandestine Teaching (of doctors by technologists), Role Reversals, in which radiologists asked technologists about pathology and technologists offered interpretations of scans, and Blaming the Technologist (for problems that really lay with the equipment). Of this phase, Barley (1986: 93–94) wrote:

> As role reversals, clandestine teaching, and incidents of blaming the technologist gradually defined a new interaction order, the radiologists' moral authority tarnished and the technologists . . . formulated the view that the radiologists knew less than they rightfully should. . . . Unaccustomed to having their knowledge perceived as inadequate, anxious that they might make a serious mistake, and baffled by the computer technology, they [radiologists] began to express hostility toward the technologists.

As both technologists and doctors sought to reduce occasions for anxiety and hostility, technologists began making routine decisions independently while doctors withdrew to their office to avoid interaction with technologists and the technology. Suburban started on a trajectory of joint problem solving across occupational lines, but the introduction of the inexperienced doctors sharply altered that course. After the staffing change, specialization continued to increase—technologists ran the machines, and doctors produced diagnoses—and as doctors retreated to their office, technologists gained autonomy in making decisions about how scans should be produced. Barley (1986: 103) characterized this as "decentralization" of decision making, because doctors, who hold more authority in the hospital setting, ceded scanning decisions to technologists.

**Urban.** In contrast to Suburban, Urban launched its CT unit by relying on an experienced doctor recruited from outside the hospital and on one of its own radiologists who kept current with the body-scanning literature and by transferring eight technologists skilled in other types of imaging, such as X-ray, into the new scanning unit. At Urban, Barley identified four phases based on formal and informal changes in staffing policies and the changing character of interactions between doctors and technologists. Urban's phase 1, Negotiating Dependence, was characterized by the following scripts: Direction Giving (by doctors to technologists, usually without providing a rationale), Countermands, when doctors contradicted their own previous statements, Usurping the Controls (of the CT machine by doctors), and Direction Seeking, in which technologists cued doctors to tell them about the next task. These scripts, Barley suggested (1986: 97),

> . . . affirmed the radiologist's dominance and created a work environment that the technologists perceived as arbitrary. . . . The technologists therefore continued to seek directions from radiologists not

> only because they did not know what to do, but because they were convinced that radiologists could potentially say what they wished. . . . Perversely, however, by continually seeking directions the technologists fostered a perception among the radiologists that the technologists were not attempting to learn, a perception that encouraged the radiologists to exert even greater control.

Barley called phases 2 and 3 Constructing and Ensuring Ineptitude. Phase 2 began four weeks after the CT machine came on-line when doctors, in an effort to foster technologists' independence, decided to stay out of the scanning area. Since technologists had discerned no method or reason in the doctors' directions, rather than proceed by trial and error, they often interrupted radiologists in their office to seek direction. "Since the radiologists were now more than ever conscious of the technologists' dependency in routine matters," Barley wrote, "they became increasingly irritated and began to respond to the technologists' questions in a derisive manner" (1986: 97–98). Scripts called Unexpected Criticisms and Accusatory Questions characterized this phase. Phase 3 began when, at the end of the sixth week, radiologists returned to day-to-day CT operations, effectively reaffirming interactions that characterized the first phase, Direction Giving, Countermands, Usurping the Controls, and Direction Seeking.

Phase 4, titled Toward Independence, began when the four technologists regarded by doctors as least competent were transferred out of the CT group and radiologists inexperienced with CT technology began rotating through the area as the CT-experienced doctors resumed duties in other radiology areas. In contrast to Suburban, the same staffing change of introducing CT-inexperienced doctors led to a different pattern of interaction. The redistribution of expertise between the two roles resulted in more discretion for technologists, but the inexperienced radiologists at Urban were far more likely to ask for assistance (Barley, 1986: 99). Technical Consultation, in which doctors asked technologists for direction, and Mutual Execution, in which doctors and technologists both asked for and received direction from one another, typified the interactions of this phase. Barley (1986: 103) characterized this hospital's decision making around the technology as more "centralized" than Suburban because doctors retained more traditional authority throughout the 37 weeks of his observations.

Barley concluded his analysis with graphs showing the percentage of operational decisions made by doctors at each hospital through time, pictorially demonstrating different patterns of decision making at the two hospitals. At Suburban, after the introduction of CT technology, doctors initially made the majority of operational decisions, but after the staffing change, technologists assumed significant responsibility for operational decisions. At Urban, doctors made a high percentage of the operational decisions and conducted many scans themselves. Only after the introduction of doctors inexperienced with CT did technologists begin to make an appreciable portion of operational decisions, yet even then doctors remained present to guide the scanning processes.

## Integrating Activities, Accumulated Expertise, and Recursion

New technologies both disrupt existing knowledge and blur customary occupational boundaries and so provide an "occasion for structuring" between doctors and technologists. Barley offered detailed descriptions of the interactions between doctors and technologists using the new CT technology as evidence that mutually adaptive relations shape social structures evolving around new technology. These assertions, however, leave some questions unanswered. What kind of knowledge matters—expertise in running the machine, expertise in interpreting the scans, or both? Further, how can expertise explain the different interactions between doctors and technologists that emerged at the two hospitals, despite similarities in settings, technology, and staffing changes? And what can relative differences in knowledge tell us about the disruptions or benefits that this technology had on each organization?

Proposing answers to these questions requires specifying how differences in daily interaction in using the new scanning technology are accommodated to generate the outcomes Barley observed. Our approach integrates three elemental themes of organization and social theory: activities, accumulations of capital, and recursive relationships between these. Because these categories are empirically tractable over time, they provide insight into what actions are possible for doctors and technologists in the activities related to using the new CT technology.

**Activities.** Weick (1979), Orlikowski (2000), and others (Bourdieu, 1977; Giddens, 1984; Lave, 1988) have called attention to the ways in which daily activities and practices shape organizational and social patterns. The emphasis on activities is an important reminder of the agency of individuals and the dynamic nature of social environments. Focusing on how CT scans were performed calls attention to two features of the interactions Barley observed. First, the nature of the scanning activity could differ depending on whether doctors were in the room. When doctors were not present during Suburban's phase 2, technologists made numerous decisions related to operating the machine and presented the results of those decisions to doctors after the scanning activity had concluded. This pattern of activity both reinforced technologists' claim to occupational knowledge and doctors' fear of status-challenging role reversal, thereby enacting limited communication about the new technology between the two roles. In contrast, when doctors were present during Suburban's phase 1, interactions between the doctors and technologists about conducting scans were far more frequent.

Second, when doctors were present, the scanning activity differed significantly across sites. In phase 1 at Suburban, even though doctors were present, technologists bore responsibility for operating the machine and made a significant portion of operational decisions. When performed this way, the scanning activity led to a desirable pattern of "complementary professions working in concert" (Barley, 1986: 91), as doctors stated preferences and technologists worked to act on them in an iterative cycle of requests, learning, and execution. In Urban's first three phases, however, the doctors made the majority of operating decisions, either by issuing commands or simply by operating the machine themselves, creating an environment that reinforced doctors' skill with and control over the CT machine, while limiting technologists' ability to cultivate useful skills (Weick, 1990).

**Accumulations.** While focusing on activities highlights how differences in the conduct of scanning resulted in significantly different patterns of interaction between doctors and technologists, it does not explain why the scans were conducted differently. To address this, we turn to the stream of research that identifies how relative accumulations of knowledge or expertise determine who has power and influence in relations between actors (Bourdieu and Passeron, 1970; Pfeffer and Salancik, 1974; Carlile, 2004). The type and amount of knowledge or expertise actors possess often determines who gets to do what in a given activity. Credentials and titles serve as proxies for institutionally legitimated accumulations of knowledge and power (i.e., capital), often leading people to defer to those who have them. Further, previous accumulations often afford some actors a "relative position" that is more powerful than others' in a given activity (Bourdieu, 1980).

Although Barley noted the importance of expertise in how relations in radiological work played out during the introduction of CT scanning, his analysis did not articulate what kind of expertise is important or why. From scripts such as Direction Seeking, Direction Giving, Usurping the Controls, Preference Stating, and Anticipatory Questioning, which all center on conducting the scans, we infer that operational expertise, the ability to manipulate the new technology, plays a pivotal role in doctor-technologist interactions. The importance of operational expertise is perhaps most clearly evidenced by patterns of interaction at CT's initial deployment. Although the two hospitals were similar on many dimensions, the relative accumulations of knowledge in operating the machine differed at the launch of their CT units. Initially, Suburban, which began with joint problem solving, staffed its scanning unit by hiring two technologists and one radiologist, all of whom had experience with body scanning, and two inexperienced technologists. In contrast, Urban, which began with scripts such as Direction Seeking and Usurping the Controls, started with two CT-experienced doctors and eight technologists who had never used a body scanner.

Operational expertise alone, however, cannot shed light on scripts such as Clandestine Teaching and Role Reversals, which center on interpreting the scans for pathology. Therefore, attending to diagnostic knowledge, or the ability to interpret output produced by new technology, is also critical to understanding the doctor-technologist patterns of interaction. Moreover, doctors, because of their previous training and credentials, which signify accumulated diagnostic knowledge and ability to recognize pathology, were clearly in the more powerful position. Given that the technology was new and CT technician certification programs did not exist at the time of Barley's study, technologists had no formal means of accumulating diagnostic knowledge. Because of their legitimated and higher hierarchical position, doctors could choose whether they were present for scanning and who conducted the scan.

Distinguishing between operating and diagnostic expertise is essential to explain all the patterns Barley observed. Further, the distinction helps us recognize why new technologies blur the boundaries between occupational groups: in the case of new computerized scanning technology, expertise for operating the machine and expertise for interpreting the images for diagnosis were no longer clearly defined and separable, as they were with X-ray. Although focusing on relative distributions of expertise helps explain why the two hospitals started on different paths, it does not explain why they continued to diverge. For example, in phases 2 and 3 at Urban, realizing that the lack of technologists' skill was hurting performance, doctors decided to stay in their office to "break the technologists' dependency" on them (Barley, 1986: 97). Yet, as Barley (1986: 98) described, the doctors' intervention of spending less time in the scanning area did not increase technologists' autonomy in operating the machine, as it did at Suburban. The dynamics at Urban reinforced the patterns of interaction in which technologists asked for direction from doctors, and doctors made most of the scanning decisions, despite the explicit attempt to cultivate independence in technologists' decision making. Furthermore, the focus on activities and accumulated knowledge does not explain why the same staffing change at both hospitals, rotating in doctors inexperienced with CT technology, produced such different outcomes.

**Recursive relations.** To explain the different outcomes in Barley's study, we connect activities and accumulations of knowledge with the notion of recursion arising in the work of Giddens (1984) and Bourdieu (1980) and used by others (Barley, 1986; Poole and DeSanctis, 1990; Orlikowski, 1992). Actors and the accumulations of knowledge they possess recursively interact through activities. The relative accumulations of expertise held by these actors constrain what outcomes are possible, which in turn influences who accumulates expertise and what outcomes arise in future interactions. In this case, CT-related activities create additional accumulations of CT knowledge, and accumulations of knowledge determine who gets to do what in the scanning and diagnostic activities. Depending on the relative accumulations of expertise, these interactions either "modify or maintain" (Barley, 1986: 81) the current relations as individuals draw on their knowledge to meet the demands of producing scans and diagnoses.

Distinguishing between operating and diagnostic expertise, attending to activities at the doctor-technologist boundary enabled by expertise, and acknowledging the recursive dynamics between accumulated expertise and in-the-moment activities suggest three patterns of interaction neither noted nor adequately explained by the centralization-decentralization continuum asserted by Barley (1986: 103): *collaboration* (in Suburban's initial phase and Urban's final phase), in which both doctors and technologists accumulated

CT-specific expertise; *occupational separation* (in Suburban's final phase), in which doctors limited their learning by leaving the CT area and technologists conducted scans without insight into how the images created informed diagnosis; and *professional dominance* (in Urban's phases 1, 2, and 3), in which doctors accumulated CT expertise and technologists did not. We summarize the scripts Barley described at Suburban and Urban in table 1, along with our characterization of these patterns of interaction.

Table 1

**Summary of Barley's Observations at Two Hospitals and Patterns of Interaction for Each Phase**

| | Suburban | |
|---|---|---|
| | Phase 1: Negotiation of Discretion | Phase 2: Usurping Autonomy |
| Staffing change | | CT-inexperienced radiologists added on day 21 |
| Experienced with CT | 1 of 1 radiologist<br>2 of 4 technologists | 1 of 6 radiologists |
| Scripts | Unsought validation<br>Anticipatory questioning<br>Preference stating | Clandestine teaching<br>Role reversals<br>Blaming the technologist |
| Pattern of Interaction | Collaboration | Occupational separation |

| | Urban | | |
|---|---|---|---|
| | Phase 1: Negotiating Dependence | Phases 2 and 3: Constructing and Ensuring Ineptitude | Phase 4: Toward Independence |
| Staffing change | | Radiologists stay in office to encourage technologists to make decisions on their own | CT-inexperienced radiologists added and least competent technologists transferred out on day 105 |
| Experienced with CT | 2 of 2 radiologists<br>0 of 8 technologists | 2 of 2 radiologists<br>0 of 8 technologists | 2 of 6 radiologists<br>4 of 4 technologists |
| Scripts | Direction giving<br>Countermands<br>Usurping the controls<br>Direction seeking | Unexpected criticisms<br>Accusatory questions | Technical consultation<br>Mutual execution |
| Pattern of interaction | Professional dominance | Professional dominance | Collaboration |

## Using Dynamic Modeling to Generate Grounded Theory from Ethnographic Data

If the doctor-technologist interactions revealed through this analytic approach are to provide explanatory leverage, we must be clear about the conditions under which each type of interaction can emerge. Distinguishing between operating knowledge and diagnostic knowledge and their relative amounts poses a plausible explanation of why the doctor-technologist interactions Barley observed unfolded as they did at each hospital, but we take these ideas further by testing the relevance and explanatory power of these concepts and their internal coherence. Operationalizing these concepts in a dynamic model representing the context of the field study allows us to hypothesize about how operating and diagnostic expertise enables and constrains activities in the CT-scanning area. Although we cannot re-create the field conditions of Barley's ethnographic study, we can represent the interactions described in his research in an abstracted way that allows exploratory leeway while preserving key context-specific aspects of the empirical setting, such as doctors' authority over technologists and prerogative in engaging in scanning activities.

We represent these relations between doctors and technologists in a system dynamics model (Forrester, 1961; Sterman, 2000). Unlike many formal models in the social science literature, this one is not deduced from axioms that idealize human motivation and behavior but, rather, is induced from Barley's data and analysis. We used a grounded-theory approach in conjunction with the method customary to system dynamics modeling as we worked with the data. Although grounded theory methods are commonly used to build theory from raw data using qualitative analysis, they are not limited to this activity. Strauss and Corbin (1990) have advocated the development of formal (or general) theories grounded in previously generated domain-specific, or "substantive," analyses. They remind us that Glaser and Strauss (1967) not only urged the use of grounded theory in conjunction with qualitative and quantitative analyses but also recommended its use to generate theory from substantive analyses (see Glaser and Strauss, 1967: 98). We iteratively proceeded with model building by constructing model elements and relationships to represent our inferences from the data about the causal relationships generating the patterns observed (e.g., experience levels of doctors and technologists), simulating the structure, comparing the simulated behavior qualitatively and in degree with patterns observed by Barley, and then returning to the data and to the literature to refine the hypotheses represented in the model by changing its elements and the connections among them (Black, 2002).

A dynamic modeling tool such as system dynamics helps tease out dense, repeated interactions among actors using the new technology, through systematic simulation of numerous possibilities that together yield insight into which elements of a complex interaction dominate others in producing an outcome and why. By mapping out hypothesized causal relations between each central variable in the situation under study and by representing the relationships mathematically, a model formalizing the relations proposed above serves as a disinterested party, playing out over simulated time the hypotheses represented. When, based on the hypothesized relations, the model produces behaviors similar to those documented in the field, then the constructs expressed in the model may have validity in explaining why the patterns observed empirically emerged as they did. While it is impossible to "prove" the validity of any textual or mathematical model, by inductively constructing the model from data reported in the 1986 paper, we hope to show that this more abstract formalization is both consistent with Barley's observations and helpful in addressing persistent theoretical challenges (Lant, 1994). Our objective is to describe how activities and accumulations of expertise recursively interact, and under what conditions, to generate the patterns of collaboration, professional dominance, or occupational separation, in a way that is operationally relevant and true to the cases of

Suburban and Urban and yet formalized to reveal a more general structure than the detailed qualitative analysis rendered in the original study.

## A MODEL OF RECURSION BETWEEN ACTIVITIES AND EXPERTISE IN CT TECHNOLOGY IMPLEMENTATIONS

We combine our analytic approach and the method of system dynamics to create a series of formal representations and analyses. The first set of representations and analyses focuses on the recursive interactions between accumulations of operational expertise and the scanning activity and how these can explain the pattern of collaboration observed in Suburban's phase 1 and Urban's phase 4, as well as the pattern of professional dominance observed at Urban in phases 1, 2, and 3 (see table 1). The second set of representations and analyses builds on the first by adding accumulations of diagnostic knowledge to explain the complex pattern of occupational separation at Suburban in phase 2 after that hospital's initial pattern of collaboration.

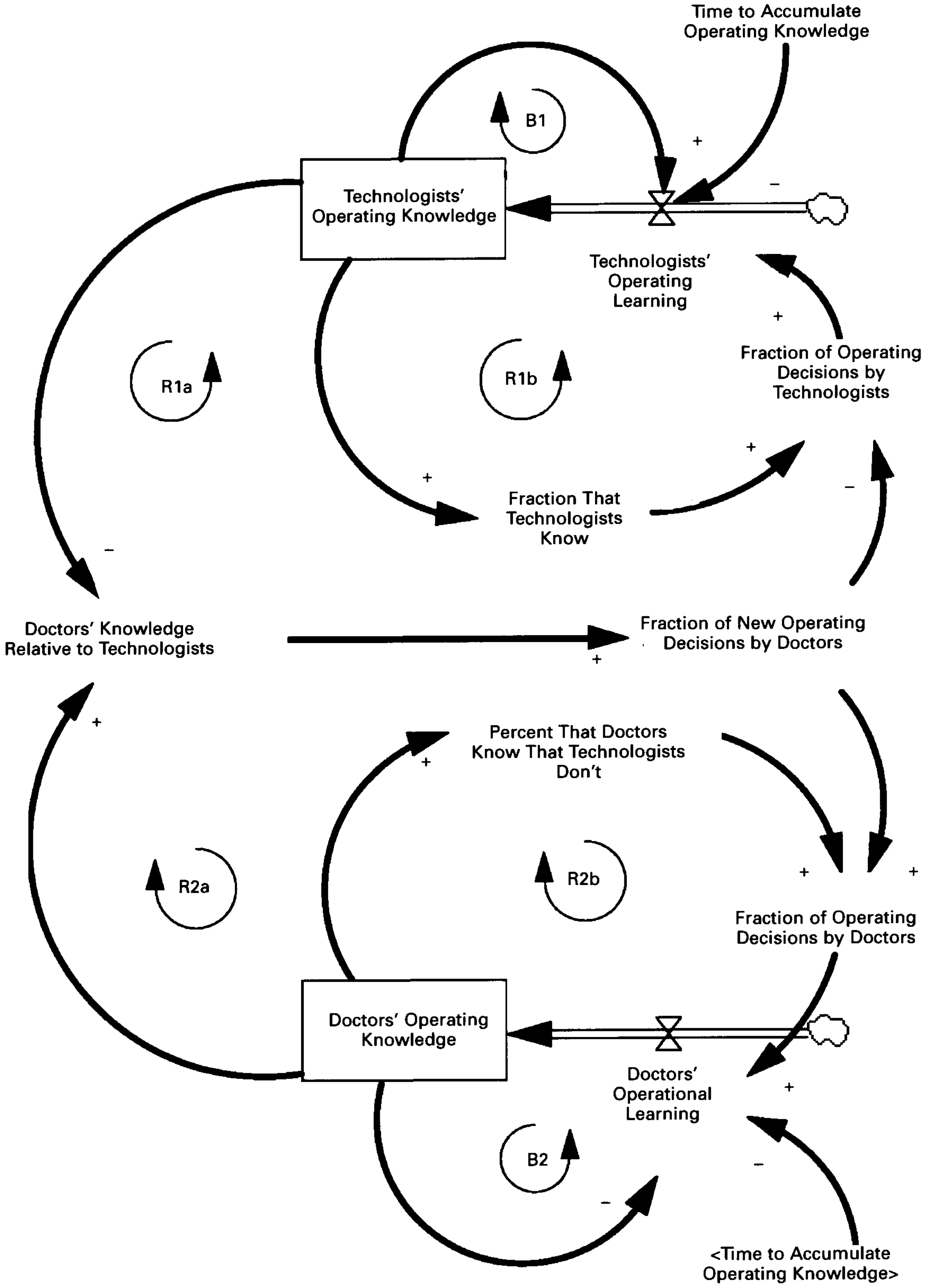
In the figures that follow, accumulations are represented by stocks (boxes), while flows (double-lined arrows with valves) represent rates that alter accumulations over time. A thin arrow between model elements depicts one variable's influence on another, and associated with each variable icon is an equation mathematically specifying the nature and degree of that influence. We describe the specifics of representing in a formal model our inferences from this analytic approach to Barley's (1986) data, and then we discuss how the model representation simulates patterns of interaction between doctors and technologists. In the first set of representations and analyses, we elaborate model specifics to the equation level, to demonstrate how we mathematically formalize our inferences. Complete model documentation of the model is available as a technical appendix at http://www.montana.edu/cob/Faculty_and_Staff/bio/black.htm or http://web.mit.edu/nelsonr/www.

### Effects of Operational Knowledge on Collaboration and Professional Dominance

We first focus on collaboration, seen in Suburban's first phase and Urban's final phase, and professional dominance, as seen in Urban's first three phases. Figure 1 portrays the variables and interrelationships capable of generating both these patterns.

**Representing operational knowledge.** Figure 1 portrays accumulated knowledge of how to operate the new CT machine as critical to scanning activities, and doctors' operating knowledge is distinct from technologists' operating knowledge. Both doctors and technologists can learn more by doing more; they can accumulate more operating knowledge by making and executing decisions about conducting scans. For this coarse formalization, we represented knowledge stocks as the fraction of CT-scanning procedures for which an actor has skill. We defined the knowledge stocks over the interval from 0 to 1, because knowable procedures for practical use of the new technology are not infinite, especially in light of the nine-month duration of the ethnographer's

**Figure 1. Overview of initial model formulation.**



Signs (+ or −) at arrowheads indicate the polarity of casual relationships. A plus denotes that an increase in the independent variable causes the dependent variable to increase, ceteris paribus, and a decrease causes a decrease; that is, $X \xrightarrow{+} Y \Leftrightarrow \partial Y/\partial X > 0$. Similarly, a minus indicates that an increase in the independent variable causes the dependent variable to decrease; that is, $X \xrightarrow{-} Y \Leftrightarrow \partial Y/\partial X < 0$. Boxes represent stocks; arrows with valves represent flows. A stock is the accumulation of the difference between its inflows and outflows (see Sterman, 2000).

observations. We represented learning as an increase (inflow) to the knowledge accumulation, which integrates all learning that has occurred, and we chose not to represent forgetting or obsolescence of operating knowledge because of the fairly short time frame of Barley's study. Mathematically:

$$\begin{gathered}\text{Technologists' Operating Knowledge}(t) = \\ \int_t [\text{Technologists' Operational Learning}(s)]ds + \\ \text{Initial Technologists' Operating Knowledge}\end{gathered} \tag{1}$$

$$\begin{gathered}\text{Doctors' Operating Knowledge}(t) = \\ \int_t [\text{Doctors' Operational Learning}(s)]ds + \\ \text{Initial Technologists' Operating Knowledge}\end{gathered} \tag{2}$$

Stocks are critical to the dynamics of systems because they represent the accumulated and enduring impacts of activities. In this case, even if the inflows of technologist operational learning and doctor operational learning are zero on a particular day or week, because no new learning is taking place, the knowledge accumulated remains unchanged as the capability of the technologists or doctors, respectively. The stocks of knowledge thus capture how activities undertaken in the past influence activities and interactions that occur today.

Figure 1 portrays that scanning can be conducted either by doctors or by technologists with doctor supervision. From the scripts Direction Giving and Direction Seeking (Urban's phase 1) and Unsought Validation and Anticipatory Questions (Suburban's phase 1), we inferred that the portion of operational decisions made by each actor depended on doctors' perceptions of their own and technologists' relative accumulation of skill in operating the new CT machine. Even though the set of skills needed to operate a new technology is almost certainly not defined explicitly by the actors involved, each actor may infer by observation of others' language, posture, and actions, as well as by direct and indirect inquiry, others' level of skill relative to his or her own (Garfinkel, 1967). By portraying that doctors continually assess their scanning skills relative to technologists', the model represents common experience and Barley's observation that doctors, not technologists, have the social, professional, and institutional role to call the shots in the radiology unit.

From the scripts Preference Stating and Unsought Validation (Suburban, phase 1) and Technical Consultation and Mutual Execution (Urban, phase 4), we inferred that if both doctors and technologists knew how to perform a specific procedure, then doctors deferred to technologists. While this may seem a generous assumption on its face, it is consistent with the behaviors Barley described in the phases we characterize as collaboration. For scanning procedures in which technologists have skill, even if the doctors also possess knowledge, the model represents that technologists perform the scans; doctors perform the scans for which they possess skill and technologists (doctors perceive) do not. In the model, scanning procedures for which neither doctors nor technologists yet possess skill are performed by doctors and technologists in proportion to their relative knowledge. That is, as doctors know relatively more than technologists, doctors are likely to make more decisions for which neither actor has knowledge. Conversely, as technologists know relatively more, doctors ask them to execute a larger fraction of the scanning procedures for which neither has yet acquired skill. Who makes these decisions is important because it is through performing new procedures that doctors and technologists accumulate more knowledge. We mathematically represent these inferences with these equations:

$$\begin{gathered}\text{Doctors' Knowledge Relative to Technologists'} = \\ \text{Doctors' Operating Knowledge} \,/\, \\ \text{Technologists' Operating Knowledge}\end{gathered} \tag{3}$$

$$\begin{gathered}\text{Fraction of New Operating Procedures by Doctors} = \\ (\text{Doctors' Knowledge Relative to Technologists'})^{\alpha} \,/\, \\ (1 + \text{Doctors' Knowledge Relative to Technologists'})^{\alpha}\end{gathered} \tag{4}$$

Equation (4) depicts that, as doctors know relatively more than technologists—as the knowledge ratio given in equation (3) rises—then they execute more of the procedures for which no actor yet possesses skill; the parameter $\alpha$ indicates the strength of doctors' bias for allocating decisions based on a developmental approach or an efficient approach. For example, $\alpha < 1$ suggests that doctors want to develop the actor with less relative skill (whether technologists or they themselves) and ask the less-skilled person to make the scanning operational decision; $\alpha > 1$ indicates that doctors have a bias toward efficiency and expect the more skilled actor (whether they themselves or technologists) to make the operational decision. In this formalization, we set $\alpha = 2$, indicating a mild bias toward the actors having more knowledge, reasoning that a mild efficiency bias was consistent with scripts such as (doctors) Usurping the Controls at Urban. Sensitivity analyses show this parameter value to be robust for the Urban and Suburban cases. The variables specified in equations (3) and (4) are used in equations (5) and (6) to represent our inferences that doctors allowed technologists to execute all the scanning procedures for which they had skill and a proportion of the procedures for which no one had skill, if they knew relatively more than doctors.

$$\begin{gathered}\text{Fraction of Operating Decisions by Technologists} = \\ \text{Technologists' Operating Knowledge} + \\ (1 - \text{Fraction New Operating Decisions by Doctors}) \bullet \\ (1 - \text{Doctors' Operating Knowledge}) \bullet \\ (1 - \text{Technologists' Operating Knowledge})\end{gathered} \tag{5}$$

$$\begin{gathered}\text{Fraction of Operating Decisions by Doctors} = \\ \text{Doctors' Operating Knowledge} \bullet \\ (1 - \text{Technologists' Operating Knowledge}) + \\ \text{Fraction New Operating Decisions by Doctors} \bullet \\ (1 - \text{Doctors' Operating Knowledge}) \bullet \\ (1 - \text{Technologists' Operating Knowledge})\end{gathered} \tag{6}$$

In the model, fraction of operating decisions by technologists and fraction of operating decisions by doctors must always sum to one, given that either doctors or technologists must make decisions about how to conduct a scan.

We acknowledge the limitations of this simplified doctor-technologist representation, which suggests that occupational expertise is relatively homogenous within a role instead of differentiated among individuals. For example, the formalization does not consider the possibility that more experienced technologists could have taught less experienced ones how to use the machine. Our objective in modeling, however, was to use the ethnographer's data, as viewed through the analytical approach of activities, accumulations of expertise, and recursion, to understand why the documented doctor-technologist patterns emerged as they did. Because the ethnographer's data were silent on interactions within occupational roles, we did not explore this dimension.

The remaining equations represented by figure 1 regulate the flow of learning by doctors and technologists, indicating that how fast an actor learns depends on the gap between what he or she is attempting to do and what he or she already knows how to do, a notion widely accepted in the literature on individual learning (Dewey, 1972; Vygotsky, 1978; Piaget, 1980). The two balancing loops (B1 and B2) indicate that, as the stocks of knowledge grow, the learning rates slow. Equations for the flows into the two knowledge stocks, Technologists' Operational Learning and Doctors' Operational Learning, are:

$$\begin{gathered}\text{Technologists' Operational Learning} = \\ (\text{Fraction of Operating Decisions by Technologists} - \\ \text{Technologists' Operating Knowledge}) \,/ \\ \text{Time to Accumulate Operating Knowledge}\end{gathered} \qquad (7)$$

$$\begin{gathered}\text{Doctors' Operational Learning} = \\ (\text{Fraction of Operating Decisions by Doctors} - \\ \text{Doctors' Operating Knowledge}) \,/ \\ \text{Time to Accumulate Operating Knowledge}\end{gathered} \qquad (8)$$

Together these eight equations formalize the notion that the activity of scanning affects who learns what and, thereby, recursively feeds back to the levels of accumulated CT operational knowledge, which in turn influences who dominates in making and executing operational decisions about conducting CT scans. Figure 1 portrays four reinforcing loops that depict interrelationships between learning and doing. As doctors learn more, they know more relative to technologists, and they themselves attempt new procedures, leading to their learning still more about how to run the new CT machine (R2a and R2b). We theorize that the lower feedback loops can explain the pattern of interaction Barley (1986) observed in Urban's first phases, characterized by doctors' usurping the controls. Conversely, as technologists learn more, their knowledge increases relative to doctors', and doctors accord them latitude in attempting new procedures, leading to technologists' acquiring still more skill in using the CT machine

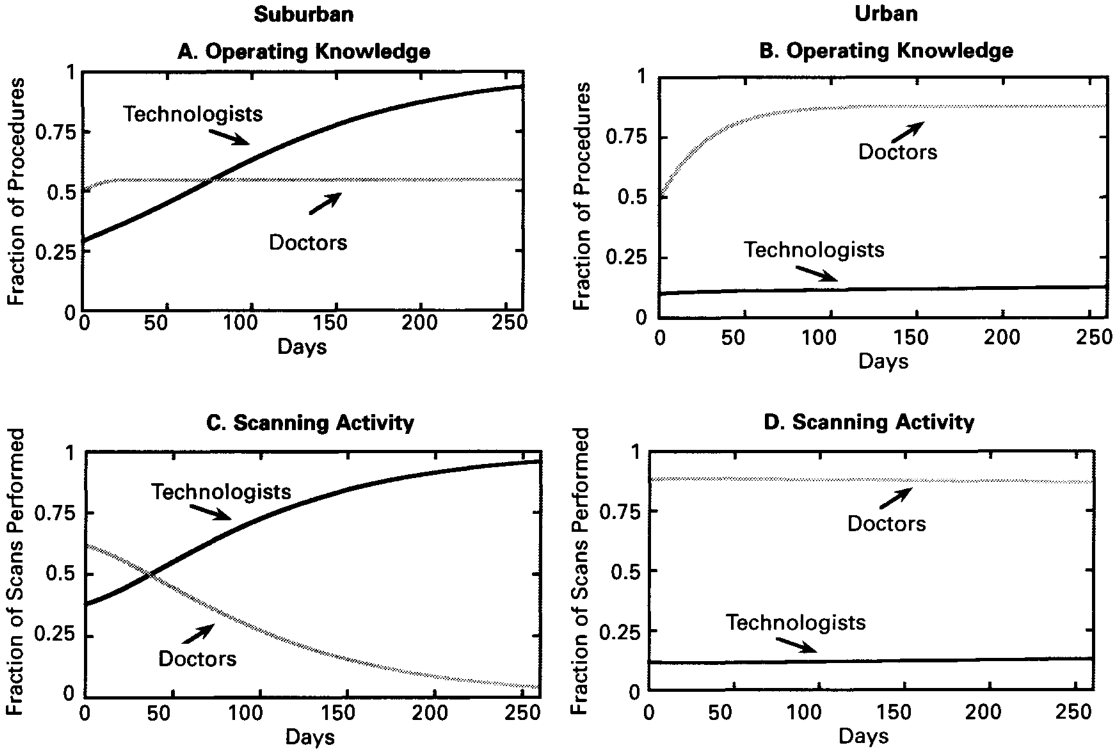
(R1a and R1b). We theorize that the upper feedback loops explain the pattern of interaction Barley documented in Suburban's first phase, characterized by joint problem solving and scripts of Unsought Validation and Anticipatory Questions.

These two reinforcing loops are interdependent, because who is afforded discretion to make decisions about scanning does not strictly depend on occupational role or an actor's absolute level of skill, but on relative accumulations of operational knowledge between doctors and technologists. In these two intertwining processes, sometimes the doctors' learning/doing process dominates and at other times the technologists' learning/doing process dominates the social construction of who does what. Simulating the relationships allows us to explore when one process will dominate the other as well as helps us check whether our thinking is internally coherent and consistent with the case study from which we constructed the relationships. The behaviors produced by the model arise simply from the mathematical relationships hypothesized, played out over time on the initial accumulation values with which the model starts.

**Simulating interactions around operational knowledge.** This two-accumulation model accounting for the operational expertise of doctors and technologists can reproduce two of the patterns Barley observed, as assessed by the simulated pattern of decisions made by technologists (continually low in the professional dominance pattern prevalent in Urban's first phases and relatively higher in the collaboration pattern prevalent in Suburban's first phase). We simulate the model for 260 days, the duration of Barley's nine-month study.

Figure 2 shows the simulated interactions produced by the model for the doctors' and technologists' CT operating knowledge and the fraction of scanning procedures they execute for both Suburban and Urban. The only difference between the simulations for the two sites are the initial conditions of expertise for doctors and technologists when the model begins to run; otherwise they are identical. Because Suburban launched its CT-scanning unit with a radiologist with some CT experience, we initialized the accumulation of operating knowledge for doctors at Suburban at 50 percent, indicating our inference from Barley's description that he had moderate experience with the procedures possible with the new CT machine. Because Suburban's CT unit began with two technologists with some CT experience and two technologists without CT skill, we initialized the technologists' operating knowledge accumulation at 30 percent, indicating that, while two of the technologists may have experience with more than half (say, 60 percent) of the known CT procedures, the other inexperienced technologists draw down the average skill level among technologists. Because Urban launched its CT unit with two radiologists with some research skills in CT, we initialized the accumulation of operating knowledge for doctors at Urban at 50 percent, again, indicating our inference they had exposure to roughly half of the procedures possible with the new CT machine. Because Urban's CT unit started with eight technologists with no experience with CT technology, the technologists' accumulation of operating knowledge was initialized at 10 percent, indicating our infer-

**Figure 2. Initial patterns at Suburban and Urban.**



ence that, although some of their experience with other scanning technologies may have been relevant, collectively they possessed little knowledge of how to operate the new CT machine.

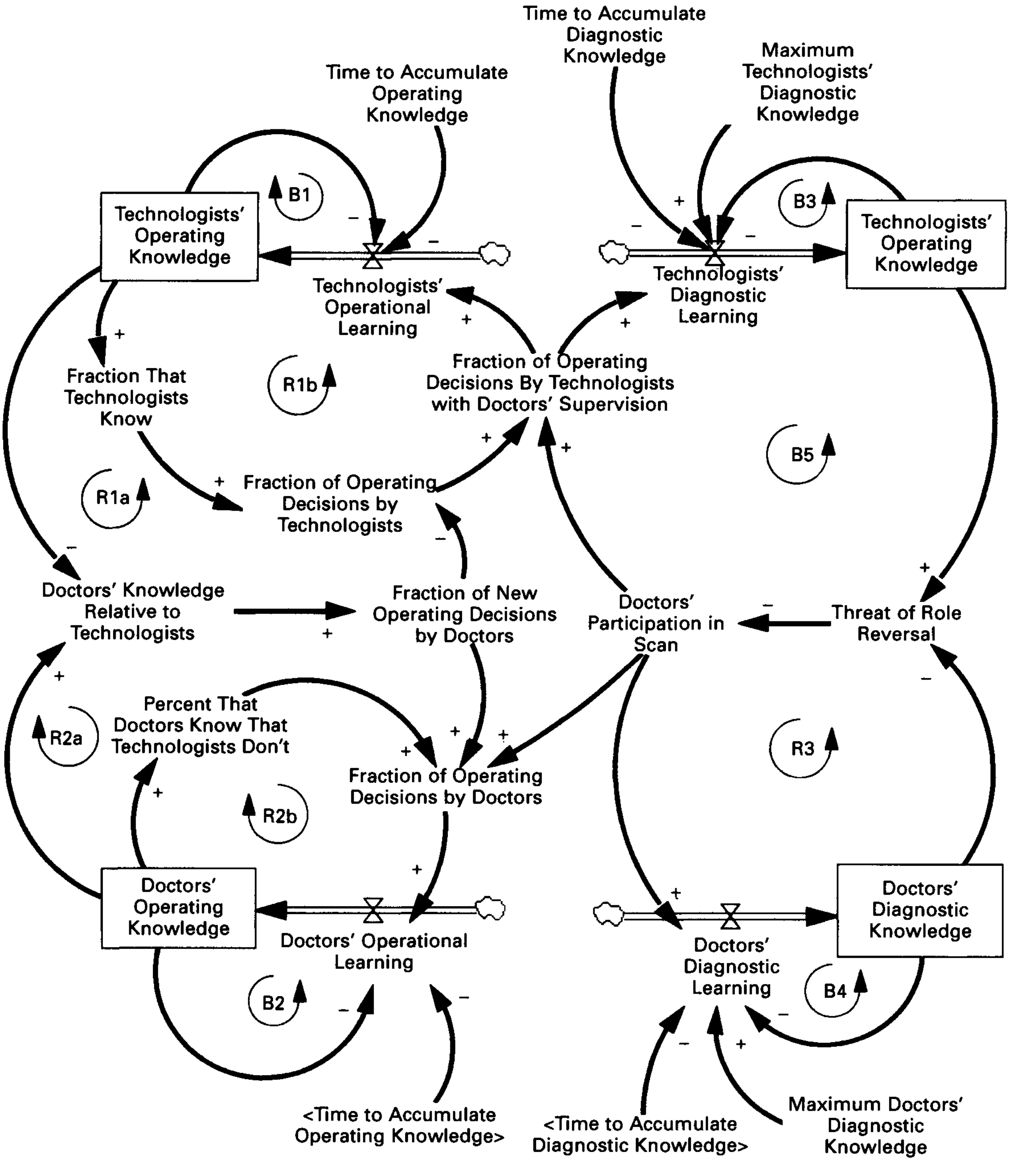
As figure 2(A) indicates, at Suburban, the simulated technologists grow in CT operating knowledge as they undertake a greater proportion of the scanning decisions (2C). As their knowledge relative to doctors' grows, they come to dominate the scanning activity. At Urban, the simulated technologists do not increase their operating knowledge (2B), primarily because they are not afforded discretion in the scanning activity (2D). Clearly the reinforcing patterns depicted in the model amplify and reinforce the differences in initial conditions of the operational expertise of doctors and technologists. The model's simulated patterns are consistent with the patterns Barley described of who operated the new CT scanner in the first phases of Suburban's and Urban's new units. The representation gives new weight to Barley's assertion that accounting for expertise—operational expertise—can help explain the daily differences in accommodating new technology, but a perspective that specifies how expertise and activities recursively interact at the occupational boundary is needed to unpack the differences in discretion in using the new technology.

## Effects of Diagnostic Knowledge on Occupational Separation

While accounting for actors' expertise in operating the new CT equipment offers some insight into the disruption that new technology can create in organizations, it helps explain only two of the three patterns observed in the two hospitals. To understand the dynamics typified by scripts such as Clandestine Teaching and Role Reversal and doctors' withdrawal from the CT-scanning area in Suburban's phase 2, we returned to Barley's data. Reexamining those scripts, we found that the expertise of consequence was not only operational skill in using the new machine, or giving direction to scanning procedures; rather, it was also in understanding how the new CT scans indicate pathology—expertise in interpreting the scans. Questions from CT-inexperienced doctors led technologists to respond "by attempting to teach without appearing to do so," but when technologists supplied information to correct the radiologists' "irrelevant question or . . . faulty suggestion," they up-ended the traditional roles, in which radiologists educated technologists (Barley, 1986: 92). Interchanges characterized as Role Reversal, in which radiologists asked technologists about pathology and technologists provided interpretations, created anxiety in both doctors and technologists. Barley reported that one technologist "nervously" said of such an incident, "'It's not my job to tell them how to do their job'" (Barley, 1986: 93). We therefore extended our representations to account for the diagnostic expertise of technologists and doctors. Figure 3 shows a diagrammatic overview of the model that includes accumulations of diagnostic knowledge.

**Representing diagnostic knowledge.** The scripts Clandestine Teaching and Role Reversal in Suburban's phase 2 suggest that the uncomfortable doctor-technologist interactions after the staffing change were rooted in the diagnostic knowledge accumulated by technologists. Through collaborative interactions with the doctor who first staffed the new CT unit, Suburban technologists accumulated not only more knowledge in operating the CT equipment but also some understanding of how the scans are used to recognize pathology. When the experienced radiologist offered his rationale for a preferred scanning procedure by explaining how it would generate robust diagnostic evidence, he often discussed "the signs of pathology in a scan" and continued with "lengthy conversations about disease and interpretation" uncharacteristic of other scanning areas (Barley, 1986: 91). When inexperienced doctors began rotating through the unit after day 21, these knowledgeable technologists, paired with CT-inexperienced doctors, felt pressure to assist doctors in properly interpreting scans to aid in diagnosis. While openly correcting an inexperienced doctor's off-the-mark question "would have been to risk affront and boldly invert the institutionalized status system" (Barley, 1986: 92), technologists often supplied corrective information, albeit in a deferential or tangential way. When doctors perceived their diagnostic abilities as inadequate, their primary form of competence—the ability to make an accurate diagnosis—was threatened. Thus in the model we represented that, along with operating knowledge, each actor can accumulate diagnostic expertise, depending on the nature of the scanning activity. These accumulations are represented in figure 3 as the stocks Technologists' Diagnostic Knowledge and Doctors' Diagnostic Knowledge.

**Figure 3. Overview diagram of extended model.**



Barley's data suggest that doctors' decisions not to participate in scans arose from the perceived threat of role reversals, occasions in which radiologists' lack of diagnostic knowledge necessitated asking a technologist whether a CT image revealed pathology, thus creating discomfort for both groups. To reduce opportunities for awkward exchanges, the CT-inexperienced doctors "began to withdraw from the scanner's minute-by-minute operation to save face," retreating to their offices and leaving technologists with considerable autonomy in operating the scanner (Barley, 1986: 94). Then the doctors saw the scans only once they were complete. To portray more effectively doctors' latitude, we added the variable Doctors' Participation in Scans, representing the fraction of time doctors are present in the scanning room. The model represents diagnostic learning in a way similar to that used for operational knowledge. Technologists' CT diagnostic knowledge grows as they execute scans while doctors are participating. Similarly, the model represents that doctors accumulate additional CT-specific diagnostic knowledge only when they participate in the scanning process.[1]

As when specifying the stocks of operating knowledge, we defined diagnostic knowledge on a 0-to-1 scale. We modeled the threat of role reversal as the fraction of diagnostic knowledge technologists have that doctors do not. Following Barley's assertion that role reversals posed a significant challenge to the normal social order, we created a steep and negatively sloped mathematical function to relate the threat of role reversals to doctors' participation in scanning; in other words, in the model, just a few role reversals can result in a significant decline in doctors' participation. Because doctors spend years in classroom and clinical training in diagnosis, we infer they possess some general diagnostic skills transferable across technology platforms and types of images. We thus represent that doctors entered the scanning area with a significant amount of general diagnostic knowledge, even if they were unfamiliar with CT imaging. The model represents that doctors acquire CT-specific diagnostic knowledge by participating in using the new machine to see how it can most effectively produce images to aid diagnosis, and they can, as the doctors that Urban and Suburban especially hired to staff the new units did, also bring CT-specific diagnostic knowledge with them from previous research and experience.[2] Just as we portrayed that doctors have a lower bound on their diagnostic knowledge, we depicted that the technologists represented here had an upper bound on the diagnostic knowledge they could acquire, given that at the time of Barley's study, before CT technician certification programs, it is unlikely that any amount of on-the-job experience could provide the understanding of anatomy and pathology doctors gain through medical school and residency. The equations for the model are available in the technical appendix available at http://www.montana.edu/cob/Faculty_and_Staff/bio/black.htm or http://web.mit.edu/nelsonr/www.

Incorporating diagnostic knowledge and the threat of role reversals into the representation introduces several new feedback loops, shown in figure 3. The balancing loops B3 and B4 regulate the accumulation of diagnostic knowledge, just as B1 and B2 do for operating knowledge; as the stock of knowledge grows, the learning rate slows. More significant, doctors' participation in the scanning activity creates a learning/doing loop (R3) in which doctors accumulate more diagnostic knowledge, which, as it increases relative to technologists' diagnostic knowledge, reduces the threat of role reversals and reinforces their participation in scanning. This dynamic is similar to the reinforcing processes R1 and R2 arising from the accumulation of operating knowledge. Finally, doctors' participation in scanning influences the learning of

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[1] There are numerous ways for doctors to accumulate additional diagnostic knowledge, such as attending training or conferences, that we did not represent in the model. We omitted these other sources of learning because, although they may be effective, they are likely to proceed on a slower time scale than considered in the 260 simulated days of this analysis.

[2] We acknowledge that the model simplistically represents that doctors learn how to diagnose accurately as they work with the CT technology. While there is research that calls into question that doctors learn perfectly (e.g., Freed et al., 1998), we do not incorporate this aspect of learning into the model because the ethnographer's data were silent regarding the quality of the diagnosis rendered in the hospitals studied.

technologists: as technologists accumulate diagnostic knowledge, the threat of role reversals increases, thereby reducing the participation of doctors and slowing technologists' learning. In contrast to the reinforcing learning loops arising from other accumulations of expertise, technologists' accumulation of CT diagnostic expertise results in a balancing feedback (B5), which then limits their further learning.

The new computerized CT technology, unlike previous forms of scanning such as X-ray and fluoroscopy, required some skill in interpreting the images produced, in order to create scans useful to diagnosis. In both Suburban's and Urban's first phases, doctors revised their ideas of how to conduct scans based on the images currently being produced. The implementation of CT technology, because it introduced a non-separable aspect of scanning and diagnosis, blurred the customary occupational boundary between doctors and technologists. Based on our analysis, we theorize that Suburban technologists' acquisition of diagnostic skill further blurred the occupational boundary between doctors and technologists, creating a mismatch between expected occupational activities and the behaviors occurring in the newly established CT units. The representation here suggests that technologists' accumulating diagnostic knowledge is not in itself problematic. Only when doctors perceive that technologists' diagnostic skills, relative to their own, challenge the "institutionalized roles" of doctors and technologists (Barley, 1986: 92) does the mismatch become uncomfortable for all actors involved. Because doctors hold the position of authority, they have discretion in who performs which activities; when threatened by role reversals, doctors remove themselves from the scanning area, thereby reducing the possibility of uncomfortable challenges, however oblique, to their social and professional position. We theorize, however, that exiting the CT scanning area limits doctors' own potential for acquiring CT-specific diagnostic knowledge, perpetuating the possibility that technologists' knowledge of CT-scan interpretation will remain relatively threatening and thereby creating an enduring occupational separation.

**Simulating interactions around diagnostic knowledge at Suburban.** In simulating the extended model, we retained initial values for accumulations of operating knowledge specified above for Suburban, and we simulated the effect of CT-inexperienced doctors moving into the unit by reducing doctors' knowledge stocks proportionately on the day of the staffing change, to reflect that the CT experience of the doctor initially staffing the unit was outweighed by the new doctors' unfamiliarity with the technology. Figures 4 and 5 show the simulated behaviors of the model under the Suburban scenario, when CT-inexperienced doctors began staffing the unit on day 21.

In the model, when the new staffing causes an immediate drop in doctors' accumulation of operating and diagnostic knowledge (4B and 4D), technologists immediately begin making more of the operating decisions (5C). The new doctors afford technologists greater discretion in making scanning decisions because technologists' operating knowledge, relative to their own, is high (4A). As technologists execute

Figure 4. Knowledge accumulation at Suburban.

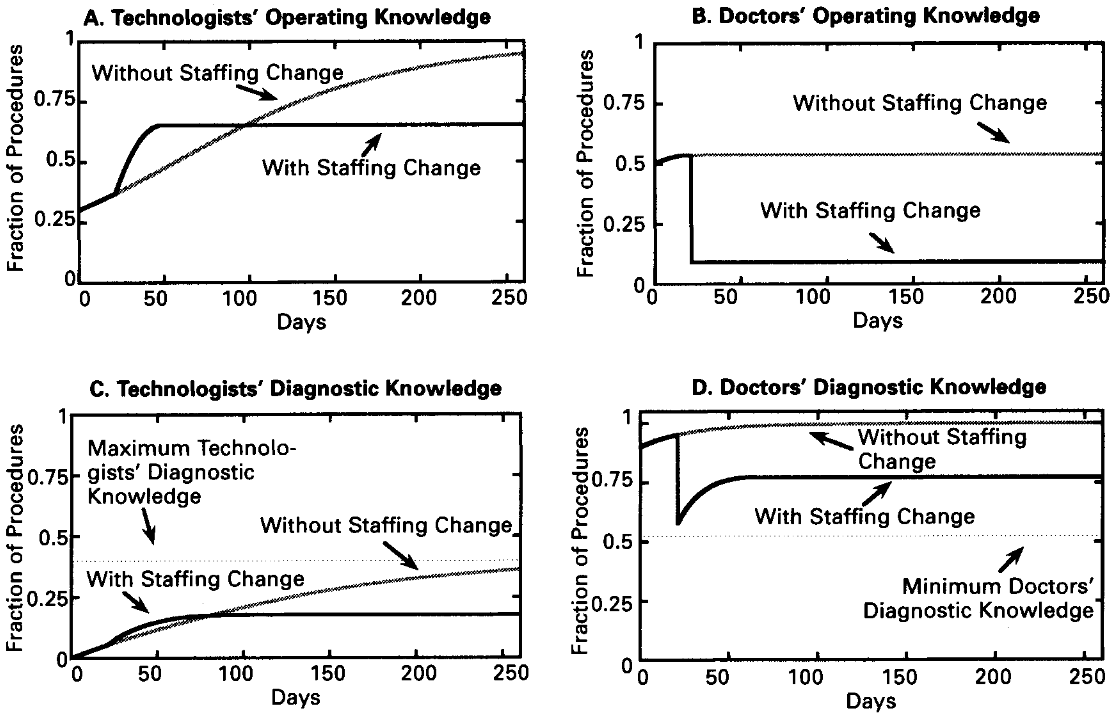
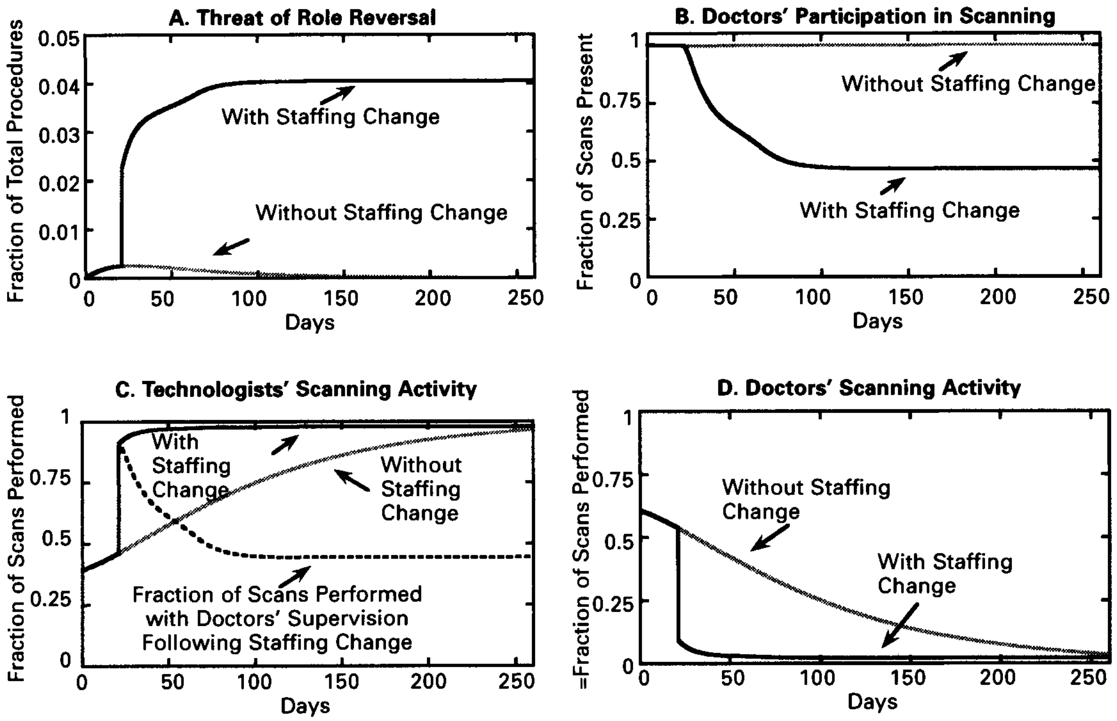


Figure 5. Scanning activity at Suburban.



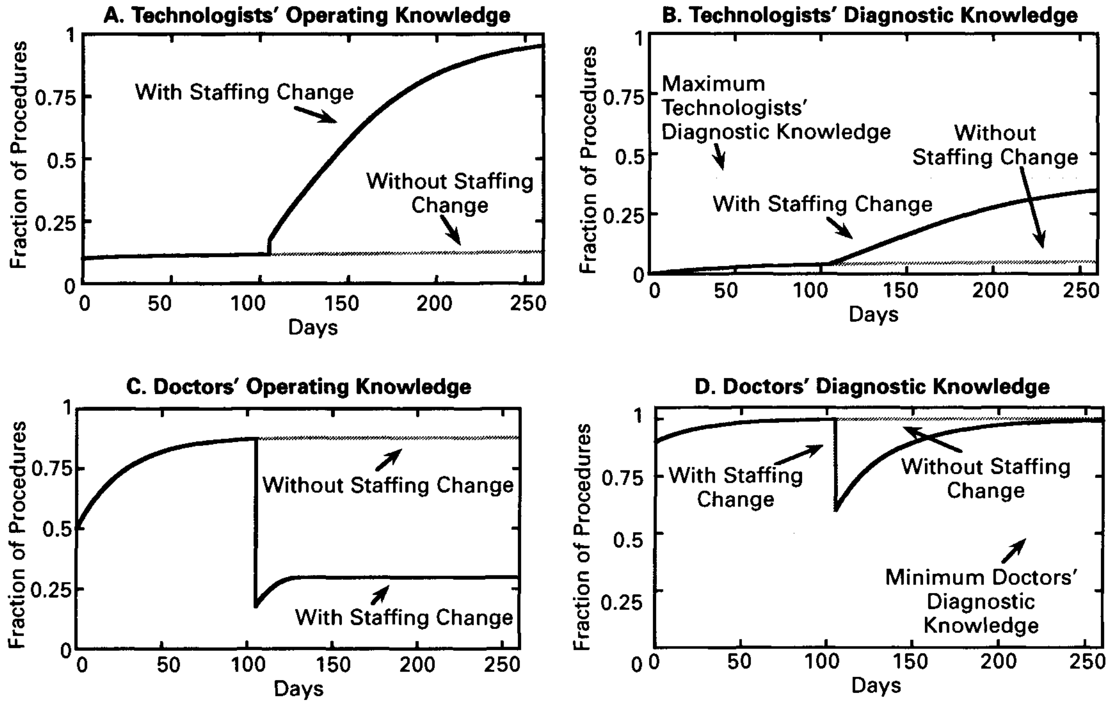
scans with doctors present, they gain in both operational and diagnostic understanding of the new CT technology. The new doctors, though learning little about operating the machine because technologists make most of the operational decisions, begin to accumulate additional diagnostic knowledge, but these gains do not continue. The staffing change pairs technologists who gained a modest amount of CT diagnostic knowledge during the first 21 days, when they worked collaboratively with the CT-experienced doctor, with doctors inexperienced with the new technology and so creates the threat of role reversals (5A). The threat causes doctors to reduce their participation in the scanning process (5B), slowing all forms of learning, both doctors' and technologists'. The simulated behaviors in figures 4 and 5 marked "without staffing change" highlight how the change in relative expertise that occurs with inexperienced doctors rotating into the CT unit disrupts the trajectory of learning begun with the collaborative doctor-technologist interactions in Suburban's phase 1.

**Simulating interactions around diagnostic knowledge at Urban.** Even though we found interactions around operating knowledge sufficient to explain both the professional dominance and collaboration patterns observed at Urban, we can further refine our understanding of the situation there by examining how the model including diagnostic knowledge simulated behaviors in the situation at Urban, which experienced a staffing change similar to Suburban's. At Urban, CT-inexperienced doctors began rotating through the new unit on day 105, decreasing doctors' knowledge stocks; at the same time, the four technologists whom doctors deemed least competent were transferred out of the CT unit, modestly increasing the technologists' limited operational knowledge. Figures 6 and 7 portray the extended model's behaviors in the situation at Urban.

During the early phases, the relative imbalance of doctors' operating knowledge to technologists' leads doctors to dominate the scanning activity, thereby accumulating more operational and diagnostic knowledge (6C and 6D), while technologists remain inexperienced with the technology. The staffing change on day 105 reduces the doctors' accumulations of knowledge, effectively redistributing operating knowledge and causing an immediate increase in the fraction of operational decisions made by technologists (7C). As technologists begin to make operational scanning decisions, they accumulate operating knowledge (6A), while doctors learn relatively little about how to operate the machine (6C). Because, during Urban's first three phases, doctors' dominating behavior afforded technologists few opportunities to learn, technologists have little diagnostic knowledge when the staffing change occurs (6B). Consequently, the new doctors experience little threat of role reversal and remain active participants in the scanning area (7B), which allows them to rapidly accumulate additional diagnostic knowledge through interactions with technologists while they produce scans (6D).

In the simulations, after the staffing change at Urban, both doctors and technologists possess little expertise in the new technology, but their limited expertise is relatively balanced across the occupational boundary. Because doctors do not know more than technologists about the CT machine, they afford technologists significant discretion in making operating

**Figure 6. Knowledge accumulation at Urban.**

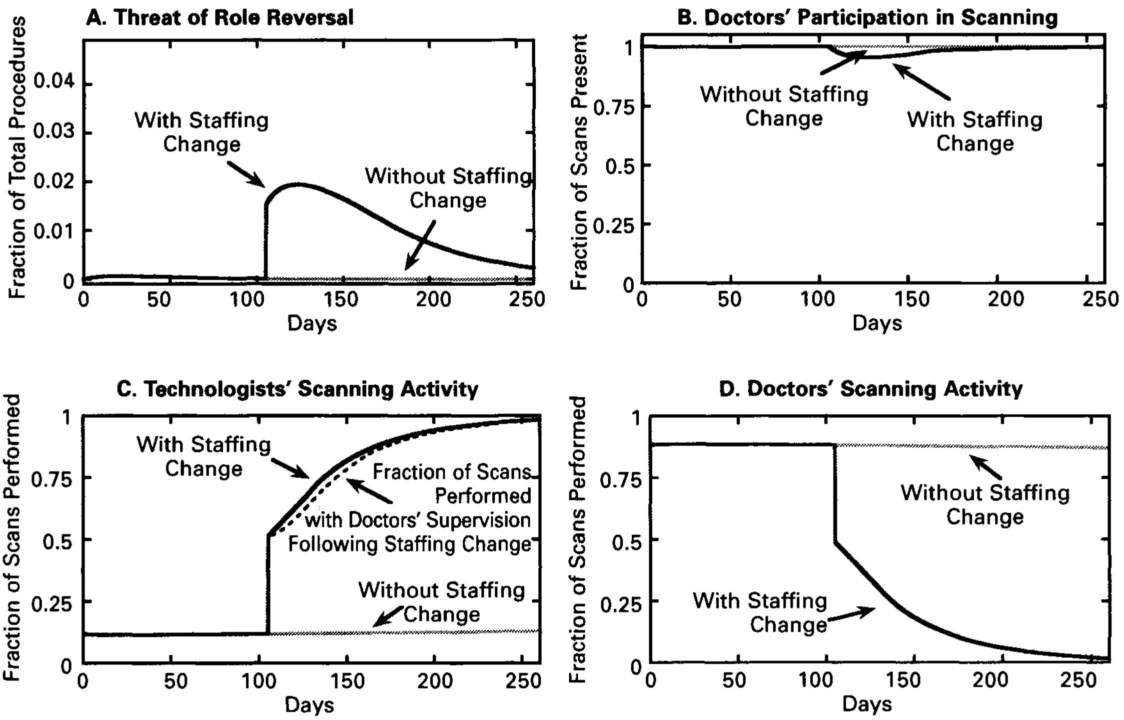

A. Technologists' Operating Knowledge

B. Technologists' Diagnostic Knowledge

C. Doctors' Operating Knowledge

D. Doctors' Diagnostic Knowledge

**Figure 7. Scanning activity at Urban.**


A. Threat of Role Reversal

B. Doctors' Participation in Scanning

C. Technologists' Scanning Activity

D. Doctors' Scanning Activity

decisions, which allows technologists to learn by doing. With little threat of role reversals, doctors remain present during the scanning process and so increase their understanding of how CT technology can inform the diagnostic process. The simulated behaviors indicate that both doctors and technologists exercise and accumulate expertise in keeping with their expected roles, even as those roles become modified by collaborative interactions. The simulated behaviors labeled "without staffing change" in figures 6 and 7 accent how Urban's staffing change alters a trajectory of technologist incompetence to establish instead a pattern of deepening expertise and collaboration.

## The Consequences of Relative Expertise in Different Scenarios

This formalized theory of expertise in using a new technology helps draw together and illuminate in a single picture the interactions Barley observed at the two hospital sites. The analyses suggest that all the patterns documented in the field can emerge from a single representation that distinguishes operational expertise from diagnostic expertise related to the new CT-scanning technology, with differences in expertise only set by initial conditions and altered by staffing changes. Despite the abstractions inherent in mathematical representations of people's interactions with new technology and with each other, we believe this model operationalizing recursion between accumulated expertise and activities provides explanatory leverage in understanding why different patterns of doctor-technologist interactions emerged at the two hospitals Barley studied under two staffing arrangements at each. Following Glaser and Strauss's (1967) distinction between formal and substantive theory, we have put forth a formal theory grounded in the substantive theory that Barley used to make sense of his data.

To explore more completely the challenges faced when implementing a new technology, we used the model to explore conditions other than those suggested by the Suburban and Urban staffing scenarios to better understand the conditions under which these theorized relationships hold. We systematically varied the initial accumulations of knowledge for doctors and technologists and summarize the outcomes of some of those scenarios in table 2, as assessed by total practical knowledge, defined as the sum of doctors' diagnostic knowledge (both CT-specific and general) and technologists' operating knowledge, relative to potential, at the end of the simulation. Values indicate the percentage of procedures and tasks well understood and executable by staff using the new CT equipment (*operating knowledge*) or using the images produced by the new CT equipment (*diagnostic knowledge*). Because both doctors and technologists can acquire and exercise operational and diagnostic expertise, initial values of both operating and diagnostic expertise are shown for both actors. Total practical knowledge is the sum of knowledge practically brought to bear on activities in the CT area, with technologists performing the scans and doctors interpreting the scans (i.e., the normalized sum of technologists' operating knowledge and doctors' diagnostic knowledge).

The values in table 2 suggest that by the end of nine simulated months, an organization attains the highest levels of

Table 2

**Total Practical CT Knowledge among Doctors and Technologists after Nine Simulated Months, Given Various Initial Knowledge Accumulations**

| | Technologists' Initial CT Knowledge | | |
|---|---|---|---|
| Doctors' Initial CT Knowledge | Low CT expertise<br>*Operating 10%*<br>*Diagnostic 0%* | Medium CT expertise<br>*Operating 50%*<br>*Diagnostic 18%* | High CT expertise<br>*Operating 90%*<br>*Diagnostic 35%* |
| Low CT expertise<br>*Operating 10%*<br>*Diagnostic 20%* | **99%** | 55% | 75% |
| Medium CT expertise<br>*Operating 50%*<br>*Diagnostic 60%* | 56% | **98%** | 85% |
| High CT expertise<br>*Operating 90%*<br>*Diagnostic 90%* | 55% | 81% | **96%** |

expertise (the cells along the diagonal) when the initial accumulations of knowledge on either side of the doctor-technologist boundary are relatively balanced. Only when each actor possesses sufficient expertise (relative to other actors) in using the new technology do collaborative patterns of interaction emerge. Collaboration allows each actor at a disrupted occupational boundary to accumulate additional knowledge through engagement in ongoing activities and bring it to bear on using the new technology. We emphasize that it is the relative, not absolute, level of skill that influences whether interactions are collaborative. As long as expertise is balanced across the boundary, status-challenging behaviors that prove so disruptive do not arise and, by the end of the simulated period, technologists have nearly mastered using the CT machine, and doctors have learned almost all they can about interpreting CT scans. The relative balance in expertise has allowed change to occur in the form of increased discretion and mutual learning. In contrast, when doctors initially know more than technologists (the cells below the diagonal), the doctors often produce the scans themselves. Practical knowledge is lower because technologists have little access to the activities that generate learning. Conversely, when technologists begin with more experience than doctors (the cells above the diagonal), doctors reduce their participation, limiting their ability to acquire diagnostic knowledge and the technologists' ability to learn how to produce scans that aid diagnosis. The latter two patterns of interaction reveal outcomes in which a given specialization is not able to contribute fully, resulting in a situation in which the full benefits of the technology cannot be realized.

## DISCUSSION

Prior to CT scanning, X-ray technology had been used as the primary imaging technology in hospitals for several decades. At the time of Barley's study, the roles and relations between technologists and doctors in using X-ray were embodied in a set of standard procedures and interactions (e.g., a complete arm X-ray should consist of four images of the arm in certain positions). Properly trained X-ray technologists could create useful images despite having little knowledge of how to interpret them (Barley, 1986, 1996), and, conversely, trained radiologists could accurately interpret those images despite not being able to create them. The division of labor was clear, and successful diagnostic outcomes could result with little or no interaction in an "industrial atmosphere" (Barley, 1996: 435).

At its introduction, CT scanning blurred and disrupted the occupational relations between doctors and technologists (Barley, 1996: 435), and there were few if any standard procedures to use. The formalized distinction we made between operational knowledge (i.e., manipulating the machine) and diagnostic knowledge (i.e., interpreting the images) sheds light on what is disrupted and blurred when a new technology is introduced at an occupational boundary. The newness of the CT technology rendered operational and interpretive expertise inseparable, disrupted the accepted expertise roles, and challenged existing occupational notions of discretion and control. Fully realizing CT imaging as an improved diagnostic tool, then, required that doctors and technologists learn to interact in different ways (Barley, 1988). Formalizing both types of expertise and their recursive interaction in the context of the new technology allowed us to move beyond mere observation and theorize dynamics that were deeper and more complex than Barley's centralization-decentralization continuum implied. These dynamics revealed three distinct patterns of interaction: collaboration, professional dominance, and occupational separation.

Such varied patterns are not unique to the situation Barley studied. Scholars from a variety of disciplines, studying a broad range of technologies, have shown how introducing new technology blurs accepted divisions of labor and generates both positive and negative interactions (e.g., Sproull and Kiesler, 1986; Bijker, 1987; Zuboff, 1988; Adler and Helleloid, 1987; Edmondson, Bohmer, and Pisano, 2001). These studies indicate that such disruptions are more than theoretical puzzles; when unproductive patterns of interaction emerge, the benefits offered by the new technologies are often quite limited (e.g., Robey and Boudreau, 1999; Repenning and Sterman, 2000; Black, 2002). Turning our analytical perspective on Barley's study yields several new hypotheses concerning the sources of these dynamics and the variables that determine whether collaborative and, therefore, productive outcomes result.

First, our analysis began by linking accumulations of operational expertise to the conduct of scanning. While most studies of technology implementation have focused on the absolute skill levels of those using the new technology (Repenning and Sterman, 2000) as defined by the novice-to-expert continuum (Dreyfus and Dreyfus, 1986), our analysis suggests that the relative difference in expertise between actors is pivotal in determining if a collaborative or non-collaborative pattern will emerge. An imbalance in the distribution of operational knowledge puts one actor in a relative position (Bourdieu, 1983) that is more powerful than another's in using the technology. Barley characterized such imbalanced doctor-technologist interactions with scripts such as Usurping Controls (when doctors knew more) in Urban's phase 1 or Role Reversal (when technologists knew more) in Suburban's phase 2. Non-collaborative patterns of interaction resulted from these imbalances as doctors excluded technologists from touching the new technology (Urban's phase 1), or when doctors withdrew from all contact with the new technology and the technologists who operated it (Suburban's phase 2).

Connecting the conduct of the scanning activities to the rates at which actors accumulated CT expertise, and recognizing the recursive relationship among accumulations of operational knowledge and access to the activity that generates the knowledge, explains two of the three patterns we identified—collaboration and professional dominance. When the initial distribution of operational knowledge was relatively balanced between the two occupational roles, both engaged in the conduct of scanning and accumulated additional knowledge, thus maintaining a relative balance of expertise that allowed further productive interactions and sustained a collaborative pattern. When doctors knew more than technologists in using the technology, however, they were likely to dominate the use of the technology, accumulating more operational knowledge at the expense of technologists' learning and thus reinforcing a pattern of professional dominance.

Our second analysis focused on interactions in which the technologists had significantly more experience in operating the CT machine than doctors. Here the dynamics were even more complicated because they ran counter to a deeper social order. Because of the inseparability of operational and diagnostic expertise surrounding the new technology, experienced CT technologists had gained some diagnostic knowledge as they had gained skill in operating the machine. While this amount of diagnostic knowledge was still very small in comparison to doctors' with their years of medical training, it was diagnostic knowledge accumulated only while using CT and so was of particular value in operating the machine to produce images useful for diagnosis. Our analytic formalization of operational and diagnostic knowledge explains Barley's important but unqualified observation that "the traditional distribution of diagnostic expertise was difficult to sustain in the CT area, since the inexperienced radiologist initially knew less about the images than did the experienced technologists" (1986: 92). When technologists observed CT-inexperienced doctors failing to use the new technology to inform their diagnoses, the technologists tried to correct and improve the doctors' understanding of CT. Barley's scripts such as Clandestine Teaching and Role Reversals capture well this situation. So although doctors may have been comfortable ceding control of the new CT machine to technologists, having their diagnostic authority mediated and sometimes challenged by technologists was uncomfortable for both actors. Eventually doctors separated themselves from technologists and the CT-scanning activities to avoid these uncomfortable role reversals. This occupational separation significantly limited the joint learning across occupational boundaries necessary to develop the capability to use the technology effectively in improving diagnosis.

Occupational separation clearly reveals how the dynamics in the introduction of a new scanning technology are affected by the deeper and significant difference in diagnostic knowledge that historically has allowed doctors to have authority over technologists. When doctors had the edge in operational expertise, they came to dominate the technology and relegated the technologists to a minor role (professional domination), but when technicians had the edge, we did not observe the complementary pattern of "technologist domination" because it is incompatible with doctors' diagnostic authority (i.e., medical training, professional credentials, hierarchical position). In terms of diagnostic expertise, doctors occupied a relative position that was much more powerful than technologists' and so could withdraw from the CT-scanning activity when it grew uncomfortable, thereby preventing any further interactions that could subvert their traditional authority. In contrast, in the collaborative pattern, this deeper structure of doctor authority did not constrain learning across the boundaries but allowed for "mutual execution" and "negotiation of discretion." Picking up where Barley left off, we traced these dynamics to how differences in relative expertise in operating the new technology shape future accumulations in the conduct of scanning activities and interact with the deeper social structure (the authority of doctors, rooted in their claim to diagnostic expertise) to determine collaborative and non-collaborative patterns of interaction between these actors.

An important implication of our findings is that when implementing new technology, more knowledge does not necessarily produce a better long-run outcome, and, further, collaborative outcomes cannot be achieved from every amount of staff expertise. Practitioners would be wise to consider the relative distribution of expertise when implementing a new technology. As suggested by the scenarios represented in table 2, a relative balance in expertise across occupational lines, regardless of initial expertise levels, may prove crucial in generating collaborative activities that allow the organization to bring more knowledge to bear on using a new technology at disrupted occupational boundaries and so realize the technology's benefits. This implication helps elucidate Khandwalla's (1974: 90–96) critique of the technological imperative; once he separated successful from less successful performers, he found a "soft" imperative, suggesting that some ways of organizing around technology proved better than others. Our account of the dynamics that Barley observed suggests a "relational" imperative when it comes to increasing the success of implementing new technologies. When a technology is new, a relative balance in operational knowledge leads to greater mutual learning and collaborative change in the roles and relations between actors required to realize its benefits more rapidly.

By grounding our analysis in an explicitly dynamic theory, this proposed relational imperative offers far more specificity than traditional sociotechnical arguments (Trist and Bamforth, 1951) and their broad solutions to the trade-off between efficiency and flexibility through increased participation and decentralization (Trist, 1981). In this study, we examined the "technical" as a specific new technology (here, CT scanning) that blurs the boundary between occupational roles and expertise. Given that, the foundation for effective participation around that technology arises from a balance of expertise in operating it. Further, because a new technology blurs roles and relations, it reveals the "social" as actors with varied interests and abilities. Based on this, our relational imperative recognizes that it is not necessarily decentralization that creates a useful outcome in this context but, rather, the opportunity for actors to redefine discretion and control through mutual learning. This level of specificity has broad implications for how we think about the social and technical, because a variety of technologies are often used at the boundary (see Star, 1989; Henderson, 1999; Carlile, 2002) between actors who depend on each other to create a product or service.

In the context of less-invasive surgery techniques, a relational imperative suggests why doctors are more dependent on, and must give more discretion to, nurses and technicians to obtain the benefits from this new surgical technology. Perhaps not surprisingly, what has proved most helpful in realizing gains from less-invasive surgery techniques is putting "teams" of doctors, nurses, and technicians through extensive simulated training to develop adequate technical skills in using the technology and transform how team members interact across their occupational roles (Edmondson, Bohmer, and Pisano, 2001). Such training provides actors with a developmental space in which to learn and modify their roles and interactions with each other in using the new technology. By extension, the analysis of total practical knowledge in table 2 suggests that when an organization does not have the resources to hire the staff to create an initial balance of new-technology expertise across occupational roles, establishing opportunities for developmental training may be a cost-effective path to realize better the gains the new technology offers.

There are, of course, numerous limitations associated with our findings. We formalize only two implementation episodes, and in building on someone else's study and translating these data into a formal model, we lose contextual details. Moreover, the findings are closely tied to a specific feature of the hospital setting: a clear hierarchical boundary between doctors and technologists. The outcomes we identify arise from doctors' ability to determine both who does the scan and who is present for the scan. This nascent theory is silent on questions of what happens when the power differential is less significant or when more than two occupational roles are involved. The analysis thus offers only a few of the hypotheses that might eventually be used to construct a theory adequate to explaining the complexity of the phenomenon.

Our results do, however, offer conceptual guidance about how such studies might be developed. Most generally, the results further confirm the usefulness of conceptualizing organizational patterns as the product of recursive interaction among activities and the accumulations of knowledge and power that actors possess. Whereas a static approach suggests that technology determines action, theorists taking a more dynamic view (Barley, 1986; Orlikowski, 1992) have soundly critiqued this one-sided explanation. Our analysis extends these insights not only by highlighting the central role that recursive relations play in creating organizational outcomes but also by representing and operationalizing the impact of recursive relations among activities and actors' accumulations sufficient to generate the variety of patterns observed. This context-specific formalization adds additional support to the claim that a dynamic, recursive view of organizing leads to a qualitatively different and more accurate understanding of the phenomenon.

Taking a recursive view on organizational phenomena, however, continues to pose a substantial analytic and theoretical challenge, for if features of organizational life normally conceptualized as static are themselves part of a larger dynamic system, theorists may find themselves lost among endless interconnections. If everything is connected to everything else, it is difficult to move beyond general statements about mutual adaptation to operational characterizations of structuring processes. Consider, for example, the hierarchical relationship between doctors and technologists central to our analysis. Is not the power relationship, or relative position, between technologists and doctors itself the outcome of the ongoing interactions between the two roles and the accumulations of expertise that such activities enable? Our analysis is thus premised on a seeming contradiction. On the one hand, we represent the process of *structuring* whereby the knowledge about and authority over the operation of the CT scanner evolved in different ways. On the other hand, we capture this evolution by acknowledging seemingly fixed social *structures* such as the authority that doctors have over technologists.

The resolution of the contradiction lies in the logic of accumulation and points to perhaps the most important component of our analytic approach. As Giddens (1984) and others (Bourdieu and Wacquant, 1992; Archer, 1995) have argued, some institutional roles or structures prove far more stable or resistant to change than others. From the perspective of recursion, some structures change more slowly than others, at different rates. The authority of doctors over technologists is not an immutable feature of the environment but is itself an outcome of previous structuring (i.e., education, credentials, and institutional and occupational relations). But doctors' authority over technologists results from accumulations that change much more slowly than the patterns of interest in this study of two implementations of a new technology. Specifically, it takes longer to accumulate adequate knowledge to do diagnosis (i.e., through medical school, residency, etc.) than it does to accumulate adequate on-the-job knowledge to operate CT technology. The institutional patterns dictating who is in charge of making a diagnosis change on a longer time scale than the temporal patterns related to implementing new CT technology.

So that which is considered the transient outcome of "structuring" and that which is considered "structure" is, in the end, a temporal distinction, referring to how stable or dynamic one source of structure is in relation to another. While this point may seem trivial at first glance, we believe it is fundamental to improving how we conceptualize the recursive nature of organizational phenomena. Our focus on knowledge—more specifically, distinguishing between operational and interpretive knowledge—has allowed us to describe not only sources of structure that change at different rates but also how these different types of knowledge and their relative amounts constrain what is possible in a given activity. Only when there is a relative balance can an effective "structural gearing" between structuring and structure occur—in this case, in the activity of CT scanning—and the benefits of the new technology be more rapidly realized. Structural gearing can be described more concretely as a practice at a boundary whose efficacy is determined by the adequacy of the artifact used, i.e., boundary objects (Star, 1989; Carlile, 2002), and the relative skill of the actors who use it (Black, 2002) to modify their relations.

For any phenomenon of interest, recognizing that some sources of structure change at different rates provides a way to clarify and focus both theoretical and empirical efforts. A principal benefit of taking a recursive approach is that it helps a researcher recognize the importance of specifying the observational time frames (e.g., weeks, months, years, decades) most useful in distinguishing what is dynamic, and therefore well considered in terms of structuring processes, from that which is less dynamic, and therefore appropriately thought of as stable structure for the purpose of the study at hand. This provides not only greater precision to what we mean by such phrases as "mutual adaptation" but, more important, also encourages us to specify the conditions under which mutual adaptation takes place or doesn't (i.e., the activity of CT scanning in this case). Overall, this analytic approach provides theoretical and empirical clarity that outlines the sources of structuring and structure that can interact and defines the relationships among the layers that configure "deep structure" in organizations (Drazin and Sandelands, 1992).

Finally, our approach demonstrates how formal models can be used as representational tools to bridge the gap between the "thick description" found in ethnographic accounts and the complex recursive conceptualizations found in Giddens and Bourdieu. By operationalizing accounts that use both rich data and recursive approaches (Barley, 1986; Orlikowski, 1992), our effort has been to leverage the ethnographer's insights in a way that allows for more general application. We have illustrated how empirically based mathematical formalization can provide a valuable complement to empirically rooted textual descriptions, as the purpose of both is to develop and refine theoretical understanding (Glaser and Strauss, 1967). Mathematical models do, of course, have a long history in organization studies (e.g., Cyert and March, 1963; Nelson and Winter, 1982), often providing a critical perspective on the dynamics of organizational processes (e.g., Levinthal and March, 1981). Most models, however, represent relatively general inquiries, often based on stylized axioms about the phenomenon studied. Our analysis suggests that formal modeling may also add value as a tool for more focused inquiries into specific episodes of organizing, providing a critical bridge between thick description and broader theoretical generalizations.

Although the analytic approach developed here is not a substitute for either thick description or powerful conceptualization, it can serve as a useful link between the two. This paper brings "work" back into studies of organizations (Barley and Kunda, 2001) in a unique way by providing more than just a descriptive stance. It affords an opportunity to formalize the relational dynamics between actors and their knowledge as they interact around new technological artifacts that lie at the boundaries between their occupational or functional domains. Understanding these relational dynamics can help organizations capitalize more quickly on the benefits promised by new technology.

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