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Technology Transition Pull: A Case Study of Rate Monotonic Analysis (Part 2)

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Technology Transition Pull: A Case Study of Rate Monotonic Analysis (Part 2)

Abstract: This case study reports on efforts to introduce a software technology, rate monotonic analysis, into several software-intensive programs at one site within a multinational firm. We describe lessons learned and success factors in the early use of rate monotonic analysis (RMA). We also present evidence that supports the requirement for an internal capability—in the form of technical expertise and infrastructure—to adopt and assimilate this new technology. Finally, the study applies the “whole product” concept for understanding technology adoption and use, showing how one firm compensated for lack of a whole product in its adoption of RMA.

1 Introduction

The acquisition and introduction of new software technologies (including tools, methods, and management approaches) is so much a part of most software development and maintenance efforts that we do not even call it out as a separate activity. However, one reasonable explanation for why cost and schedule overruns are so common in software projects is the continual learning required on the part of software engineers and managers. One solution to the software “crisis” [Gibbs, 1994] is to better understand and anticipate problems and barriers in the introduction of new software technologies, such as rate monotonic analysis (RMA), which is the subject of this report. [This is also the focus of the Transition Models Project at the Software Engineering Institute (SEI).][1]

RMA is a simple, practical, mathematically sound way to guarantee that all timing requirements will be met in software-intensive real-time systems. RMA allows engineers to understand and predict the timing behavior of real-time software to a degree not previously possible. The Rate Monotonic Analysis for Real-Time Systems (RMARTS) Project at the SEI has demonstrated how to design, implement, troubleshoot, and maintain real-time systems using RMA. From 1987-1992, the project worked to develop the technology and encourage its widespread use to reduce risk in building real-time systems. This report, which is Part 2 of a two-part case study, describes how several projects in one organization attempted to adopt and apply RMA technology. Of particular interest is how an innovative culture and an organization’s willingness to act as a co-developer, and an existing infrastructure for software technology transition, compensated for missing aspects of the *whole product* [Moore, 1991]. A whole product, according to Moore, is a product that incorporates the adjunct products and services

[1] The study of the maturation of RMA is one part of a larger effort to build a “thick description” [Geertz, 1972] of software technology transition. (Such an ethnographic description makes the tacit explicit; attends to cultural practice, including communication in a given community, organization, or group; attends to detail and not only abstract concepts; and captures language as it is in use—as it reveals the values and priorities of those groups.) Additional work in the Transition Models Project explores related levels of analysis; for example, Fowler & Levine [1993] offer a conceptual framework for technology transition, from the birth of a technology to its retirement.

that are necessary for popularization (i.e., training and support, courses, documentation, handbooks).

The investigation of RMA development and transition is intended to make a twofold contribution to greater understanding of technology transition.[2] Our aim is to encourage researchers to further explore the precepts presented here with respect to other software technologies and to help practitioners, developers, and transition agents alike, learn from the strategies used by teams such as RMARTS. In addition, for researchers and practitioners to better understand technology transition, they must look beyond development perspectives to examine the experiences of populations who attempt to adopt and implement software technology. People working in the area of software technology transition should be able to make practical adaptations of the heuristics and lessons identified here for their own contexts. The case study approach is a good match for our double purpose: the research method allows for close examination and interpretation, and the rich and detailed form can provide practitioners with surrogate experience of a complex transition situation.

As indicated, the case study consists of two technical reports: Part 1 (CMU/SEI-93-TR-29) is concerned with the analysis of RMA transition activities according to phases of a technology maturation life cycle; Part 2 (this report) investigates the processes of RMA adoption and implementation at ComCo,[3] Woodville.[4] Together, the two parts allow us to attend to development and user perspectives—or more colloquially put, to technology *push* and technology *pull*. Part 2 of the case study includes these sections:

- A brief description of RMA (Section 2, page 5).
- The rationale for selecting it as a topic of study (Section 3, page 9).
- Research method and procedure (Section 4, page 17).
- Results (Section 5, page 23).
- Implications for those managing software technology transition and directions for future research (Section 6, page 53).

2. The phrase “technology transfer” is usually preferred, except within the DoD. For the purposes of this report, we consider “technology transfer,” “technology transition,” and “technology deployment” to be synonymous. In addition, we agree with Tornatzky & Fleischer [1990]: “Technology transfer, while a commonly used term, has a host of nuances, not the least of which is the image that technology is something that is physical, comes in large crates or on pallets, and gets literally moved from place to place.” On this basis, they “use the more inclusive and less encumbered notion of *deployment”* [p. 118; italics Tornatzky & Fleischer]; we prefer “technology transition.”

3. Pseudonym for the firm name. ComCo is a multinational firm in electronics and related businesses.

4. Pseudonym for the name of the site where we held our interviews.

The data used for Part 2 were derived from interviews with 10 members (affiliated with 2 departments, 3 projects, and one advanced technical solutions group) at one site in one large organization. All of these individuals had some knowledge of, and experience with, the use of RMA technology. Interview findings are discussed in terms of relevant themes including

- Roles and key players
- Infrastructure
- Innovative culture
- Technology attributes
- Concept of the whole product

2 Rate Monotonic Analysis

RMA helps software engineers who are designing, building, troubleshooting, and maintaining real-time systems to understand and predict the timing behavior of hard real-time systems to a degree not previously possible. Real-time systems are often seen as a “niche” within the software world, but they are a critical niche. Real-time software is often embedded in life-critical systems such as avionics and other transportation systems; medical systems such as equipment for patient monitoring, diagnosis, and treatment; and process control systems in chemical processing and nuclear power plants.

In the software embedded in such real-time systems, multiple tasks contend for the use of a finite amount of resource—for example, of the central processing unit (CPU) to perform work within deadlines. Typically, these tasks, such as monitoring altitude, monitoring cabin pressure, or controlling fuel injection level on an aircraft, are of differing priorities and require different amounts of CPU effort to complete their work. These tasks can occur both at regular intervals and irregularly. Real-time systems must complete critical tasks (for example, the lowering of the landing gear) by particular deadlines, or place the entire system at risk. Without the appropriate handling of schedules and priorities, a lower priority task of relatively long duration—for example, intermittent monitoring of passenger cabin pressure—can monopolize the CPU at the expense of a critical task.

Traditionally, the approach to calculating appropriate task mixes has been by trial and error. Programs are written to accomplish the required tasks, but until the tasks are integrated into a system and tested as a system, there is no way to know whether all tasks can be accomplished within the constraints of the available CPU. Most often deadlines are not met until after many iterations of integration testing, program revision, and more testing. For these reasons, real-time systems have earned the reputation of being expensive, behind schedule, risky, and difficult to maintain.

While the traditional approach is manageable for simple systems, especially when particular system designers have become expert in the successful design of task mixes, it is unmanageable for large systems. As large real-time systems are increasingly built from commercial “off-the-shelf” or separately contracted subsystems, handcrafting of scheduling is increasingly risky. Rate monotonic scheduling theory and its related analytical method, RMA, provide a scientific approach that can be used, before system integration, to determine whether schedule requirements can be met and how well, and under what conditions task completion can be guaranteed.[5] Because RMA solves a difficult problem early in the development of a real-time system, it is an important innovation with respect to technical work and its management—it can result in significant savings not only of CPU resources but potentially of both system development resources, including schedule, and operational resources such as hardware.

5. The early focus of RMA ensured that as long as CPU resource utilization was below a certain bound (generally a percentage of total possible resource), all the timing requirements would be met [Sha & Goodenough, 1990]. More recently, the focus of RMA has shifted to computing the worst-case response time and comparing it to the response time requirement.

2.1 Rationale and Background

Studying the transition of software technologies is difficult for a number of reasons. First, the process-intensive nature of software technologies means that there is a complex interaction between the social context and the technical content of the technology [Tornatzky & Fleischer, 1990]. More specifically, technology introduction affects not only the technical subsystem, but the managerial, strategic, human, and cultural subsystems as well [Morgan, 1986]. The challenge of studying transition in an organizational setting is well acknowledged [Nord & Tucker, 1987; Yin, 1984].

In the previous section we described the technical characteristics of RMA. However, it is equally important to attend to the implementation characteristics of a technology [Leonard-Barton, 1988a; Leonard-Barton, 1988b; Rogers, 1983; Tornatzky & Klein, 1982]. Three such characteristics—complexity (size), observability, and maturity—were critical factors in our decision to study RMA. We discuss each of these in turn. We then briefly describe other aspects of RMA's circumstances that led us to choose to study its transition process.

2.1.1 Size

Rogers [1983] defines complexity as "the degree to which an innovation is perceived as relatively difficult to understand and use" (p. 230). Another way to decompose the issue of complexity is to look at technologies in terms of their breadth of impact in an organization [Adler & Shenhar, 1990]. According to Adler & Shenhar, adopting a technology that will change skills and procedures typically requires only the space of weeks; in contrast, adopting a technology involving a change in either structure or strategy requires months of planning and implementation. When we selected RMA for study, based on descriptions from its developers, we believed it could be adopted by an individual engineer or small group within a matter of several weeks. We discovered that this was true but that RMA might also have an effect upon strategy as well as upon skills and procedures. When used more strategically—for example, as part of system redesign—it can be incorporated (with the assistance of experts) into software engineering processes over a period of several months. [6]

RMA requirements for effective application are limited. For example, while RMA does require engineers to reframe their understanding of scheduling issues to a more abstract level,[7] moderate training and help with initial practical application is required for people to be effective in using the technology. RMA can be adopted by an individual engineer as part of his or her approach to designing or analyzing systems; it can also be applied at almost any point in time in

6. Software technologies often require not only changes to organizational behavior and values, as in the case of software process improvement [a variant of total quality management (TQM)], but also changes to existing technology, as in the introduction of computer-assisted software engineering (CASE) tools. These changes typically occur *while* software managers and developers are attempting to continue business as usual. For more information, see Bouldin [1989] and Grady & Caswell [1987].

7. One RMARTS project member and former resident affiliate stated in an interview that over a period of time, his use of RMA had caused a shift in his view of architectures. He began to see an important distinction between "architectures" and "attributes of architectures." He noted that he began to look at "software performance in terms of preemption, computation, and blocking." (These are concepts used in RMA theory.)

system development or maintenance. RMARTS Project members recount how they are able to quickly demonstrate, in consulting and classroom settings, the utility of the approach. In this respect, we classify RMA as of relatively “small” size, at least in terms of usual application.

2.1.2 Observability

These same factors make RMA transition readily “observable” [Rogers,1983] within a reasonable period of time. RMA can be adopted incrementally: its adoption can range from informal application to an existing system by one engineer to application across an entire division as standard practice in designing new systems. In addition, because RMA is a technology without extensive “cultural” content (in contrast with a technology such as total quality management), we believe its transition process is less muddied by major shifts in attitude and belief systems.[8]

The size of the technology and its obervability are directly related to the design of the case study and the determined unit of analysis. See Section 4.1.2, *Materials and Procedure*, for further discussion of these issues.

2.1.3 Maturity

Finally, the maturity of RMA is important. Given the process-intensive nature of software technologies [Tornatzky & Fleischer, 1990], less mature technologies are likely to have poorly defined and unstable transition processes. The limited impact of RMA on the structure and work processes of the organization makes it somewhat easier to separate technical problems from problems in the transition approach. In fact, while RMA is not yet fully mature in the sense of a commercial whole product [Moore, 1991], RMA as an analytical method is no longer evolving rapidly.[9]

In addition to these implementation characteristics, we chose RMA because the technology was being developed at the SEI. This gave us ready access to subject matter experts and to their contacts, including the change agent at ComCo, Woodville, who eventually arranged for our interviews. Our technical informant, a former ComCo employee, added invaluable commentary on the interaction of ComCo culture and RMA technology.

8. Any technology has some cultural content, in the sense of requiring an adjustment in the user’s belief system and behavior. For example, RMA requires acceptance of logical concurrency, a shift for most software engineers and their managers, with some implications, albeit limited, for the structure and scheduling of their work. It does not, apparently, require restructuring of the process of software project management or of reward systems.

9. We believe this is why software tools that encapsulate and guide the use of the RMA method are now emerging.

3 Related Research

Research on technology adoption and implementation is best understood in a larger context, since the literature is not specific to one field. Rather, adoption and implementation are often associated with other topics, including technology assessment, technology transfer, business, and policy and management. The diffusion research tradition is also the property of many disciplines ranging from communication, education, marketing, information technology, anthropology, public health, rural sociology, and others [Rogers, 1983; Tornatzky et al, 1983].

Thus, adoption and implementation can be considered in terms of related topics and how various disciplines instantiate the diffusion of innovations, and also in terms of the genre of the inquiry (e.g., framework or reference model, case study, experience report). The scope of this technical report precludes a full literature review or bibliographic survey; rather, we suggest that related research on adoption and implementation can be usefully framed by the conceptual model below, on technology maturation (Figure 3-1).[10]

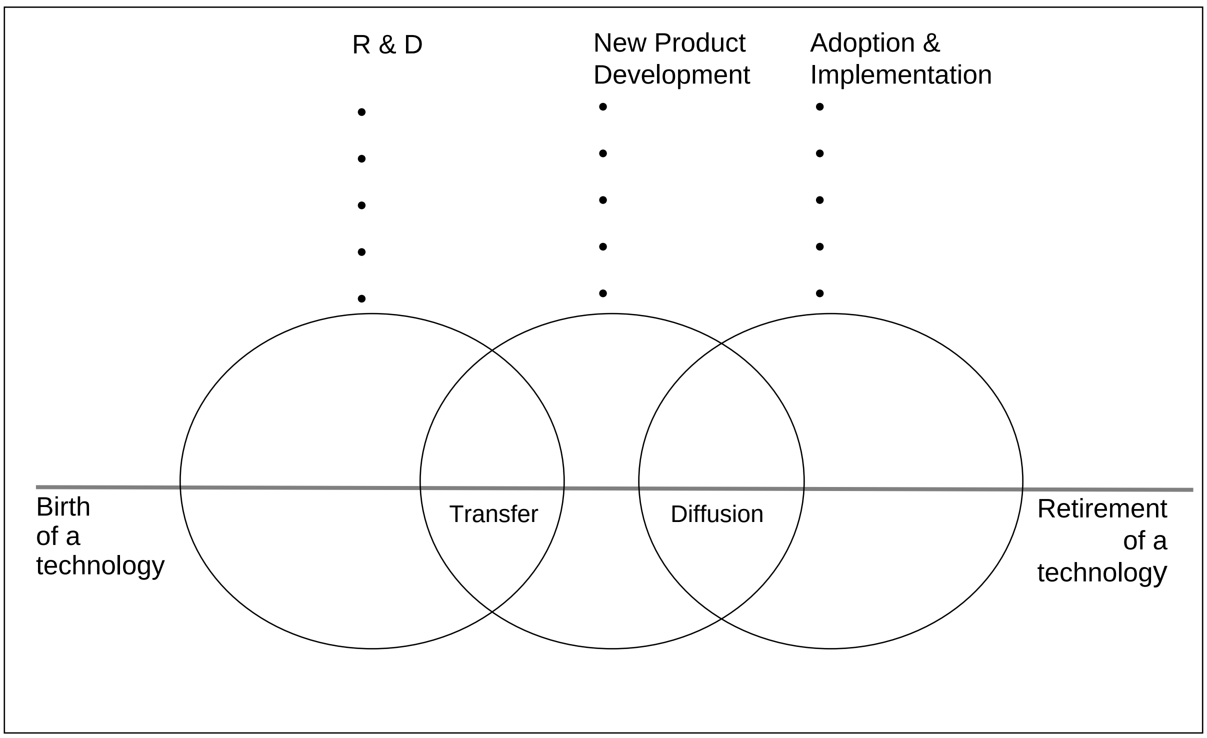

Figure 3-1: Technology Life Cycle

Technology transition occurs throughout technology development from the birth of a technology until its retirement. Technology that has been commercially developed and is in use in an

10. The technology maturation life cycle represents one part of a larger framework for software technology transition. For additional information, see: *A Conceptual Framework for Software Technology Transition* by P. Fowler and L. Levine, 1993, (CMU/SEI-93-TR-31) Pittsburgh: Software Engineering Institute, Carnegie Mellon University.

organization has most likely been transitioned at least twice, *between* communities respectively concerned with research and development (R&D), new product development, and adoption and implementation. In addition, the technology is transitioned as it progresses through its life cycle *within* each of these communities or businesses. The composite model represented here is composed of three interlocking life cycles.

In the following discussion, we concentrate on the literature that is specific to the processes of adoption and implementation.[11] This literature is then classified according to conceptual or theoretical models, case studies, and experience reports. We begin with conceptual models and meta-analyses, where we also address high-level studies of diffusion and transfer.

3.1 Conceptual Models and Meta-Analyses

Rogers' [1983] classic *Diffusion of Innovations* offers a useful point of departure. He defines implementation as follows:

> Implementation occurs when an individual (or other decision-making unit) puts an innovation to use. Until the implementation stage, the innovation-decision process has been strictly a mental exercise. But implementation involves overt behavior change, as the new idea is actually put into practice.

He asks,

> When does the implementation stage end? It may continue for a lengthy period of time, depending on the nature of the innovation. But eventually a point is reached at which the idea becomes an institutionalized and regularized part of the adopters' ongoing operations. The innovation finally loses its distinctive quality as the separate identity of the new idea disappears (pp. 174-175; italics Rogers).

Rogers is well recognized for his history of the diffusion tradition and specific treatments of adopter categories, the innovation decision process, and the attributes of innovations. His adopter population scheme analyzes the characteristics and preferences of innovators, early adopters, early and late majority segments, etc. Innovation-decision is that "process through which an individual (or other decision-making unit) passes from first knowledge of an innovation, to decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision" (p. 165). This model includes the stages of knowledge, persuasion, decision, implementation, and confirmation. Many of these concepts, including Roger's notion of the attributes of innovations, are not without limitations or critique; however, Rogers remains the most influential theorist in the diffusion tradition.

[11]. Adoption and implementation, or the introduction of a mature technology that is new to an organization, typically includes the following phases: needs assessment; selection of candidate products; evaluation of candidate products; introduction of selected product to management and to end users (including pilot use); gathering of feedback from management and users; implementation planning; implementation; product maintenance; and end user support [Fowler & Levine, 1993; Bouldin, 1989]. For descriptions of the phases associated with the R&D and the new product development life cycles, see Fowler & Levine, 1993.

Tornatzky & Klein's [1982] meta-analysis is primarily concerned with methodological issues in the study of innovation as reflected in the set of 75 studies they examine. Their list of “ideal innovation attribute studies” discusses principles in innovation research. In particular, they note that both adoption (which they define as a “yes/no” decision) and implementation must be treated as dependent variables. They suggest “...only measures of degree of implementation begin to capture the variability of post-adoption behavior” (p. 40). Tornatzky & Klein also assert that multiple innovation characteristics should be examined and that organizations as adopting agents should be studied as well as individual adopters.

Like Tornatzky & Klein, Downs & Mohr [1976] stress the need to study degree of implementation, noting that “...operationalizing innovation by the extent of implementation comes closer to capturing the variations in behavior that we really want to explain” (p. 709). Downs & Mohr point to a lack of coherence in diffusion research: “perhaps the most alarming characteristic of the body of empirical study of innovation is the extreme variance among its findings” (p. 700). They propose that “the most straightforward way of accounting for this empirical instability and theoretical confusion [in research on innovation] is to reject the notion that a unitary theory of innovation exists and postulate the existence of distinct types of innovations whose adoption can best be explained by a number of correspondingly distinct theories” (p. 701). Downs & Mohr, then, go on to define primary sources of instability: (1) variation among primary attributes, (2) interaction, (3) ecological inferences, and (4) varying operationalizations of innovation.

Damanpour’s [1991] meta analysis is concerned with examining innovativeness in organizations more generally. The study contains a brief but useful discussion of the literature describing organizational characteristics that support implementation. He holds that “organizations with diverse and differentiated task structures initiate more innovations, and those with formalized and centralized structures implement more innovations” (p. 562). Damanpour also provides a set of “organizational determinants”—for example, technical knowledge resources, managerial tenure, and slack resources—with definitions and references. (For a discussion of the role of resources in the acquisition and implementation of RMA, see Section 5.3.3.) Damanpour [1991] and Nord & Tucker [1987] note that organizations may typically adopt more than one innovation at a time. Tyre & Orlikowski [1993] argue that technological improvement is rarely steady and uninterrupted; rather, the process alternates between periods of intensive change and routine use. Their data show that “adaptation to new technologies often occurs in a ‘lumpy’ or episodic pattern” (p.13).

Tornatzky et al [1983] offer an early reference volume on innovation-process research. Their approach emphasizes organizational context, observing that many other texts are discipline- or technology-focused. In addition, the “key point which differentiates diffusion research from, say, innovativeness research or other innovation process models is that diffusion takes as its starting point the *innovation* rather than the *organization*” (p. 78; italics Tornatzky et al). These authors cover concepts, analytical themes, events from technology generation through implementation and dissemination, and strategies for managing innovation. Of special interest is the discussion of the user’s role in implementation, including the place of adaptation, modification, and reinvention. Also unusual is the closing treatment on government policy and innovation.

Tornatzky & Fleischer [1990] provide a section on the adoption and implementation of technology, and a chapter on implementation. The latter discusses the literature and attempts to integrate and synthesize an approach that may be likely to succeed. They present four perspectives on implementation: technocentric, sociocentric, conflict/bargaining, and systems design. The first focuses on technical detail at the expense of social context; the second focuses on social detail at the expense of technical issues; and the third concentrates on political relationships and power. The fourth, systems design, draws from the first three, emphasizing "designing" the technological system to meet the requirements of the situation, to integrate the system with the larger technical system, and to maintain the system. In addition, Tornatzky & Fleischer's emphasis on maintenance is atypical: it is as much an error to ignore maintenance issues in implementation as it has been to ignore implementation issues in adoption.

Several books are noteworthy for their exploration of the relationships between organizations and innovation. Kanter [1993] is attuned to modern management's need to employ mechanisms to foster and facilitate innovation in the corporation. She suggests the concept of the "parallel participative organization" as an innovation and change tool. Kanter maintains that "it is possible for a 'mechanistic' production hierarchy and an 'organic' participative organization to exist side by side, carrying out different but complementary kinds of tasks. These two organization types are not necessarily opposites, but different mechanisms for involving people in organizational tasks" (p. 204).

Morgan [1986] offers a comprehensive description of organizations as machines, organisms, brains, cultures, political forums, etc. Like Tornatzky & Fleischer, he attends to interacting organizational subsystems. In his view, technical change cannot occur independently of change in operations, business strategy, structure, and culture.

Allen [1986] focuses on the communication system in managing the flow of technology. He provides particular insight into communication among scientists and engineers, especially as he considers the gatekeeping function within a technical organization. A gatekeeper, filtering information he or she gathers from external sources, can leverage or block vital technology.

3.2 Case Studies

Nord & Tucker [1987] examine the implementation of NOW (interest-bearing checking) accounts in banks and savings and loan associations. These accounts are more organizational than technical innovations; however, they are also "process" innovations affecting differing levels and types of personnel.

Nord & Tucker offer a historical perspective on implementation in organizational contexts and remark on the lack of a theoretical basis for study. They discuss a conceptual framework developed in conjunction with their research. The framework includes: definitions of innovation and implementation, effects of innovation design on implementation (including the relativity of the concepts of routine and radical), effects of organization on implementation, and interpersonal processes in implementation. Organizational effects involve the impact of organization structure (e.g., mechanistic or organic) on innovation, temporary structures that facilitate implementation, centralization and formalization, history, size, culture, organizational learning, and interaction with environment.

Leonard-Barton [1988a;1988b;1990] studies the implementation of software innovations from within the innovation research tradition. Especially relevant is her treatment of *reinvention* in her work on mutual adaptation [1988a]. She contends that "initial implementation of a new technology is an extension of the invention process. That is, instead of the predictable realization of a preprogrammed plan, implementation is a dynamic process of mutual adaptation between the technology and its environment" (p. 252). She describes that adaptation is necessary in response to three kinds of misalignment between the technology and (1) technical requirements, (2) the system through which the technology is delivered to users, and (3) user organization performance criteria. She also discusses small-cycle adaptations and large-cycle adaptations, where the former require a relatively minor adjustment such as a new software module, and the latter may send the designers back to square one. Leonard-Barton elaborates on notions of degree of implementation [Leonard-Barton, 1988a; Tornatzky & Fleischer, 1990].

In a similar vein, Leonard-Barton [1988b] asserts that implementation can be managed well or not, depending upon how carefully factors such as implementation characteristics and organizational characteristics are taken into account. Implementation characteristics include transferability (preparedness and communicability), implementation complexity (organizational span and organizational scope), and divisibility (modularization, individualization). Although these characteristics "do not directly determine success or failure of implementation, they create conditions that must be skillfully managed to achieve success" (p. 627). Also, on the topic of degree of implementation, Zmud & Apple [1992] assert that there are two components of incorporation: routinization, which they claim has been the subject of prior studies, and infusion: "the extent to which the full potential of the innovation has been embedded within an organization's operational or managerial work systems" (p.148). In their case study of the use of supermarket scanner technology, the authors explore the relationship between routinization and infusion, and suggest measures for both.

Orlikowski [1993] studied two organizations' experiences with the adoption and use of CASE tools over time. She pays specific attention to how organizations experience incremental and radical change, and she builds a framework to represent these organizational issues in tool adoption. Of critical importance in understanding both experiences were the change process, organizational context, and intentions and actions of key players associated with adoption and use. Orlikowski observes: "where IS [information systems] managers introduce CASE tools to improve the existing process of systems development through increasing productivity or cutting costs, organizations will likely experience *process variations*. Where the CASE tools are used to improve the product delivered to clients, without significantly altering its nature, ownership, or delivery arrangements, organizations will likely experience *product variations*" (p. 331; italics Orlikowski). She then goes on to make similar distinctions between *process* and *product reorientation* in the case of radical change processes.

Leonard-Barton [1990] is also closely focused on intraorganizational themes. She distinguishes between types of transfer situations, drawing evidence gathered from over fifty cases related to the use of productivity- or production-enhancing tools. Employing her earlier distinction between innovation span (number of users) and innovation scope (number of applications), she represents four modes: simple, complex, point-to-point, and diffusion. "The fewer the user/receivers per technology application, the closer the situation is to a pure point-to-point transfer, the theoretical extreme of which would be the diffusion of a custom made tool for one user. At the other extreme would be diffusion of a generic tool to thousands of users" (p. 46). Leonard-Barton suggests that researchers' disciplinary backgrounds have shaped their concern with either point-to-point or diffusion, arguing there is much for practitioners and academics to gain by understanding the differences and commonalities of these modes.

Souder, Nashar, & Padmanabhan's [1990] discussion of best technology transfer practices derives from examining forty successful technology transfer programs at twenty organizations. Thirty-seven practices were identified and categorized according to how important they were in four different stages of technology transfer: prospecting, developing, trial, and adoption. "Adoption implies strong emotional and financial commitments to routine use" (p. 5). While other researchers refer to such characteristics, Souder goes further by ranking them from "optional" to "essential" and by statistically determining relationships among the seven types of practices: analytical, facilities, pro-actions, people-roles, conditions, technology quality, and organization. The seven types of best practices were found to "interrelate in cause-effect chains." Souder argues that "collectively, these results were shown to comprise a benchmark model that managers can consult to assist them in developing more effective technology-transfer strategies" (p.13).

3.3 Experience Reports

From the literature on software engineering and information technology, there is a set of materials best categorized as experience reports. Generally, the authors are not familiar with innovation literature but have considerable practical experience which they describe and from which they extrapolate prescriptive advice. Bouldin's [1989] book *Agents of Change: Managing the Introduction of Automated Tools* is essentially a guidebook on implementing computer assisted software engineering (CASE) tools across a large organization. It is based on Bouldin's experience as a software manager with those responsibilities. Grady & Caswell's [1987] *Software Metrics: Establishing a Company-Wide Program* is a similar treatment based on their experience at Hewlett Packard. Ackerman, Fowler & Ebenau [1983] have written about implementing software inspections in large software organizations. Two more broadly targeted treatments are Pressman's [1988], addressing the implementation of a set of software practices and technologies in support of software engineering, and Eason's [1988], on implementing information technology systems within end-user organizations. Strauss & Ebenau [1994] describe implementation strategies and guidance for the adoption of formal software inspections.

Together, such reports offer a robust composite of implementation issues particular to software organizations. While these lessons are not derived by means of empirical research, they reflect the perceptions of a number of software practitioners with extensive experience. Key concerns include forms of resistance and conjecture regarding its origin, management issues regarding cost and time to implement, and attitude toward the implementation of different software technology types.

4 Method

4.1 Design

In empirical research, it is conventional to talk about triangulation and to design studies that use converging methods and measures to investigate a question or hypothesis. Triangulating is one way to insure reliable data collection and reduce threats of invalidity. The concept is particularly suggestive for research on technology transition. A complete understanding of technology transition requires that one pay attention to multiple units of analysis, including the technical, institutional, and cultural grounds for the adoption and implementation of innovations. For this reason, the case study of the transition of RMA was conceived of in two parts. As we have explained, Part 1 was concerned with the analysis of transition activities according to phases of a technology maturation life cycle. Part 2 examines the adoption and implementation of RMA at one site in one large organization. Together, the two parts offer a robust picture of the transition of RMA, allowing us to attend to development and user perspectives: to technology *push* and technology *pull*. The more technical explanation of how the (two-part) investigation of RMA can be seen in the larger context of case study design follows.

The full study can be described as an embedded single case design [Yin, 1984]. In simple terms, the case study is about the transition of RMA, and the study involves several levels of analysis. The main unit was the technology transition effort as a whole; the two smaller subunits were (Part 1) RMARTS Project transition activities and (Part 2) a subset of adopters' and users' perspectives on the technology. For Part 1 of the investigation, a combination of data collection techniques was used, ranging from analysis of historical documents (including plans, reports, and statements) to informal data collection through the researchers' attendance at RMARTS meetings and interviews conducted with RMARTS staff. The data collection for Part 2 included interviews with 10 members at one site in one large multinational organization, henceforward referred to as ComCo, Woodville. The following subsections, *Subjects* (4.1.1) and *Materials and Procedure* (4.1.2), outline these aspects of the investigation, including the interview schedule and the procedure for reviewing the findings.

This case study on the transition of RMA is best described as enlightening with respect to our ability to observe and analyze a situation not previously accessible to scientific investigation. In this context, "the case is therefore worth conducting because the descriptive information alone will be revelatory" [Yin, 1984, p. 43]. To date, the transition of RMA technology has not been the subject of research.[12] Nor have software developer perspectives on transition activities and user perspectives on adoption and implementation been juxtaposed in one case study. In this regard, we break new ground.

As is common with single (embedded and holistic) case studies, we cannot extend our observations about RMA to other technologies and other technical projects. Emerging theory about

12. For a recent experience report, see: S.J. Ignace, R.L. Sedlmeyer, & D.J. Thuente [1994]. Integrating rate-monotonic analysis into real-time software development. In L. Levine (Ed.), *Diffusion, Transfer and Implementation of Information Technology* (A-45) (pp. 257-274). Amsterdam: Elsevier Science B.V. (North-Holland).

software technology transition must be tested through replication of the findings in a second or third technology case, where the theory has hypothesized that the same results should occur. Such replication logic (attending to both technology and organizational context) plays a key role in case study research and in experimentation, allowing one to eventually establish "external validity": the ability to generalize beyond the specific instance [Yin, 1984; Chadwick, Bahr & Albrecht, 1984].

4.1.1 Subjects

The data used for the RMA case study and on which this report is based were derived from interviews with 10 members of one large organization. These individuals were affiliated with 2 departments, 3 projects, and one advanced technical solutions group, and all of these individuals had some knowledge of, and experience with, the use of RMA technology. Included in the subjects is the change agent (DV) who served as our host, and whom we interviewed one month earlier.

Of the10 interviewees, 3 were managers, 6 were technical staff, and one was a distinguished fellow of the organization. Nine had a minimum of 9 years of experience and had spent their entire careers at this organization, and 3 had more than 20 years of experience. One person had been an employee for only 3 months; however, he had 10 years of experience at another similar organization. All but one of these individuals were considered senior personnel; that is, they were accomplished software developers, with extensive knowledge of the application domains in which they worked.

We interviewed the subjects about their experience with RMA. All of the projects that the interviewees discussed concerned software for real-time embedded systems, but the projects varied in nature. The technical people described their experiences with RMA primarily on four specific software projects that included

- A system supporting artificial intelligence (AI) applications.
- An avionics system upgrade.
- A flight simulator.
- An optical character recognition (OCR) system.

The two software development managers described experience with RMA in more general terms. The manager of the advanced technical solutions group described how her group introduced RMA across Woodville and how she supported her staff (including the change agent) in their work.

4.1.2 Materials and Procedure

In March 1993, the first interview was conducted with (whom we call) DV, the primary change agent for RMA. At that time, DV described his experiences helping software projects (across the site) to apply the technology. At the preliminary meeting and at subsequent interviews, the researchers were accompanied by a technical informant (an SEI employee) who was formerly a senior engineer at ComCo.[13] The informant was enlisted to help us with clarification of findings from a technical perspective, as well as with information about the management processes and the culture of the organization.

The preliminary meeting, which lasted about one hour, was held to confirm ComCo's willingness to participate in the interview study. After the meeting, we reconsidered assumptions about ComCo, Woodville's adoption process and the appropriate unit of analysis for study. For example, we had anticipated a classic diffusion process, where DV facilitated the introduction of RMA within each project, at a specific time, by working with and educating members of the project's technical staff in the use of RMA. The change agent explained that this was not the case, and that for each project, one or two senior personnel had applied RMA somewhat differently and as they perceived the need. We came to see that the nature of the technology in combination with its product immaturity meant that site-level support was required for project-level use.[14] On that basis, we reasoned that the appropriate unit of analysis was not the project's adoption but rather the individual's experience with RMA. Thus, as a result of the preliminary meeting, we requested that subsequent interviews be with individuals who were responsible for applying RMA in one or more projects. One month later, in April 1993, we visited the organization, once again accompanied by our technical informant.

In addition to collecting basic demographic information, such as job title, job description, and number of years in the organization, the interview schedule consisted of 14 open-ended questions (see Appendix). We were particularly interested in how the subjects became aware of RMA, when they realized RMA was relevant to their work, and when they decided to use RMA. We were also interested in issues surrounding ease of use, observability, trial use, and roles played by interviewees in the adoption process. Subjects were encouraged to provide additional information that they thought was pertinent and to respond to, or deviate from, the interview questions as they saw fit. In this respect the interview schedule was used as a guide to ensure that certain issues we saw as relevant were raised or identified.

We met with some subjects individually and with others, when they were from the same project, in a small group. A total of seven interviews were conducted on one day, with each interview lasting approximately one hour. The procedure was as follows: initially, we introduced ourselves to the interviewee/s. We explained that we were completing a two-part case study on RMA and that our goal was to understand their experiences with the introduction and use of RMA at their organization. We noted that this was part of a larger effort to understand the processes of adoption and implementation of software technologies in organizational settings. In addition, we indicated that we were interested in improving transition success for software technologies.

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13. In addition, in Part 1 of the case study, we conducted roughly five hours of interviews, over three sessions, with our technical informant. He provided considerable background on earlier events related to RMA at ComCo.

14. Early on, we anticipated being able to observe a full cycle of adoption within at least one project and perhaps partial cycles within a few others. Subsequently, we considered a number of factors that related to why it was inappropriate to study RMA adoption at the level of the project. These factors included the size of some projects, which was quite large, and their long life; the range of application for RMA so that the technology might be applied differently over time and over long intervals; and finally, the fact that packaged products and services did not exist for the purpose of introducing RMA to the projects in a replicable manner.

The subjects consented to participate in this effort given the following conditions:

1. Non-attribution of organization, project, or individual.
2. Right of the subjects and appropriate other personnel to review reports for accuracy before publication.
3. Willingness to be available to answer further questions, if necessary.

Because we were studying a technology that SEI people had worked on and advocated, we were aware that subjects might have a tendency to tell us what they thought we wanted to hear. We reminded them it was important to be as candid and critical as necessary to accurately reflect their experience.

4.1.3 Data Analysis

We elected not to audiotape the interviews because we felt that doing so would be intrusive; instead, the three of us took extensive notes during the interviews. We attempted to record as much information as possible, verbatim, in the respondents' own words.

Our procedure for reviewing the interview data included the following:

- The researchers and the technical informant discussed the interviews immediately following and, together, documented their observations.
- The researchers completed a high-level review of the interview data, noting critical issues and patterns.
- The researchers and technical informant performed a close reading of the data to corroborate findings and clarify discrepancies; this process involved multiple working meetings where the researchers took secondary notes on the informant's comments.
- The researchers coded the data according to seven key themes (see below).
- The technical informant offered necessary elaborations on the themes and on issues related to the technology and the culture of the organization; these discussions were audiotaped and transcribed.

In the data analysis, seven themes related to the adoption and implementation of RMA emerged. These took the form of issues clustered under the following:

1. Roles and key players
2. Infrastructure
3. Innovative culture
4. Innovation-decision process
5. Technology "use" and the attributes of innovations
6. Codiffusion
7. The concept of the whole product

There were two parts to this phase of coding. Initially, we derived the themes from the data; subsequently, we reviewed the data to determine if the themes or clusters failed to account for other critical aspects related to the adoption and implementation of RMA at ComCo.

In the following *Results* section we discuss each of the themes, with two exceptions. Because we view the concept of the whole product as an integrating theme, we treat it in the *Implications* section. Also, we discuss the theme of codiffusion in *Implications*, where we consider its relevance for developers and managers of third-generation R&D.

5 Results

When we first contacted ComCo, Woodville, we were interested in examining the adoption process within a software project (typically an organizational unit of a few to several dozen people, all working together to develop or enhance a system or product). We had assumed we would explore how RMA technology was diffused and applied at that level, but we discovered that this was possible only to a limited extent. The interviewees reflected on their past experience with RMA: on previous projects and on the preparation of proposals. In addition, they discussed their current experiences, including their personal assessments of RMA. From their comments, it was clear that almost all had depended on the change agent (DV) for guidance in the initial application of RMA technology. For example, one of the managers had asked the change agent to brief his project personnel and determine if RMA was suitable. In another case, the change agent had approached a technical person to try to arrange a pilot use of RMA, for which there was special funding. In all cases, the change agent was known and trusted by project members, and played a significant role in helping them to begin using RMA.[15] The change agent was a site-level resource, loaned to projects working with RMA.

Once we discovered that the adoption and implementation process was not self-contained at the level of the project, we began to wonder how the technology had actually come to be used. Application of RMA had occurred at the project level, but assistance and support for implementation had come from the site level. In turn, the latter observation led us to consider the nature of the relationship between site-level support and the concept of the whole product. We hypothesized that ComCo, Woodville was successful in adopting RMA because of how they had compensated for the lack of a whole product. Evidence for this grew as we considered a number of themes that emerged out of the data:

- The roles taken by key players in the adoption of RMA.
- An infrastructure within ComCo, Woodville that supported software technology adoption.
- ComCo's innovative culture.
- The attributes of RMA as an innovation.
- The codiffusion of RMA with the Ada programming language.

Each of these themes is discussed in one of the following sections.

15. Another senior technical person, DL, with a corporate-level assignment, was a strong champion. He provided, either through the seminar or through personal contact, information on RMA to five of the interviewees. The change agent provided ongoing technical assistance with practical application.

5.1 Roles: Key Players in RMA Adoption

A number of people played key roles in RMA adoption at ComCo, Woodville. Most of the individuals we interviewed were change participants; in addition, we spoke with the change agent (who also assumed a gatekeeper role), one of the sponsors, and an individual who can be described as an innovator.[16] We learned about other individuals who were involved in the introduction of RMA from the interviewees. The roles we identified were consistent with descriptions by Rogers [1983], Conner & Patterson [1982], and Fiman [1989]. Table 1 identifies these roles and the key players (referenced by initials only) who assumed these roles at ComCo.

Table 1: Roles and Key Players

Roles	Key Players
Gatekeeper	DL, DV
Champion	DL
Change agent / Early adopter	DV
Sponsor (initiating)	CK
Sponsor (sustaining)	CK, LH, RB, AMB
Change participant	All
Innovator	PK

The *gatekeeper* provides access to information from outside the group or organization of which she or he is a part [Allen, 1977]. Five of the interviewees mentioned the champion (DL), who now worked largely at the corporate level, as being responsible for their initial exposure to RMA.[17] The distinguished senior engineer (PK) had the earliest contact with the champion, sometime in 1982 or 1983. About ten years ago, he told us, the gatekeeper/champion had provided him with the Liu & Layland paper [1973].[18] Senior software engineer TK remarked that he first heard of RMA from the gatekeeper/champion in 1985-86 in "an academic-flavored discussion." In 1986-87, software engineer BH had contact with the gatekeeper during a troubleshooting activity. The manager of the advanced technical solutions group (LH) noted that the gatekeeper "came to speak with them" (to her and her group of software developers). Software engineer JO had more recently had contact with the gatekeeper/champion, at a conference tutorial in December 1990.

DV, whom we characterize below as the primary change agent, acted in part as a gatekeeper. He was responsible for introducing the other four interviewees to RMA during 1987-1990. Two

16. Rogers [1983] describes five categories of "adopter populations." These include innovator, early adopter, early majority, late majority, and laggard. A given population typically follows a bell curve distribution.

17. DL, champion and gatekeeper, was operating at the corporate level at the time of our interviews, and so he was not interviewed.

18. Carnegie Mellon University faculty evolved the original [Liu & Layland, 1973] rate monotonic scheduling theory from which RMA was derived.

of these four were engineers, and information on RMA was provided in the context of a trial use of RMA (1990-GP) and a new application of it (1989-SN). In the latter case the engineer said he “relied on DV to get him started.” The remaining two interviewees were managers and had been introduced to RMA in conjunction with a proposal (AMB) for a time-critical application, and also in conjunction with a research contract (RB) for early work on RMS.

Gatekeeping[19] is not unusual, according to Allen [1977], who describes the function as follows:

> There will always be some people who, for various reasons, tend to become more acquainted with information sources outside their immediate community. They either read more extensively than most or develop personal contacts with outsiders. A large proportion of these people in turn attract colleagues from within the community who turn to them for information and advice. (p. 150).

While the gatekeeper typically provides general information, others assume roles associated with the process of introducing technological change and the tasks involved in applying a new technology.

The *champion* advocates the adoption of a new technology and proselytizes on its behalf at every opportunity. DL, described earlier as a gatekeeper, also acted as a champion. Our technical informant told us that DL continues to act as champion and gatekeeper, now mainly at the corporate level, whereas previously he had done so at the level of the site as well.

The *change agent* is the project manager of the change effort—he or she plans the tasks in the effort and then leads, tracks, and reports on the effort to management sponsors and participants. The change agent must be technically expert and perceived by management as highly reliable. The change agent for RMA (DV) was an experienced engineer, convinced of the importance of RMA, and adept at applying the technology in a range of situations. DV had spent his entire professional career at ComCo and was familiar with the nature of technical work and contracts executed at Woodville. He was an expert in real-time systems and, at the time of the interviews, was assigned to the advanced technical solutions group.[20] In addition, the change agent was active in an external professional working group, which exposed him to outside perspectives and technical information. He was then able to bring these perspectives back and share information, credibly, at Woodville.[21]

The change agent was well received in his role—several interviewees commented that they had first had contact with RMA through the change agent or had worked with him to apply RMA. Our technical informant felt that the number and organizational level of the interviewees

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19. Gatekeepers are often opinion leaders, people whose advice may be sought with respect to particular technologies.

20. According to the manager of the advanced technical solutions group (LH), their job was “to be a source of help in resolving development problems.”

21. This supports Rogers’ [1983] concepts of *homophily* and *heterophily*, where the successful change agent is enough like the constituency she or he works with to have credibility with them, but enough unlike them to be a conveyor of information from outside the social system.

who made themselves readily available to us was an indication of their respect for the change agent.

The *initiating sponsor*, usually a highly placed executive, sanctions the adoption and any related changes and provides strategic leadership, support for policy changes, and resources. Without a sponsor, technological change is limited to whatever can be accommodated with little or no change in budget, schedule, etc. Each group of engineers interviewed mentioned the importance of one senior manager (CK) at Woodville, who was responsible for all software work at the site. He was identified as a sponsor for RMA when it was included in one project proposal; here he acted as an initiating sponsor. In another case, CK was mentioned as one reason why Woodville was "ahead of the state of the art in software." In addition to his role as initiating sponsor, CK acted as a *sustaining sponsor*, providing ongoing resources and leadership for software technology more generally.

The manager of the advanced technical solutions group (LH) acted as a sustaining sponsor with respect to RMA. The change agent (DV), we recall, was a member of her group. LH supported him by maintaining the group (budget and credibility) and providing an organizational home. She also offered support by facilitating lunchtime seminars and planning to produce a videotape.[22]

Finally, both second-level managers (RB and AMB) acted as sustaining sponsors. RB managed software development for a varied group of programs developing real-time systems for defense and non-defense government applications, including optical character recognition (OCR). He supported the introduction and use of RMA on his programs because he saw the value of new technology to ComCo's competitive position. His sponsorship was not unconditional, however; he wanted to avoid the risks that might, for example, come from retrofitting RMA to systems built largely on pre-existing software. He admitted that this "might be a short-term view."

AMB oversaw a number of software development programs, primarily in the avionics area, and supported the application for RMA in design as well as system evolution work. She said that for one program her department is working on, she "doesn't think they have an alternative" to using RMA; "the program is so complex, they can't afford not to know what's happening in the box." She said they planned to use RMA through each phase but primarily "up front to lay out architecture and tasking." AMB was the sole manager who mentioned reading "lessons learned" papers. She also read research papers on RMA.

The remaining six interviewees were participants in the adoption of RMA. Indeed, anyone affected by the change is a *change participant;* this role is prerequisite to and subsumes all the others. All but one of these people were attempting, with the help of the change agent, to apply RMA in a manner consistent with the intent of its inventors. The exception, the distinguished senior engineer (PK), held a position in which his job was to "do whatever you think is appro-

22. The advanced technical solutions group sponsored a series of lunchtime seminars. One of these included a talk where the change agent (DV) and a colleague presented information about RMA. LH was considering putting this talk on video.

priate," and he was working on an experimental system applying artificial intelligence technology. He had adopted RMA very early (1982), after minimal exposure—reading a research paper—and with no assistance. In addition, he had used RMA in an unanticipated manner.[23] In this respect, he plays the role of an *innovator* [Rogers, 1983; Tornatzky et al, 1983], transforming a technology into something new.

While the actions taken by people in these roles supported RMA adoption, there are other factors that also made a strong contribution. Next, we examine how the existing organizational infrastructure supported software technology transition in general and RMA more specifically.

5.2 Infrastructure

ComCo, Woodville had a number of features—particularly, project functions—that aided the adoption and application of RMA. Collectively these features compose an infrastructure—the structures within the organization and the formal and informal practices that support the process of software technology transition. In this section, we describe those elements of the infrastructure that supported the transition of RMA and were mentioned by the interviewees. Some of the elements we discovered were fairly conventional, whereas others were atypical. For example, we were less surprised by the existence of a technology research group to track and evaluate new technology, internal research and development (IR&D) work, or mechanisms for training and education. More unusual were the lifetime employment policy, parallel career ladder for managers and technical professionals, a site-level software executive committed to the use of new software technologies, and a proposal process for new business that allowed for the opportunity to introduce new technologies at a convenient time. We will discuss each of these; the more conventional structures first, followed by the more unusual elements. Last, we look at the site-level change agent, who belonged to the advanced technical solutions group. Since he and his manager played a key role in support of the introduction of RMA, we describe their activities in greater detail.

5.2.1 Technology Research Group

The technology research group helps to keep ComCo, Woodville technologically competitive by tracking software research and screening it for application within the site. We did not interview the manager for the group, although we spoke with him briefly.[24] Three interviewees (all managers) mentioned the technology research group and their interactions with it. Both software development managers saw the research group as a resource. AMB, (avionics system upgrade) noted that she first heard about RMA from the group in 1987-88, when she discussed

23. Tornatzky et al [1983] make the following distinction: "Where this process [organizational innovation] begins with a general idea which becomes different things in practice, the term *adaptation* is often used. Where a well-specified innovation, receives minor changes, *modification* is sometimes found. Where a well-specified innovation undergoes major change, the term *reinvention* has some currency" (p. 136; italics Tornatzky et al). PK's use includes elements of "benign adaptation" and reinvention.

24. We had asked our host, the change agent (DV), to set up interviews with project members who had adopted RMA and with his own manager (LH). Also, DV arranged a technical interchange meeting for us on software technology transfer with a member of the technology research group.

preparation of a proposal for a time-critical[25] application. RB (OCR project) referred to the technology research group when he discussed his perception of the relevance of RMA to his work (during the mid 1980s). Later, he characterized the group as “PhDs looking at technologies that people perceive are applicable to development work they are doing.” He added: “Depending on the contract, I try to draw from that knowledge.” The third interviewee who mentioned the research group was the manager of the advanced technical solutions group (LH). She referred to the technology research group as a “sister group.”

Previously, the technology research group had provided an organizational home for the (corporate) champion of RMA (DL), and for the change agent (DV). DV transferred to the advanced technical solutions group in 1990, with “the Ada and real-time [system] people.” Our technical informant told us that the site-level software manager (CK) had used the champion (DL) as a high-level troubleshooter. The champion, in turn, used these taskings as opportunities to apply RMA in solving problems and to teach others about using it.

5.2.2 Internal Research and Development

Internal research and development (IR&D) is speculative work performed by government contractors. According to our informant, if, once completed, IR&D meets with government approval, the contractor firm is reimbursed for a percentage of the total cost. One second-level manager, AMB, said “lots of IR&D work helps groups like DARPA[26] explore technologies of the future: can the technology be applied to a real task?” She noted that, using IR&D funding, her organization had tried “prototyping, object-oriented programming, an integrated development environment [CASE-like tools], and massively parallel processing.” The advanced technical solutions group manager (LH) said she “has a variety of projects—usually prototypes or something new,” that she is trying to introduce to the site. She decides what the solutions group should work on based on a number of factors, including what technologies are current, what technologies Headquarters is interested in, what the hardware people are doing (“it’s important to keep up with the hardware guys”), and what IR&D tasks can be funded.

5.2.3 Training and Education in the Application of RMA

Various forms of training and education were readily available to personnel at ComCo, Woodville. For example, one second-level manager referred to an “extensive education program” and “strong training internally” in describing how design techniques for object-oriented software were introduced. Our informant described a corporate training organization that provided classroom training as well as video broadcasts for executives. The advanced technical solutions group also sponsored informal educational seminars for technical professionals and developed videotapes for individual use. We consider all of these mechanisms and distribution channels as part of infrastructure because they were not only established for RMA; rather, such forms of training and education existed for any new technology. Here, we sketch the in-

25. “Time-critical” means that the time taken to execute system functions is extremely limited; for example, a function to sense a change of altitude or orientation in an aircraft to correct course.

26. Defense Advanced Projects Research Agency, an organization within the U. S. Department of Defense that funds research, now has a new name, Advanced Projects Research Agency (ARPA).

terviewees' comments on how the vehicles were used to provide information and skills in the application of RMA.

Our informant told us that the ComCo corporate training organization generally developed its own courses. In the case of RMA, corporate training had funded part of the informant's year (1988-89) as a resident affiliate at the Software Engineering Institute and had requested that he develop a course on RMA in conjunction with his stay. He and other members of the SEI Rate Monotonic Analysis for Real-Time Systems (RMARTS) Project prepared a tutorial for delivery at three different technical conferences.[27] This tutorial was then adapted for use at ComCo and team-taught, variously, by the champion (DL), the change agent (DV), and our informant (TR). Only two of the interviewees mentioned attending a tutorial on RMA at external conferences; and no one mentioned attending ComCo's related corporate course. We can only speculate about why this was so. However, we suspect that since all of the interviewees had a history of working with the change agent (DV), they were much more likely to hear about RMA directly from him.

Later, the champion (DL) worked with corporate training to produce a three-hour version of the course for an educational broadcast to middle and senior management. He eventually joined the corporate training organization and, at the time of the interviews, we learned that he was continuing to teach the full course. Apparently, there was need for alternative means of communication about RMA: LH, manager of the advanced technical solutions group, said that the change agent, DV, "gets spread thin. I'm thinking about putting his talk on video."[28]

5.2.4 A "Lifetime" Employment Policy: Tenure and Trust Among Employees

Personnel policies at ComCo resulted in de facto "lifetime" employment. All but one of the interviewees, a new employee who had been at ComCo only 3 months, had not worked elsewhere. Excluding the new employee, the average tenure of the interviewees was 17 years, with a range of 9 to 26 years. One individual was a second generation ComCo employee. The informant corroborated our conclusion that a high level of trust existed among the interviewees, all of whom knew each other. He said most would have "grown up together at ComCo."[29]

The issue of trust was evident in considering how the change agent and the champion were viewed as reliable and credible sources of information about RMA (with only one individual learning about RMA from an outside source). Our informant summarized as such: prospective users of any new technology asked three questions of its proponents:

27. TriAda; IEEE Real-Time Systems Symposium; and the SEI Software Engineering Symposium.

28. This talk was one in a series of lunchtime seminars sponsored by the solutions group. The change agent, DV, and a colleague presented information about RMA.

29. Personal interviews with TR, October and November 1991.

1. Will it help me?
2. Have you used it?
3. Will you help me?

If the answers to all three questions were "yes," then people were convinced to use the technology, in this instance RMA. More "objective" proof of its worth, such as factual measures of improved quality and productivity, were not as important as the judgment and competence of their long-time peers. We suspect that these "objective" measures would play a more significant role when dealing with outsiders, for example, if a vendor suppled the technology. Then, a different credibility check might occur.

5.2.5 Parallel Technical/Managerial Promotion Paths

ComCo has parallel career paths for managers and technical personnel: managers progress through one set of job classifications, and technical personnel through a different but equivalent set. Our informant explained that because of this, even though very senior technical people may report administratively to lower level managers, they interact freely and directly with senior managers. As noted, our informant told us that the senior software manager at Woodville, CK—who was also the initiating and sustaining sponsor—used the champion, DL, for technical troubleshooting while he (DL) reported to the manager of the research group. Our informant felt that the senior manager, CK, sought the champion's judgment based on experience and expertise rather than detailed technical information. The senior manager communicated directly with the champion, avoiding the filtering by intervening levels that might occur in a single-ladder system.

Another effect of the dual ladder is that new technology receives direct consideration at multiple levels of the organization. Senior technical people influenced the early use of immature technologies. Both of the second-level managers (AMB and RB) expressed interest in RMA and other new technologies. RB (OCR project) said, "I'm impatient RMA is not getting implemented faster. I think it is a key technology we should be embracing. But I'm part of the problem because I'm not mandating it. I can advocate but not dictate." Thus, technical personnel were able to take the lead in choosing to apply new technologies; and the existence of technical staff at higher ranks increased the number of organizational "pores" through which technologies could flow into ComCo (Kanter, 1983; pp. 204-205, 359).

5.2.6 Site-Level Software Executive

In Section 5.1, the discussion of roles, we commented on the importance of an initiating sponsor, usually a senior executive. Any senior executive can serve as a sponsor; however, when the sponsorship role is institutionalized, as was the case of the executive responsible for software (as a separate organization) at Woodville, the role and function must also be considered as infrastructure. At the time of the interviews, this executive (CK) had transferred, and the position no longer existed. Nonetheless, according to two software engineers (GP and SN), CK played a significant role in supporting RMA adoption early on; they felt the presence of an executive for software was critical to Woodville's being "ahead of the state of the art in software." CK was mentioned in conjunction with Woodville's "good process" for software along with a range of software development practices considered exemplary.[30]

5.2.7 Proposals Process

The timing of technology introduction is important [Fiman, 1989; Bouldin, 1989; Tyre & Orlikowski, 1993]. People resist the change associated with new technologies if they have recently adopted other technologies, if the organization is under stress (for example, due to a takeover), or if the status quo is perceived as adequate. Thus, having a point in the work process where technology can be introduced routinely can expedite the introduction of a new technology. At ComCo, Woodville, the proposals process provided this opportunity.

The Woodville site works primarily as a government contractor, using the proposal and bidding process to win business. The process was viewed by the interviewees as a natural point for the incorporation of new technologies. For example, three members of technical staff, interviewed as a group (TK, senior software engineer; and BH and JO, software engineers) listed eight technologies in addition to RMA that they had "explored or used on a trial basis" for the development of a system that they were proposing. (They viewed the introduction and use of these technologies not as risks but as "risk mitigators.") The manager of the advanced technical solutions group, LH, "tried to make people aware of what's there" in the way of useful technologies. She saw it as "her business to know what's starting, to know when to send [the change agent, DV] out." The solutions group was "very active in the proposal stage, because it's where the tone is set for what happens." LH observed that, at the time of the interviews, things were slow: "Not as many projects are starting, so there are not as many opportunities to introduce [new technologies]."

In 1990, during an effort to determine whether to prepare a proposal, one member of the technical staff, TK, senior software engineer, said he was assisted by the champion in using RMA to "judge risk on behalf of ComCo in doing a proposal." (This was the engineer's first exposure to RMA.) Another member of technical staff, BH, software engineer, noted that he was on a proposal team for a new system and was "delighted the decision was made" to use RMA. The manager of the avionics systems upgrade, AMB, said we "try to insert at least one new technology in each program." The OCR system manager, RB, said that new technologies are tried "depending on the contract" and that suggestions came from "people who keep up with what's going on." PK, distinguished fellow and project manager for the AI system, discussed the use of RMA in writing a proposal for a precursor to the system he was working on.

While interviewees described the use of RMA at various times, the process of preparing proposals offered a special window of opportunity to consider the application of RMA and other new technologies in their work. When a system was already under development, it was more

[30]. These included "a structured approach to requirements definition, high-level design, and low-level design; prototyping and 'spiral' development; an independent test group, a software quality organization, and a language for design independent of [software] implementation; and software inspections." These practices were identified by GP and SN, software engineers.

difficult to find time and funding, and often these engineers were adapting or adding to existing systems. RB (OCR system manager) said, “We can’t find money to do RMA when reusing systems that already exist.”

5.2.8 Advanced Technical Solutions Group

The advanced technical solutions group was the organizational home for DV, the change agent. The existence of this group made it possible for him to learn about RMA on behalf of the programs at the site and disseminate his expertise. We briefly describe the group and then the RMA change agent located within it.

The solutions group acted as gatekeeper and boundary spanner, tracking technology and filtering it on behalf of the site. Members of the group also acted as change agents, with responsibility to disseminate and support the initial use of technologies (including RMA) new to the site. According to the manager, LH, the group “introduces Ada technology and real-time technology into the software world on site. Our job is to be a source of help resolving development problems.” Group members gain knowledge of new technology by attending “lots of conferences,” by performing small internal R&D projects, and by subcontracting pieces of work from programs elsewhere on site. The manager indicated that some technology is brought into the solutions group by members who have worked at other sites: people in the advanced technical solutions group often come out of development programs, and then eventually transfer back into development, taking their knowledge and experience with new technologies along with them. Some technology “comes in the door” via word of mouth, advertising materials, and professional and technical journals. The technologies that they identify as potentially useful provide an inventory from which they draw to supply others.

LH (manager) and the solutions staff also track needs at a corporate and program level. They work closely with headquarters to understand programs and “what they are interested in”; and the solutions group looks at what contracts are coming. They follow new proposals and, as described earlier, identify the use of new technologies during proposal preparation.

The advanced technical solutions group worked in a number of modes. They disseminated information, for example, through “technical vitality” seminars at lunch time (used with RMA) and training courses, such as the one-and-one-half day course on RMA. They created demonstrations: for RMA, the change agent (DV) prepared software to demonstrate RMA principles. Solutions staff served as consultants to development projects. According to DV, consultations could be as simple as answering a phone inquiry or distributing a technical paper, or might involve weeks of work alongside system developers.[31] Solutions group members knew they were finished working in a technical area “when all lead technical people know” [LH, manager] and when they “get beyond the point of knowing to call” [DV, the change agent].

The manager of the advanced technical solutions group, LH, had a strong intuitive understanding of how to bring technology-based solutions to programs and projects at ComCo, Woodville. In particular, she spoke at length about the type of people who were most effective

31. If solutions staff were needed as consultants for a “block of time,” the program using them provided funding.

in her group. She said they “must have a feel for what many people are doing and talk in their language.” They have to “make it less abstract [and] talk to them [their clients] when they have a problem.” LH observed that people on her staff “must be very flexible. No serial operators.” Solutions staff must have “parallel circuits,” and they “need a variety of personalities and techniques: people may be less strong with technologies but better able to relate to other groups.” LH, herself, stays in touch with other managers. Advocacy and salesmanship were critical: it was her business to know who was starting what and to make people aware of what was available. Her staff was “always looking for what they have to show for their efforts.”

The solutions group manager had a number of characteristics typical of an effective change agent. She was “cosmopolite” [Rogers, 1983]; while she had spent her professional life in software at ComCo, Woodville, she had “always [held] different jobs.” She acted as a boundary spanner and was aggressive in making contact with other technical managers. LH sought them out, found ways to assess their needs, and appeared to enjoy such interaction. She understood “salesmanship” and had a strong customer orientation. LH remarked that she saw the change agent’s promotion to a more senior position as a “good sign of appreciation”—an indication that her customers understood and appreciated the services her group provided.

At the time we conducted the interviews, DV, the change agent for RMA, had been in the solutions group for roughly three years. Previously, he had been a member of the research group. He had been at ComCo, Woodville for 25 years and had worked with or knew most of the interviewees before his involvement in RMA. According to the interviewees and our informant, DV had an excellent reputation as a consultant, in addition to domain expertise and skills related to RMA technology. He was instrumental in developing software that demonstrated RMA. Because of the range of consulting experiences he had with RMA, he was able to develop heuristics for the application of RMA in many situations. The latter sustained and increased the demand for his services. DV’s technical expertise and his official base in the solutions group were critical to ComCo, Woodville’s application of RMA.

The change agent was viewed as a resource by managers as well as by members of the technical staff. Both software development managers (RB and AMB) had contact with DV regarding RMA. AMB (avionics system upgrade project) mentioned studies done “by the [change agent/solution] group.” RB (OCR project) noted that the change agent “was always concerned with predictability, especially in the Ada world.”[32] In 1991, RB “asked that teams get briefed [by DV] and apply RMA to what they were doing.” The change agent did brief them and used the university-developed tool for demonstration.

[32]. According to our technical informant, this meant the “world” of Ada compiler development.

All the personnel we interviewed, except PK, the distinguished fellow, had assistance in applying RMA from the change agent. In one case, when DV was looking for a pilot of RMA concepts, he had a cost center that others could charge to. This was apparently almost as important as his technical credibility. According to one member of technical staff, GP, software engineer, involved in that pilot, RMA

> had a good salesman... enthusiastic, dedicated to seeing it work. If I hadn't known [the change agent], I wouldn't have used it. I might have turned him down if he hadn't brought funding.

Three members of technical staff from another project (TK, BH, and JO) observed that their use of RMA still depended on outside expertise. BH commented that RMA

> ...concepts are relatively simple to grasp; modeling a system is much more difficult. ...No one has taken it to a large system. It would be nice to have [the change agent] or [the champion] for a couple of weeks.

Another, TK, senior software engineer, noted that

> RMA can be applied at a couple of levels: (1) simple-minded application to give grasp of general characteristics of a system ... and (2) analysis of problem stage: a whole different level of understanding—[the change agent] ... can help.

DV's "official" role as consultant for those trying to use new software technologies made it more likely that he would be used and that the technologies he was purveying would also be used. Had DV been working as a member of a project assigned to development, even with his enthusiasm and expertise for RMA, he would have had only limited time to apply to the technology. Given the difficulty of application, it is unlikely RMA would have been used by others without dedicating DV as a resource. Locating him (and others like him) within the advanced technical solutions group provided the organization with a resource (both time and expertise) that they could draw from as necessary. Thus, the solutions group was a major piece of the infrastructure supporting the adoption and implementation of RMA.

5.3 An Innovative Culture

An innovative organization responds rapidly to changing conditions in its environment by virtue of its openness [Kanter, 1983], its flexibility [Peters & Waterman, 1982], and its ability to "learn" [Morgan, 1986; Kim, 1994]. ComCo, Woodville's innovativeness is shown partly through the infrastructure that allowed Woodville to absorb new technologies. It is also present in its culture, the set of "patterns of belief or shared meaning" that guide the actions of its employees (Morgan, 1986, p. 121). In this section we examine the aspects of culture that we believe expedited the adoption of RMA as an immature technology. These aspects, all connected to the value placed on new technology, include

- Viewing new technologies as risk mitigators.
- The value of developing and rewarding the technical professional.
- The benefit of resources allocated to technology acquisition and implementation.
- The value placed on organizational learning.

5.3.1 New Technologies as Risk Mitigators

Because of the impact of technological change on organizations, adopting new technologies is often viewed as inherently risky [Fiman, 1989]. This was not the case at ComCo, Woodville. Two of the senior members of technical staff, TK, senior software engineer, and BH, software engineer, reported that they saw the adoption and implementation of new technologies as "risk mitigation," not risk. They also said new technologies provided them with better and sometimes cheaper ways to accomplish technical work, and with competitive advantage, although they "look for tools that fit into our process and not vice versa." RB, manager of OCR software development, told us that they expected to maintain a "level of know-how" and that "competitive pressure pushes this." AMB, manager of the avionics systems upgrade, sought out "lessons learned" papers, where experiences with new technologies or with problems that might respond to new technologies were described; she also mentioned reading technical papers on RMA and looking at studies done by the solutions group. PK, the distinguished engineer, remarked that RMA made a difference in a proposal award; he saw including RMA in the proposal as an opportunity rather than a risk.

5.3.2 Developing and Rewarding the Technical Professional

ComCo, Woodville invested in its employees. This was clear in three ways:

1. Woodville personnel had access to continuing education in a variety of forms.
2. The dual career ladder gave those interested in a technical career the opportunity to grow and influence the direction of the organization.
3. The "lifetime" employment policy gave employees a secure context within which to take risks, including technological risks, on behalf of the firm.

Woodville employees could take advantage of a range of opportunities for developing new technical skills and knowledge, including seminars and training courses. Funds were available for attending conferences. For example, the IEEE Real-Time Systems Symposium and TriAda conferences were referred to by name by two members of the technical staff. LH, manager of the solutions group, noted that she and her group "go to lots of conferences." AMB, (manager, avionics system upgrade) mentioned an "extensive education program" and "strong training internally" at Woodville. Another member of the technical staff, GP, software engineer, noted that as they "moved toward object-orient[ation]" they obtained "training as needed, and now it is offered as initial training to new programmers."

According to our informant, employees worked with their managers to develop annual training plans: all personnel were expected to attend training and continuing education courses, and time was allocated for them to do so, despite demanding project schedules. We asked our informant if ComCo viewed training and continuing professional education for its technical and managerial employees as a perquisite or as a strategic investment. He replied that it was "somewhere in between," because employees were responsible for choosing their own training, but training was included in personal objectives, reviewed by one's manager, and paid for by the corporation. Also, promotion was linked to competence, which in turn required continual upgrading of technical skills. And ComCo benefitted overall as well because its employees were technically current.

In keeping with the value placed on training and education, ComCo employees had access to skills and knowledge about RMA. ComCo's corporate education had paid for the development of an RMA seminar by partly funding the SEI resident affiliate (our informant, TR). The seminar was tailored to ComCo, and the champion (DL) taught it a number of times, across the corporation. The change agent (DV) also taught the seminar in Woodville and presented a short lunchtime version with a colleague. The manager of the advanced technical solutions group said she was considering development of a videotape of an RMA presentation by the change agent; she clearly had funds at her discretion to do this.

The dual career ladder, described in Section 5.2, provided parallel technical and managerial promotion paths. By enabling technical professionals to move into positions of influence, it allowed technology to affect business direction. Both the champion (DL), in the next-to-highest technical rank, and the change agent (DV) ranked just below the champion, held positions that required others to take their opinions on RMA seriously, and encouraged others to trust in their counsel.

The longevity of tenure of all but one interviewee, including our informant, seemed to reinforce the value of calculated technological risk. Employees' jobs were not at stake when they made decisions. Our informant said that there was "very little personal risk. Because even if you blow it big time, you're not going to lose your job." He told us about a mistake he made early in his career at ComCo:

> My boss called me in and said “You’ve got to understand something. If you blow it here at [ComCo] for $10,000, I’m going to give you $100,000 responsibility because I know you won’t make the $10,000 mistake again. And if you blow it at $100,000, I’ll give you a $1,000,000 responsibility because you already learned those lessons...that’s what it’s about here.” And so [about] this longevity, there is no perceived personal risk other than to reputation. But remember, reputation is very important for moving up the ladder. It means a lot. So, in terms of your paycheck, there’s not a personal risk here. So what you risk is your reputation.

We commented, to our informant, that this seemed to create a situation where everyone would want to do well. He replied, “Exactly.”

5.3.3 Resources Allocated to Technology Acquisition and Implementation

Interviewees expressed interest in obtaining new technology that would help them do their jobs more effectively. They looked especially to the champion (DL) and the change agent (DV) for information and consulting support. Thus, one way to view the champion and the change agent is as “slack” resources—resources that are not assigned to specific contracts, but that are available for unanticipated tasks that must be accomplished, such as troubleshooting, tracking and screening new technologies, and consulting.[33]

The champion was a slack resource, being a very senior person who worked partly at his own discretion and partly on request by senior management to solve problems across the corporation (not just at Woodville). The change agent also was available for consulting, and this work was funded by the budget of the advanced technical solutions group. Three interviewees learned about RMA through other sources, such as the original Liu and Layland paper or conference seminars. PK, distinguished fellow, used the paper to determine by himself how to apply RMA, but the other two, AMB, manager, and GP, software engineer, used the change agent as a resource when it came to application in their programs.

The technology research group and the advanced technical solutions group can also be seen as slack resources because they were not dedicated to contracts or product development. (While the solutions group did perform subcontracted work and IR&D, it did so to “keep its hand in” and to support its primary task: tracking and assisting with the use of new technology. Both groups were mentioned by the two software development managers as resources for new technology. ComCo, Woodville treated these as “official” slack resources by assigning managers and technical personnel, full time, and by providing them with funding.[34]

The champion (DL), the technology research group, and the change agent (DV) and the advanced technical solutions group that he belonged to were dedicated to looking ahead for answers to emerging needs, identifying and sharing information on these, and then providing

33. Rogers [1983] notes that slack resources more frequently occur in larger organizations (p. 359). Damanpour [1991] associates slack resources with more innovative organizations (p. 562).

34. An example of “unofficial” slack resources is when managers “pad” their budgets to allow for expansions and contractions in workload.

assistance in their assimilation. In this respect, they function as *advanced technology groups:* their job is "not only to evaluate new concepts but to implement strategic technologies as well" (Santosus, 1994, p. 56). By reserving people to anticipate future directions in technology and to respond to demand for application of identified technologies, ComCo, Woodville remains flexible and open, ready to innovate when it makes sense to do so.

5.3.4 Organizational Learning

The change agent (DV) and the champion (DL) also represent a form of organizational learning. They are able to work—at corporate and site levels—in a way that allows them to gain broad experience. They see how one technology, RMA, can be applied in many different ways. Thus, ComCo "learns" how to apply RMA in a range of situations. No one program can provide that range of opportunities within a reasonable time period. For example, each interviewee with whom the change agent or the champion worked mentioned the application of RMA as something that occurred only once or twice. Because the change agent and the champion can gain much broader experience, the corporation benefits each time they work to help a program apply the technology. They draw from singular experiences in specific settings and gradually build an important competency that can be applied to competitive advantage in building software for real-time systems.

5.4 Innovation-Decision Process

The literature on diffusion and transfer carries implicit assumptions about the "adoption" of an innovation, including the rate of its spread and the characteristics, or attributes, of the innovation [Augliere, 1994; Downs & Mohr, 1976; Tornatzky & Klein, 1982]. The data gathered in these interviews on the adoption and implementation of RMA raise questions about underlying assumptions in diffusion theory. Here, we are primarily concerned with two aspects:

1. *How* individuals in an organization come to "adopt"—the innovation-decision process—[Conner & Patterson, 1982; Rogers, 1983].
2. *What* it is that is adopted, namely the nature of the technology as revealed by users' perceptions of its attributes [Fichman & Kemerer, 1993; Rogers, 1983; Tornatzky & Fleisher,1990; Tornatzky & Klein, 1982].

Traditional approaches to diffusion assume a universally applicable process of adoption; however, our findings indicate that the processes of adopting and implementing RMA, as well as perspectives on the technology's use, were not uniform. In this section, we consider the *decision-making* aspects during the early stages of commitment, before and up to trial. In Section 5.5, we concentrate on the attributes of RMA: the degree to which the technology was perceived as advantageous, complex, trialable, etc. The discussion on attributes picks up with the later stages of commitment, during trial and pilot use. The innovation-decision process and the attributes of innovations *are* related: one's perception of an innovation affects the decision to adopt and implement. However, for the sake of clarity we consider these themes separately and note places of overlap.

Rogers [1983] defines the innovation-decision process as “the process through which an individual (or other decision-making unit) passes from first knowledge of an innovation, to forming an attitude toward the innovation, to decision to adopt or reject, to implementation of the new idea, and to confirmation of this decision” (p. 165). His model of the stages of the innovation-decision process includes

- Knowledge
- Persuasion
- Decision
- Implementation
- Confirmation

Similarly, Conner & Patterson [1982] treat the process of building commitment for change in terms of three phases.

- Phase 1, Preparation, includes the stages of contact and awareness.
- Phase 2, Acceptance, involves understanding the change and positive perception.
- Phase 3, Commitment, includes installation, adoption, institutionalization, and internalization.

With respect to the individuals we interviewed about RMA, we did not see evidence of a unitary commitment process, although we did see patterns of behavior, decision making, and influence. As already noted, our informant summarized his impression of the innovation-decision process succinctly: an individual at ComCo would be seeking answers to the following questions: Will it (the technology) help me? Have you used it? and, Will you help me? In this regard, we see a connection between the processes of commitment and of problem solving. Rogers [1983] alludes to this connection when he notes that the diffusion of an innovation is an “uncertainty-reduction process” (p.217), but he fails to observe that risk and uncertainty reduction typically occur at at least two levels:

1. In response to the original need or problem that exists separate from the innovation (the problem that the innovation or technology may be attempting to address).
2. With respect to the uncertainty associated with the technology itself.

Rogers’ limited interpretation of risk and uncertainty reduction may be a natural consequence of his preoccupation with diffusion as *purchase* of consumer goods and services. The adoption and implementation of new technologies to solve technical and business problems is a different matter.

The avionics software development manager (AMB) responded to this precise issue: to risk reduction in the project (as opposed to the uncertainty reduction associated with RMA technology). When asked, “How will you decide whether to continue using RMA?”, she responded: “I don’t think we have an alternative. A program of this complexity—I can’t afford to not know what's happening in that box at any given time. I would think we'd use it (RMA) through each phase—primarily up front but also to understand changes and the consequences of those changes." A senior software engineer on the same project, TK, told us: "Ill-defined problems are the problem, not just the introduction of new techniques, tools, and people."

Moreover, we observed how perceptions of risk reduction for technical problems and uncertainty reduction with respect to new technology varied in level of granularity. For example, two of the engineers on the avionics system upgrade project both "adopted" RMA technology, but at different levels. Our informant used an aerial metaphor to illustrate the distinction. In his view, the senior software engineer was concerned with adopting the technology and with associated risks at the highest level, at "300,000 feet." The senior engineer (TK) remarked: "If it pans out, we'll have a system that's predictable, and we'll have a better product." On the other hand, the informant thought that TK's colleague, a somewhat more junior software engineer (BH), was operating at "30,000 feet." When we asked BH if RMA helped him to do things better than he had before, he responded cautiously. He said, "Ideally, but it's early. The concepts were relatively easy to grasp in class; modeling a system will not be so easy." What was interesting to us was the informant's conclusion: he observed that if BH was successful at implementation—at modeling the system—his senior colleague would never need to get the more detailed look at the lower level application problems. Typically we might assume that project members benefit from sharing the same perspective; however, here, the two perspectives are different and possibly more efficient because of their wider compatible scope.

We cannot generalize about the benefits of complementary or divergent perspectives about a technology; however, attention to the "degree to which individuals converge in the meaning-space of their common experience" may help us to consider the role of concurrence in an innovation's spread (Augliere, 1994, p. 3). In addition, while researchers and practitioners have generally come to expect variance between management and technical perspectives on the value of a technology, the differences we see here at the level of adoption of *technical* personnel are noteworthy. Such differences are another indicator that risk reduction, uncertainty reduction, and perceptions on adoption and implementation are more complex than current theories of diffusion and transfer would have us understand.

Diffusion is concerned with technology spread, with the movement of technologies through a consumer population. Thus, research has focused on broad adoption. More recently, some attention has turned to descriptions of the technology "as it is experienced" [Augliere, 1994] and to technology incorporation or infusion. Zmud & Apple [1992] observe that "the incorporation of many, if not most, innovations follows a sequence of configurations across discrete *levels of use*, with advanced incorporation enabling the deeper and more comprehensive embedding of an innovation within an organization's operational and/or managerial work systems. It is this elaborated use that we connote as the *infusion* of an innovation" (p. 150; italics Zmud & Apple).

The concept of infusion is helpful in understanding the processes of adoption and implementation of RMA at ComCo, Woodville. For example, we have seen that the granularity of perceptions of RMA (from 300,000 to 30,000 feet) relates to levels of use—a topic that will also be relevant in Section 5.5 on technology attributes. In addition, the idea of infusion underscores the need to see innovation decision as a lengthy, labor-intensive process. Management sponsorship and the user's exposure to a technology occur through time, not as a single transaction. Support for an innovation and the users' commitment evolve as individuals within an organization reference each others' opinions. TK, a senior software engineer, remarked: "Convincing people to use RMA on [the new avionics project] was especially easier after the helicopter project." His colleague (BH) notes that even though "a previous program proposal to use RMA did not win, they had already decided to use RMA on [the new avionics project]."

With the adoption of RMA, we saw multiple (sometimes overlapping) levels of sponsorship. The senior-level manager (CK) was the official sponsor, but others served as advocates, including the champion, the change agent, the manager of the advanced technical solutions group, and the distinguished software engineer. As each of these individuals came to see value in RMA, there was more reason for others to come "on board." One engineer, GP, whose office was two doors down from the change agent's, observed: "RMA had a good salesman. [The change agent] DV was very enthusiastic and dedicated to making it work." The engineer added that the salesman-change agent, DV, had a cost center for charging work related to the application of RMA. "If DV wasn't two doors down, we wouldn't have used it. [It] also helped that DV came with dollars." Proximity, funding, and sales reinforced the innovation-decision process. The senior software engineer (TK) commented on the reputation of the champion. When we asked him (TK) when he had realized that RMA was relevant to how he did his work, he referred to a project that the champion had consulted on, and he said, "Anything that DL [the champion] advocates looks good to the whole world." TK was "convinced that the approach was viable" on the basis of the earlier project and the champion's support for the technology.

While these individuals referenced one another, another dynamic related to advocacy was also at work. This concerns the dual ladder related to business and technical issues. RB, software development manager (OCR), indicated that he would "advocate but not dictate use" of a technology. Although current theories of diffusion wash out distinctions between advocacy and mandate, these cultural imperatives represent more than nuance: diffusion in the village, university, or business setting are not the same. In each of these environments, exigency, culture, and time play a role in the adoption and implementation of new technology. The innovation-decision process, as experienced by the individuals we interviewed at ComCo, spanned eight years, from 1982 until 1990. Table 2 summarizes the following information: interviewee, source of influence, and time of initial exposure.

Table 2: Exposure To RMA Technology by Year

1982-83	Distinguished Senior Engineer and Project Manager (PK), via champion (DL)
1985-86	Senior Software Engineer (TK), via champion (DL)
1986-87	Manager Advanced Technical Solutions Group (LH), via champion (DL)
1987	Software Engineer (BH), via champion (DL)
1987-88	Manager Avionics Software Development (AMB), via Manager Technical Research Group
1987-88	Manager Software Development (OCR) (RB), via change agent (DV)
1989	Software Engineer (SN), via change agent (DV) / public tutorial
1990	Software Engineer (JO), via public tutorial
1990	Software Engineer (GP), via change agent (DV)

The innovation-decision process varied from person to person, although we did see patterns in support and commitment. Proximity, funding, and advocacy were influential. At ComCo, Woodville, there is also precedent for innovation: the avionics software manager (AMB) told us that she tries "to insert at least one new technology in each project: object orientation, risk, rate monotonic scheduling, multiprocessing, Ada."

As suggested, the timing and circumstances of an individual's adoption and use of the technology were tied to that person's perception of the technology, specifically its attributes and the degree of information or experience that he or she needed to solve the technical problem. The following section on attributes of innovation touches on factors related to innovation decision.

5.5 Attributes of Innovation

The interview schedule was designed to capture memorable events in the individuals' processes of adoption and implementation—their exposure to the technology and perceptions about its use. Our goal was not to focus specifically on attributes of the technology and yet, indirectly, many of the questions we asked called up issues relating to relative advantage, compatibility, complexity, trialability, and observability.

The following is illustrative. The question we asked, "When did you realize that RMA was relevant to your work and how did you know it was relevant?" suggested issues related to relative advantage. Similarly, the question, "Were you able to observe how RMA was helpful to others?" called up the matter of observability. On occasion, we asked a question that we thought related to one attribute, and we received information more closely associated to another attribute. For example, when we asked the software development manager, RB, (OCR project) about how easy or hard it was to use the technology (associated with complexity and "ease" of implementation), he commented on his definition of the technology and perception of its relevance. His remarks were more closely related to relative advantage than to complexity. This blurring with respect to technology attributes underscores a critical dilemma, namely their supposed integrity and stability.

Table 3 offers a summary of key attributes of innovations and their definitions. In the discussion that follows, we concentrate on the five attributes discussed in Rogers [1983] (first five rows in the table); however, the table also includes the set of ten attributes covered in Tornatzky & Klein [1982].[35]

Table 3: Attributes of Innovations

Name	Definition
Relative advantage	Degree to which an innovation is perceived as being better than the idea it supersedes [Rogers, 1983]
Compatibility	Degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters [Rogers, 1983]
Complexity	Degree to which an innovation is perceived as relatively difficult to understand and use [Rogers, 1983]
Trialability	Degree to which an innovation can be experimented with on a limited basis [Rogers, 1983]
Observability	Degree to which the results of an innovation are visible to others [Rogers, 1983]
Cost	Cost of an innovation assumed to be negatively related to the adoption and implementation of an innovation [Tornatzky & Klein, 1982]
Communicability	Degree to which aspects of an innovation may be conveyed to others [Rothman, 1974]
Divisibility	Extent to which an innovation can be tried on a small scale before adoption [Fliegel, Kivlin & Sekhon, 1968]
Profitability	Level of profit to be gained from adoption of the innovation [Tornatzky & Klein, 1982]
Social approval	The status gained in one's reference group, a "nonfinancial aspect of reward" [Fliegel, Kivlin & Sekhon, 1968]

A number of researchers have treated the notion of technology attributes [Downs & Mohr, 1976; Fichman & Kemerer, 1993; Fliegel, Kivlin & Sekhon, 1968; Rogers, 1983; Rothman, 1974; Tornatzky & Klein, 1982]. Initially, Downs & Mohr [1976] distinguished between primary and secondary attributes, where primary attributes represented "objective" features or characteristics such as size or cost of the technology; on the other hand, secondary attributes were

35. Tornatzky & Klein [1987] note that a total of thirty different characteristics were studied in the articles that they reviewed. They remark that "while the identification of 'new' innovation characteristics (e.g., risk and impact on work relationships) may be useful, there is a real need to determine the empirical independence of these characteristics and to eliminate redundant characteristics" (p. 41).

subjective and perceptually based, including relative advantage, complexity, etc. Tornatzky & Klein [1982] argued that while supposed

> primary attributes of innovations can be measured "objectively," the meaning of the objective measure of the characteristic is subjective, that is, in the mind of the perceiver. Thus, while an innovation may cost a fixed amount (and cost is a so-called primary attribute), the cost of the innovation is evaluated by the potential adopter relative to his or her financial resources. The innovation's cost may seem expensive to one, exorbitant to another. In this sense, there can be no primary attribute of an innovation. Perceptions are always evaluated in reference to some internalized system of values or cognitive framework; the result is a subjective rating of the "fact" (e.g., size, cost, etc.) (p. 28).

Rogers [1983] also ties the attributes of innovation to perceived use. He suggests that these characteristics by which an innovation can be described illustrate "how individuals' perceptions of these characteristics predict their rate of adoption" (p. 210).

The link between technology attributes and the perceived benefits of use is critical. Nonetheless, present critiques only minimally attend to variance within attributes and rarely contend with overlap and variance between characteristics. The overriding assumption is that these attributes are discrete and stable. This, however, does not appear to be the case. Perceived differences exist *within* and *between* attributes. For instance, in the study of RMA, we expected that the interviewees would have different perceptions of trialability and that the attribute would not be perceived as absolute or unitary. However, we were more surprised to see blurring between attributes, as, for example, when one person viewed the opportunity to see a demonstration of RMA (observability) as a trial (trialability). Understanding the dynamics of adopting and implementing new technologies requires that we investigate issues surrounding attribute definition and degree of variation: what constitutes a trial (rather than, say, an observation) as well as the range of perspectives on trialability.[36] We might describe this as a necessary shift in orientation—away from characteristics thought to reside *in* an innovation—and toward perceptions of use; in other words, as a move away from conventional attributes and toward the more suggestive concept of attribution. Opening such a dialogue is the purpose of the present discussion.

In the following, we identify Rogers' key attributes of innovation and discuss the interviewees' comments relating to these attributes. Only one of the interviewees did not discuss specific attributes: LH, the manager of the advanced technical solutions group, explained her approach to introducing new technologies. Our conversation with her took a more free-ranging

36. Some researchers do not find the notion of technology attributes problematic. Fichman & Kemerer [1983] observe that "although Rogers' synthesis is based mostly on studies of adoptions by individuals (e.g., of consumer goods), Van de Ven and others have argued that innovation attributes also play an important role in adoptions by organizations...The explanations for the relative advantage, compatibility, and complexity attributes are straightforward enough: organizations are more likely to be willing and able to adopt innovations that offer clear advantages, that do not drastically interfere with existing practices, and that are easier to understand. Trialability and observability are both related to risk. Adopters look unfavorably on adoptions that are difficult to put through a trial period or whose benefits are difficult to see or describe. These characteristics increase the uncertainty about the innovation's true value" (p. 9).

tack, since given her role as manager of the advanced technical solutions group, she did not focus exclusively on the adoption and implementation of RMA.

5.5.1 Relative Advantage

Relative advantage is "the degree to which a new idea is perceived to be better than an existing practice." The attribute is also an indicator of "the strength of the reward or punishment resulting from the adoption of an innovation" (Rogers, 1983, p. 217). Advantage may be borne out in terms of business and technical goals and decisions (for example, with respect to a dual ladder such as the one described at ComCo) and may translate into corresponding, sometimes overlapping, business and technical advantages.

As we might expect, relative advantage is itself relative or variable: one may perceive all, some, or none of the advantages that others might associate with a technology. The advantages and disadvantages perceived by a team that has developed a technology are no more correct or significant than the perceptions of others. In fact, if such a team was focused on technology use, they would more likely be interested in the responses of users (standing in for customers) than in their own perceptions. With respect to RMA, we saw that one software development manager, RB, (OCR project), perceived some but not all of the advantages enumerated by others. When we asked him about how easy or difficult it was to use RMA (information related to complexity and its ease of use), he said, "The hardest part was probably doing the design of the software; it has nothing to do with RMA." This remark, when corroborated by our technical informant, led us to speculate that RB did not perceive that RMA was of value in design. Rather, he saw RMA as an analysis tool. He indicated that one should analyze early to solve timing problems; however, he did not see RMA as a design tool. In terms of relative advantage, RB's observation of RMA did not include a perception that RMA could yield prescriptions and that this prescriptive aspect was relevant to seeing its place in design.

More generally, RB discussed the relative advantage of RMA. He said, "I'm impatient that it's not getting implemented faster. I think it's a key technology. I'm part of the problem though because I'm not mandating it. As soon as I dictate technical issues, I'm not managing." As we observed in the earlier discussion on the innovation-decision process, RB was sensitive to the tension between dictating and advocating the use of the technology.

For GP, software engineer, the deciding factor was the agent for the technology. When we asked GP about how RMA was relevant to his work, he said, "I'm not sure it was relevant. We went along with [the change agent, DV] because we were one of the first Ada programs. DV's model sounded like it would give us insight into tasking and priorities. After the fact, it was helpful, but I don't think our program fit the model. We didn't have severe timing constraints." With respect to the question of "fit," our informant observed that at that time, RMA technology, independent of an expert consultant, may not have been sufficiently mature to bridge the gap between GP's knowledge of how to apply RMA and his requirements for RMA (his system was event-driven). In Section 6, *Implications*, we consider the relationship between technology maturity and the concept of the whole product.

Even though GP perceived a limited fit, he was still positive about ongoing use of RMA. When we asked him if he would continue to use RMA, he said, “Absolutely. Would definitely use it if I was working on a new program. I think it’s a very useful tool for understanding how you will meet your timing constraints. I hope the new avionics program would use it...”

SN, another software engineer and colleague of GP, observed that he had difficulty trying to extrapolate the model from periodic to aperiodic tasks. He noted that the tutorial made it seem easy, but the real world was different. SN stated that “since the [air flight simulator] program is not traditional real time, initially, it’s hard to apply the theory to the program. We couldn’t find periodic tasks; we worked with DV [the change agent].” SN’s perception of relative and limited advantage resembled that of GP and was also tied to the immaturity of the technology—and the missing tools, training, and materials that would have more readily enabled engineers to translate RMA theory to practice. Our informant also considered this to be so. In his terms, these individuals were responding to a gap in the technology that still remained to be closed at that time. However, the informant observed that “they were looking for the tool to fit the problem, and they could have redefined the problem to fit the tool.”

When we asked PK, distinguished engineer and manager of the AI system project, whether RMA helped him to do things better than he’d been able to before, he said, “Without RMA we’d be struggling with ad hoc problems, everything we’ve struggled with before. We’re getting at the procedural issues, and the reason for making decisions.” Later, we asked him if he would continue to use RMA. He replied, “DL [RMA’s champion] has shown enough horror stories that I would not design a system that would not be programmed re: RMA.” At the close of the interview, he mentioned that the long-time initiating sponsor (CK), “the czar of software land at ComCo,” had moved to another site but he (this engineer) could not conceive of ComCo, Woodville’s “forgetting the formula.”

5.5.2 Compatibility

Compatibility is defined as the

> degree to which an innovation is perceived as consistent with existing values, past experiences, and needs of potential adopters. An idea that is more compatible is less uncertain to the potential adopter. An innovation can be compatible or incompatible (1) with sociocultural values and beliefs, (2) with previously introduced ideas, or (3) with client needs for innovations (Rogers, 1983, p. 223).

Typically, in the areas of computer science and software engineering, “compatibility” is associated with methodological incompatibilities or with platforms: hardware, software, or protocols. However, an innovation’s perceived compatibility also relates to an adopter’s values, experiences, and needs. In the discussion of relative advantage, we noted references to compatibility and incompatibility. Sometimes a perception took the form of a connection or a lack of association; for example, RB, one of the software development managers, did not associate RMA with design. GP, software engineer, said that he went along with the change agent’s model, but he wasn't sure about RMA's relevance: he didn't associate the technology with the event-driven system he was building. In each of these instances, there was a lack of connection or association, if not an outright incompatibility.

We asked the interviewees about how well RMA fit in with how they did their work, and as a follow-on question, whether RMA was perceived as an added requirement. RB, software development manager (OCR project), said "It fits in well with how they want to do their work." "Yes," he added, "they see it as an added requirement."

Our informant speculated that these individuals were perceiving RMA to be an added requirement and not a savings of future effort or future integration costs. He remarked, "They don't see timing as the root cause."

The distinguished senior engineer and project manager for the AI system project stated that RMA is "fundamental [to how we do our work], it's one of the reasons we got the contract."

5.5.3 Complexity

Complexity is "the degree to which an innovation is perceived as relatively difficult to understand and use. Any new idea may be classified on the complexity-simplicity continuum. Some innovations are clear in their meaning to potential adopters while others are not" (Rogers, 1983, p. 231).

Rogers suggests the following generalization: "The complexity of an innovation, as perceived by members of a social system, is negatively related to its rate of adoption" (Rogers, 1983, p. 231). We maintain that this interpretation is too limited and simplistic. Complexity must be understood in terms of the user's intent and expertise. With respect to the adoption of RMA, it is critical to stress the domain knowledge of the users. RMA is not a general-purpose technology; hence, it is largely used by a specialist population with expertise in real-time systems, such as we saw in the population at ComCo.

Product complexity is not unidimensional. There are different types of complexity. Technical complexity refers to the extent to which something may be hard to learn. A technology or effort may also be complex with respect to its impact on many parts of an organization. Thus, the attribute of complexity straddles issues related to

- The purpose of the user.
- His or her prior knowledge and expertise.
- Levels of use.
- Ease of implementation.

On the surface, complexity may appear to be obvious, related to the "objective" or operational features of an innovation; however, perceived complexity may be a highly individualized ratio based on the technology features and user characteristics identified above. Tornatzky & Klein [1982] raise similar questions about this attribute. They ask

> Does "complexity" refer to the technical knowledge needed to use an innovation? To the impact of the innovation on existing work relations? To the innovation's physical appearance? A useful approach to answering these questions might involve examining the statistical relationship between perceptual and objective descriptions of innovations" (p. 42).

In the discussion of relative advantage, we recall that one of the software engineers, SN, pointed out that the RMA tutorial made extrapolating the model (from periodic to aperiodic tasks) seem "easy" but that the effort was more difficult in the real world. It was "hard to apply the theory to the [air flight simulator] program." This simple remark illustrates the problematic nature of the attributes in general and, specifically, complexity. Where does relative advantage leave off and complexity begin? In terms of complexity, is this task "easy," "hard," or both? Which use is primary: the "easier," more theoretical representation in the tutorial or the "harder," real-world application? As noted, technology attributes appear straightforward; however, closer examination reveals that the characteristics of innovation constitute a ball of tangled concepts that it is difficult to untangle.

5.5.4 Trialability

Trialability is "the degree to which an innovation may be experimented with on a limited basis. New ideas that can be tried on the installment plan will generally be adopted more rapidly than innovations that are not divisible" (Rogers, 1983, p. 231). In addition, Leonard-Barton [1988b] treats divisibility as "the degree to which an innovation can be partitioned to allow trial adoption" (p. 613). She goes on to identify two types of divisibility:

> (1) modularization, the division of a technology into stages or segments, each of which delivers some benefits upon implementation, even if no further segments are adopted[37] [and] (2) individualization, the potential for beneficial use of a technology for individual output by some organizational members independent of the innovation responses of others engaged in the same task (e.g., the use of computer work stations by some secretaries, or some engineers, or some draftsmen) (p. 613).

Trialability and divisibility are not one and the same; modularization, as Leonard-Barton defines it, most closely resembles incremental use. Trialability is a multifaceted characteristic, one we only begin to discuss here.

37. On the topic of incremental use, our technical informant stressed that to some extent, at the smallest level, a principle could be useful: one as simple as "Things that run faster should get priority." However, RMA could be applied to the level necessary to suit a person's purpose to see the benefit. This extension of use is possible because RMA is based on mathematical principles.

With respect to RMA, we saw many types of trials—variance within the attribute of trialability—and evidence of blurring between trialability and other attributes. The first of the two following examples illustrates differences within trialability; the second suggests overlap between trialability and observability. PK, the distinguished senior engineer and project manager, mentioned two levels of trial: proof and activity. Moreover, he linked relevance judgments to trialability. When we asked him about when he realized RMA was relevant, he said, "right off the bat because what we deal with is real time in nature. I read the paper [Liu & Layland, 1973] and went through the proof once." Shortly after, we asked him if he tried out RMA. He said, "We broke the scheduling tool [they tried to use DV's university prototype tool] and we're trying it out now. Given an understanding of the technology and having gone through the proof, I'm really trying it out now."

TK's response (senior software engineer) was quite different. When we asked him about whether or not he tried out RMA, he said, "Yes, [the helicopter project] served in part as a trial. [The project] was a multiprocessor. The program had lots of problems and they were always looking for ways to assess risk in assuming maintenance. The results are not in but they did determine risks based on that analysis." For TK, trialability is embodied in the nature of analogizing; he is not picturing trial as pilot use. Instead, his remarks suggest that trial use occurs by individual engineers who pick up so many technologies for their toolbox. In this instance, there is a noticeable overlap between a trial and an observation.

Our technical informant suggested that TK's trial was at a high level. Not surprisingly, this matches TK's interests as expressed earlier. We recall, for example, in our discussion of the innovation-decision process, that two of the engineers on the avionics system upgrade project "adopted" RMA technology at different levels. TK, the senior software engineer, was concerned with adopting the technology and with associated risks at the highest level, at "300,000 feet." Our informant speculated that TK's (somewhat junior) colleague, also a software engineer (BH), was operating at "30,000 feet." When we asked this engineer if RMA helped him to do things better than he had before, BH said, "Ideally, but it's early. The concepts were relatively easy to grasp in class; modeling a system will not be so easy."

These perspectives associated with high and low concerns and levels of trial, including proof and activity, suggest that trialability is more multifaceted than common thought allows. The high/low distinction should not be reduced to making a slice between managerial and technical perspectives; both levels of concern expressed here relate to technical issues.

Finally, we are unable to comment on whether the change agent's (DV's) demonstration served as a trial or observation. The simple existence of a demo may have been persuasive enough for some; however, we have no data on the number of people who actually went through the entire demo.

5.5.5 Observability

Observability is “the degree to which the results of an innovation are visible to others. The results of some ideas are easily observed and communicated to others whereas some innovations are difficult to describe to others.” Rogers [1983] goes on to note that a technology has two components: “(1) a hardware aspect that consists of the tool that embodies the technology as material or physical objects, and (2) a software aspect that consists of the information base for the tool” (p. 232). He suggests that the software component of an innovation is less visible; thus, the lesser degree of observability means that software innovations are adopted more slowly and affect people’s work in subtler ways. Rogers’ distinctions are important; however, we will see shortly that understanding technology use and the relationship between technologies and whole products is more complex than distinctions between hardware and software aspects. Similarly, forms of observation must be extended beyond seeing a thing *work;* forms of observation must also account for the observed behavior of people as well as the time, space, and number and relationship of people involved in the use of a technology and its transition.

When we asked the software development manager (RB of the OCR project) whether he was able to observe how RMA was helpful to others, he said, “Initially, no; I didn’t see its usefulness early on.” He went on to add, “We did not apply it to what we were doing. We weren’t doing a real-time application, so it wasn’t applied.” Previously, however, when we asked him about his decision to use RMA, he referred to the time when the change agent (DV) had been able to work with them and they had sat down and used the university prototype tool. Some overlap exists here between observation of RMA and observation of the usefulness of RMA. This may suggest a blur between observability and usefulness (relative advantage); or the source of ambiguity here may be the result of our question, which touched on both characteristics at the same time.

At the close of the interview with the avionics software development manager, AMB, we asked her if there was anything else she’d like to talk about. She responded, “I’m waiting to see if it [RMA] will go from theory to reality. “Is there anything that would help you more?” we inquired. “A real RMS [rate monotonic scheduling] tool would help even more where you could feed it tests and it would pump out results. We are using that more primitive tool from [the university].”

5.5.6 Summary Remarks

In general, the interview data we gathered relating to technology attributes, especially trialability and observability, confirmed that technology use was not a unidimensional or homogeneous practice. We discovered noticeable spread in how and when technologies were used—at different times with different constraints and degrees of freedom. Use of RMA included troubleshooting, analysis of an existing system, and design, at different phases of the software development life cycle. Several individuals with experience in these varied kinds of use were able to extrapolate about how RMA might be used not to solve a particular problem so much as to predict what would be problematic. There seemed to be a preventative aspect to this kind of use, and it occurred earlier in the life cycle.

PK (distinguished senior engineer and project manager) used RMA in a manner unprecedented and unanticipated by RMA's developers. He bypassed consideration of normal use; he had a vision for something bigger and more important, seeing the repercussions of applying RMA concepts to systems, not just software. For PK, in true innovator style, the technology was just a point of departure. In his remarks, we saw the range of his application of RMA and his more abstract philosophical perspective on the "discipline" that the technology provided.

> The AI system was bid in 1989, started in 1990. RMA is being used with respect to scheduling mechanisms, designing interrupt handlers, assigning priorities to the rule-based system. These things are often aperiodic but we'd like to put some kind of discipline around them. We're just in the process of bringing up the runtime software, assigning priorities and then we'll use [DV's] tool set to do the analysis. RMA has been designed in from the beginning. Knowing you're going to do the analysis informs the design.

An important question remains: what relationship exists between the decision to innovate, the perceived attributes, and the maturity of the technology? This subject serves as the centerpiece in the implications discussion that follows.

6 Implications

At the highest level, the results yielded three key findings that have implications for what we identify as an integrating theme: the concept of the whole product [Moore, 1991]. To summarize,

1. We observed that existing infrastructure, including DV's efforts as change agent operating at the site level, was necessary to support the adoption and implementation of RMA at ComCo.
2. The innovative culture, in conjunction with the organization's infrastructure, compensated for missing aspects of the maturing technology.
3. We saw that a critical link existed between technology attributes and perceptions of use, and that technology "use" was more complex than current understanding of diffusion theory allows.

These findings benefit from consideration alongside ideas of technology and product maturity; thus, the whole product concept is a useful lens through which to view ComCo's processes of adoption and implementation of RMA.

6.1 The Concept of the Whole Product

As indicated, RMA was relatively more mature as a *technology*, in the sense that it was no longer evolving rapidly, than as a *product*. Geoffrey Moore [1991] argues that majority acceptance of a technology is contingent upon the existence of a *whole product:* the core technology and the availability of a range of adjunct products and services, including training and support, cables, installation and debugging, system integration, additional hardware, additional software, and standards and procedures (p. 115). (See Figure 6-1.) Moore is primarily focused on business development, on helping high-tech companies cross a "chasm" from a small custom or early market to a mass or mainstream market. Nonetheless, the whole product concept has application for understanding technology adoption and use, since a large part of what makes a business successful is its marketable products.

Typically, vendors are focused on sales. Our focus on adoption and implementation extends beyond purchase to "use" and is more unconventional in the product development arena. However, the perspective of use is relevant and timely. Increasingly, innovative companies are looking beyond product sales to the customer's experience in applying and incorporating a technology.[38] In part, the need to attend to technology use is arising out of the process-intensive nature of new software technologies. More significantly, the attention that vendors and tool builders are giving to adoption and implementation processes reveals the software community's growing concern with technology maturation, with making necessary links between technology development and transition.

[38] One forward-looking tool builder in the area of software configuration management (SCM) now sells what it calls "adoption services" packages. These packages were designed to help clients achieve maximum benefit from the implementation of the SCM tool they were purchasing.

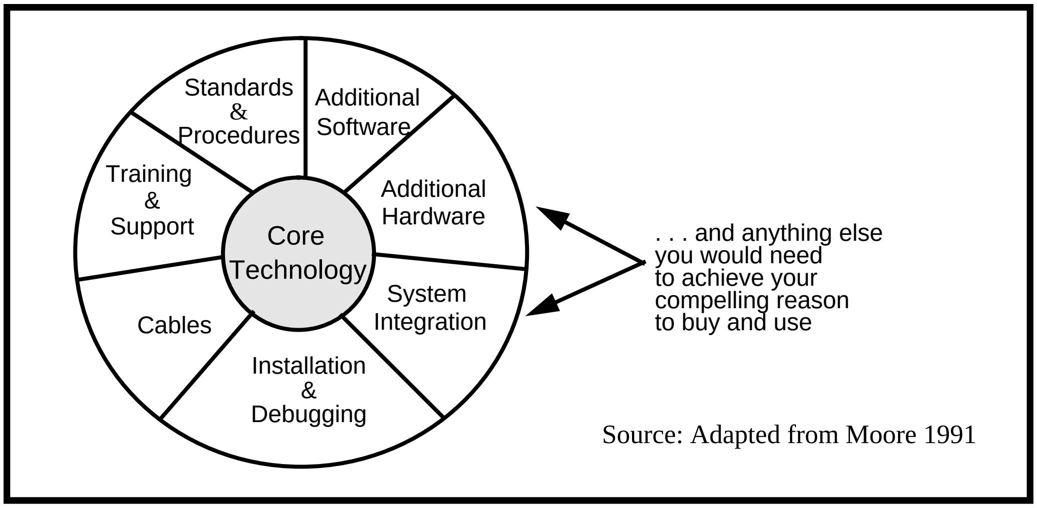

Figure 6-1: The Whole Product

Whole products are the embodiment of the maturation process. They consist of the creation of a robust technology that is commercial grade; that is, the technology is in product form, has a reasonable user interface, and performs reliably. Related products and services such as hot-lines, training, consulting, and documentation exist; distribution channels have been established; and bundling with related technologies has been accomplished through value-added re-sellers (VARs) or the equivalent. Based on these distinctions, we hypothesize that a “majority” adopter population [Rogers, 1983] is less likely to succeed with the introduction of an immature technology—one that has not been commercialized—because of their intolerance for missing aspects of the whole product.

By contrast, the people we interviewed at ComCo functioned almost as co-developers; they counterbalanced the immaturity of RMA by building an “in-house” version of a whole product, one tailored for internal use. Because of this willingness to negotiate gaps or missing pieces in the emergent technology, we see ComCo as an “early adopter” population. We noted earlier that two aspects of the organization were key in making compensation for immaturity possible: infrastructure and innovative culture. However, while these characteristics may signal early adopter tendencies, a qualification must be made. Classifying how individuals take up innovations by adopter category is more suggestive than definitive. Similarly, since organizations frequently display multiple traits, population profiles should not be endorsed wholesale. For instance, an organization may be innovative with respect to its R&D portfolio and cautious with respect to its use of enabling technologies to support development. Some organizations, especially small ones, may be hard pressed to support innovative activities on *all* fronts; and large organizations like ComCo can be viewed as using the fruits of history and profit margins—its infrastructure and deep pockets—to support aggressive innovation. With these caveats in mind, we say that ComCo’s behavior with respect to RMA revealed an early adopter disposition—a willingness to engage in joint exploration and to take calculated risk.

At what level of maturity, then, was RMA? Specific information about the status of the technology is in order. The interviewees we spoke with had access to a limited set of products[39] and services during the time that they were attempting to use RMA. Many of these products had been extended and adapted for use by the organization. Several SEI technical papers described RMA theory and application [Sha & Goodenough, 1990; Sha, Klein, & Goodenough, 1991]. A technical tutorial (developed by the SEI) had been adapted by ComCo and was taught internally as a two-day seminar. The organization had also funded university development of a prototype tool. Demonstration software had been developed in-house and was used by the change agent (DV) as proof of the practical applicability of RMA.[40] Thus, the change agent had acquired not only theoretical knowledge but significant application skills, and he was positioned to help others who expressed interest. Initially, training was available from the change agent and from the initiating sponsor (who acted as an advocate for RMA across multiple sites). In addition, ComCo had developed and delivered a three-hour technical overview for executives.

This collection of products and services might seem to imply whole product maturity; however, each component, other than the technical papers, was custom developed or adapted for ComCo rather than supplied by a commercial vendor. The individual components were discrete and had not been designed to be integrated or compatible. In fact, while interviewees spoke highly of the change agent, they expressed concern that only one very limited tool was available, and they indicated eagerness to obtain the engineering handbook on RMA that was under preparation at that time [Klein, Ralya, Pollak, Obenza, & Gonzalez Harbour, 1993]. They remarked that the classroom training provided “concepts that are relatively simple to grasp” but that “modeling a system [is] much more difficult,” and that it was helpful to have either the champion or the change agent “for a couple of weeks.”[41] Despite these difficulties, application of RMA did occur, and the interviewees agreed that RMA was an important technology that should be used whenever possible. Nonetheless, ComCo’s adaptation and enhancement of the SEI based-products and services were critical in the introduction and use of RMA during the period spanning 1985-1990.

To summarize, RMA was a relatively mature *technology* but not a mature whole *product*. We believe that features of the organizational infrastructure already described and the attitudes

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39. These “products” are not products in the usual commercial sense of being packaged and sold. Perhaps it is most appropriate to view them as elements or components of an embryonic “whole product.”

40. It was in the preparation of this demonstration software that the change agent acquired significant expertise in the application of RMA.

41. In Section 5.5, *Attributes of Innovation*, we referred to GP’s comments on perceived advantage (see pp. 45-46). When we asked GP about how RMA was relevant to his work, he said, “I’m not sure it was relevant. We went along with [the change agent, DV] because we were one of the first Ada programs. DV’s model sounded like it would give us insight into tasking and priorities. After the fact, it was helpful, but I don’t think our program fit the model. We didn’t have severe timing constraints.” We recall that our informant observed that, at that time, RMA technology may not have been sufficiently mature to bridge the gap and meet GP’s concerns about their system, which was event-driven. We also observed that SN, another software engineer and colleague of GP, had difficulty trying to extrapolate the model from periodic to aperiodic tasks. He noted that the tutorial made it seem easy, but the real world was different. SN’s perception of relative and limited advantage was also tied to the immaturity of the technology—and the missing tools, training, and materials that would have more readily enabled engineers to translate RMA theory to practice. Our technical informant also considered this to be so.

revealed by the interviewees' comments offer evidence for an innovative corporate culture. A culture similar to this appears to be prerequisite to the successful adoption and implementation of immature technology; that is, technology that has not been fully developed into a product. When products and services adjunct to a technology are not commercially available, an organization with a culture of innovation can compensate, as was the case with this organization. Moreover, the infrastructure that was in place existed to handle a continuing stream of new technologies, thus minimizing the need to make special arrangements for any one technology.

In the interim, RMA continues to evolve toward becoming a whole product. A second RMA Users Forum has been held since these interviews were conducted. Presently, two commercial vendors offer training. The handbook that several interviewees saw as necessary to fill a critical gap was published in 1993. In addition, almost all of the interviewees expressed the need for a tool to support RMA; now, two tool builders (who attended the second RMA Forum) are developing commercial tools.

In effect, what the large organization with "early adopter" characteristics was able to create internally is gradually becoming available in the commercial marketplace. The existence of a tool, which seems likely, in combination with these new products and services, will mark RMA's passage to a mature whole product. At that time, we suspect that the range of organizations able to use the technology will broaden. Previously, an organization without a culture of innovation or the infrastructure of the kind discussed here, or without the willingness and resources to build infrastructure, would have been hard pressed to successfully introduce and use RMA.

6.2 Developers of Maturing Technologies

What can be learned from the RMA case study? We might assume that the lessons and implications associated with the study would be most relevant to individuals who work to pull innovations “into” their organizations: technology receptors. Often, these receptors are members of software engineering process groups (SEPG) or advanced technology groups. They scan the horizon for new technologies and, downstream, they act as change agents in the process of introduction. Certainly, the study has implications for the technology receptor community. However, in a larger sense, the agents of change for technology maturation include *all* the individuals along the continuum from development to transition. In other words, meaningful lessons for development often come not from development alone, but from use. In the same spirit, the implications of this study on adoption and implementation and the findings related to the theme of the whole product have significance for parties on both sides of the push-pull equation.

In the following subsections, we comment briefly on implications for developers; managers of R&D, including funding agents; and researchers. We offer a final observation on the contribution that research, especially the case study, makes to a greater understanding of technology transition.

Key issues in this area include

- Concurrent technology transition.
- Prototyping of the process of technology introduction.
- Creation of a template for the whole product.

If we see mature technology as readily used or ready-to-use technology, then we must define technology maturation as a combination of technology development and technology transition. Conventionally, software technology transition begins after development, too late to influence the shape of the technology and make it responsive to user needs. The old paradigm precludes meaningful interaction between developers and users.

Leonard-Barton [1988a] describes a process of “mutual adaptation” in which both organization and technology must be adjusted for transition to be considered complete. The process is based largely on research into the transition of complex software innovations such as expert systems and manufacturing systems. The research suggests that those doing the planning for technology transition should anticipate changes not just to the technology (however mature) but to organizational processes as well. Leonard-Barton discusses the idea of reinvention and considers how organizations as well as technologies change as they modify and add value to maturing technologies.

We argue that the concepts of mutual adaptation and the whole product can be extended by the principles of concurrent engineering (see Figure 6-2), and thus lead to an improvement of the effort and time it takes to accomplish software technology transition. Moreover, the approach should lead to improved products, since use of these principles stresses that research, new product development, and implementation issues and tasks are worked concurrently. When this occurs, information about how well the technology is working in context—that is, not just information about how the technology is developing—can be obtained immediately. Two innovative strategies can facilitate concurrent technology transition and significantly reduce the length of time required for creation and diffusion of a mature technology: (1) prototyping the process of technology introduction and (2) creating a template for the whole product.

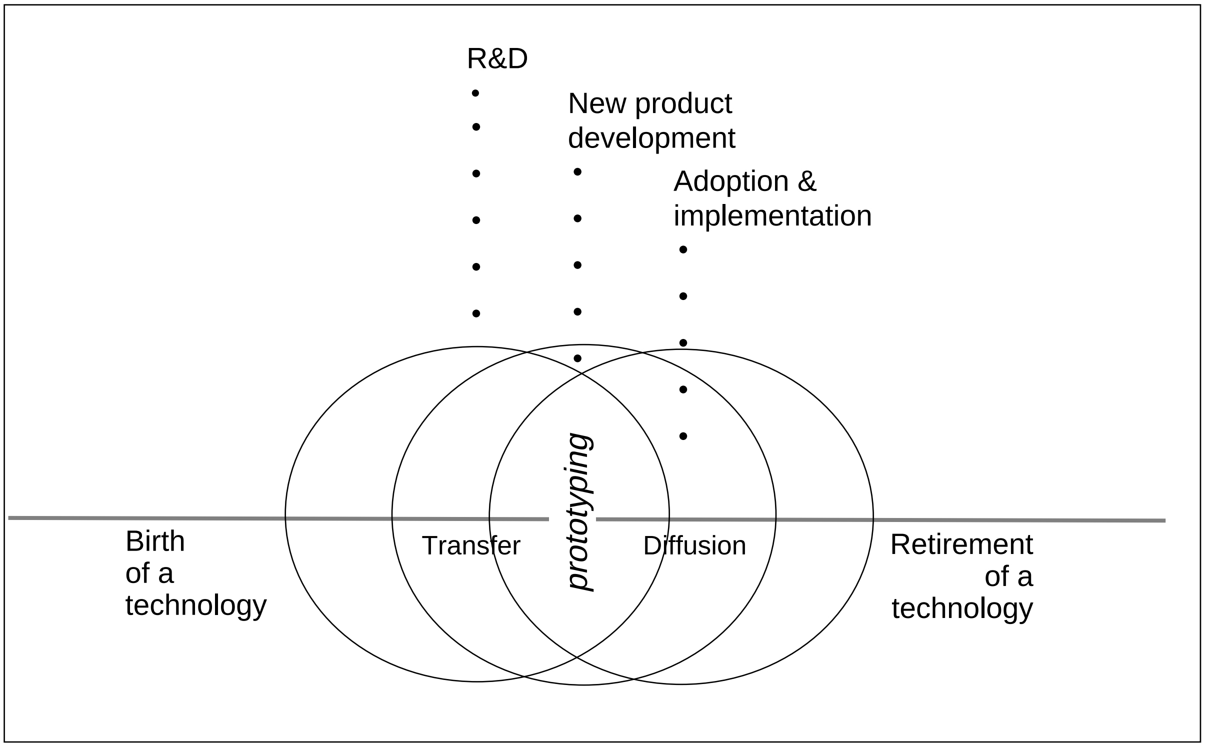

Figure 6-2: Concurrent Technology Transition

Critical information related to the process of introduction for a technology can be discovered and “captured” when the technology is in use at an early adopter or pilot site. What is required for the discovery of this process is attention—attention to the thought processes and behavior of those who are attempting to use the technology in question. In this instance, observing the use of the technology might involve monitoring

1. The innovation-decision process, including how commitment is built and sustained.
2. Usability with respect to how individuals *experience* the technology, since reliance on technology attributes is insufficient.

3. Users' compensatory strategies for coping with problematic or missing aspects of the technology.

4. Adjunct products and services, whether existing or new, that are developed or enhanced to support in-house use.

If the technology is being disseminated or "rolled out" to other parts of the organization, we can also attend to *how* this is accomplished by examining the rollout plan, related briefings to secure buy-in or commitment, and other artifacts designed to support the use of the technology, including coaching, documentation, aids for job performance, etc.

The prototype process of introduction represents one component of what is necessary to ensure use of the in-house whole product. (The equivalent for the commercial whole product would consist of a defined and tested process of adoption and implementation.[42]) Essentially, here we are able to extend Moore's notion of the whole product beyond a concern with purchase to address usage. The question driving the assembly of the whole product, then, becomes: what essential products and services are required to achieve the user's compelling reason to purchase and use the technology? Elements or components might include any of those identified above, including training and support, additional hardware and software, a prepared technical environment, hotlines, etc. The answer to this question, we suggest, can be derived from technology exploration. Thus, if we look to an early adopter site as a testbed, we can observe how a population attempts to use an immature or emergent technology. We can see how and where users expend effort to identify, develop, and/or customize (where possible, to purchase) those whole-product elements that ensure use. By close observation and collaboration, we may work at a site to discover and capture strategic information for transition:

1. A prototype process of introduction.

2. Requirements and specifications for the in-house whole product—the adjunct products and services surrounding the core technology.

The latter information offers us a template for what critical components must exist in the commercial-grade whole product.

The close observation that we advocate may be impossible or inappropriate in some circumstances. For instances in which collaboration with an early adopter site is precluded, developers and practitioners must, nonetheless, continue to reflect on their transition efforts and activities. They must find efficient ways to capture this know-how so that lessons can be shared with others through experience reports. They must consider

- What aspects of the technology maturation process are important?
- How best can they be described?
- To whom are these descriptions relevant?

42. The perspective we are taking here on defined processes for adoption and implementation based on technology use and the user's experience is new. Some basic and/or generic work has been done in this area in conjunction with software process improvement initiatives; however, we are not aware of other substantive explorations aside from our own pilot efforts.

- How early in the maturation of a technology can a transition process be captured and still predict later transition approaches?
- How can we anticipate the needs of the change agents who must introduce the technology under consideration?

These are difficult questions, requiring more than generic answers. Developers and practitioners may want to turn to case study research as well as others' experience reports for guidance in answering these questions.

6.3 R&D Managers and Funding Agents

If transition is a goal early in the development of a technology, then concern about transition success is integral to the development effort. While the need for a detailed vision of application may strike some as obvious, many technology developers are unfamiliar with strategic planning or third-generation R&D management [Roussel, Saad, & Erikson, 1991]. Those funding technology development within their own organizations or in external organizations such as universities appear to expect that the technology being developed will automatically be used. While advice for technologists and managers on processes for selecting an optimal mix of R&D projects is available (for example, Roussel, Saad, & Erickson, 1991), guidance on how to attend to the transfer of specific types of technologies that these projects may develop is rare. In addition, software technologies require a transition—not just a binary transfer—process, and a process not just from R&D to product development, but also (as we have been discussing) from product suppliers into the day-to-day use that reflects incorporation [Zmud & Apple, 1992].

In Part 1 of the case study, we observed that co-development partnerships and distribution partnerships were necessary to ensure the transition of RMA. We also speculated that the SEI Rate Monotonic Analysis for Real-Time Systems (RMARTS) Project engaged third-party vendors for training and publication late in the technology development life cycle. In hindsight, project members observed that partnerships with training firms and tool vendors might have been worked on earlier in the life cycle. We cannot say to what extent the transition of the technology would have been accelerated by focusing on new product development concurrently, alongside technical development and extension.[43] However, managers and funding agents are wise to remember that an increasing number of indicators argue in favor of concurrency and facilitated interaction between technology development and implementation [Leonard-Barton, 1988a; Orlikowski, 1992].

6.3.1 Codiffusion

The principles of concurrent technology transition that we have discussed support the integration of research, new product development, and implementation, making the concept useful

[43] This is a problematic issue. Evidence indicates that accelerating technology transition requires focusing on technology development and product development concurrently. However, if there is no clear existing or potential market, it is difficult to engage the interest of product developers early in the technology life cycle. The question remains: what would make product developers take the leap of faith that they needed to invest earlier than they did?

for developers and R&D managers.[44] A similar shared concern is codiffusion—a critical factor in the strategic management of R&D. By codiffusion, we mean that a technology may be diffused in relation to another technology. This can occur in a number of ways:

- Multiple innovations may spread simultaneously in response to a common need or market condition.
- An innovation may emerge in response to a need or niche created by an earlier commodity.
- An innovation or technology may connect itself to or "piggyback" on a previous entrant.

With the case of RMA, codiffusion occurred with Ada, more specifically with a U.S. Department of Defense initiative to mandate use of the Ada language for mission-critical software-intensive systems.[45] However, the relationship of RMA to Ada was more complex: the association was initially an asset, and then subsequently a constraint. To understand the phenomenon, we must look back at SEI project plans for the emerging technology. In 1989 and 1990, the statement of the project purpose read

> The purpose of the Real-Time Scheduling in Ada Project is to transform a new, analytic approach for designing real-time systems into routine software engineering practice, particularly for systems implemented in Ada.

Two years later, in 1991, the emphasis on Ada was found to be deflecting the attention of potential users from the fact that the theory did not depend on Ada. Therefore, in 1991, the project name changed from *Real-Time Scheduling in Ada* to *Rate Monotonic Analysis for Real-Time Systems*. Moreover, linking the work to Ada was not helping to make the technology easier to transition; it tended to raise questions that ultimately proved irrelevant to the adoption process. The name change also reflected the project's understanding that the theory had a broader range of application than was originally understood. In particular, the project came to realize that the theory could be used to analyze the behavior of systems that had not been designed or implemented with the theory in mind. In this sense, the project was lucky to have picked a theory that turned out to apply so broadly. By 1991, the purpose statement for the project had been tuned to read

> ... to improve the state of the practice for real-time systems engineering by providing a solid scientific foundation for dealing with timing behavior of real-time systems.

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44. Funders need to understand what development and/or transition activities they are funding: where in the value chain or maturation life cycle the technology is, what arena the technology is intended for, and what the relative cost will be. (They will also benefit by attending to the issues for developers described above.) The example of RMA transition does not provide all the answers, but the level of detail about types of activities over a significant time period may stimulate thinking about requirements for other technologies. These requirements might concern staffing, facilities, schedule, and financing.

45. For information on the adoption and history of Ada, see *Ada Adoption Handbook: A Program Manager's Guide* by W. E. Hefley, J. T. Foreman, C. B. Engle, Jr., and J. B. Goodenough, 1992, Technical Report (CMU/SEI-92-TR-29, ADA258937), Software Engineering Institute, Carnegie Mellon University. See also *Understanding the Adoption of Ada: A Field Study Report* by G. N. Smith, W.M. Cohen, W.E. Hefley, & D.A. Levinthal, 1989, Technical Report (CMU/SEI-89-TR-28, ADA219188), Software Engineering Institute, Carnegie Mellon University.

Here, rate monotonic scheduling theory is presented as the technology of choice for accomplishing this, and the project is no longer "focused primarily on scheduling algorithms..." because of the realization that the theory could be applied more widely than was previously understood.

The issue of codiffusion is more complex than this brief characterization allows. For example, from the development perspective, codiffusion is often tied to the vision for the technology. We have seen how RMARTS articulated its purpose and the role of RMA technology. However, aspects of codiffusion were influential, as the project formulated strategies to achieve the vision. This required an understanding of how the technology began. For instance, in 1988 and 1989, RMARTS personnel worked with engineers outside the SEI and learned early about what roadblocks would occur when people tried to adopt RMA to build "real" systems. Knowledge of these obstacles was subsequently translated into questions and actions:

- How would compilers have to change?
- Would engineers see RMA as applicable to the design of new systems and to the tuning and upgrading of old systems?
- What would engineering managers need to know?

Such questions underscore how codiffusion and standardization issues[46] intersect with strategy. The vision for the technology is only meaningful when one considers present conditions —the status quo—in relation to a future state. These considerations take us, in turn, back to a critical technology attribute (especially for those taking a systems perspective): namely, compatibility.

Our discussion may suggest that codiffusion is only relevant to development and strategic management. However, this is not the case; the individuals we interviewed at ComCo, Woodville were well aware of the early relationship between real-time scheduling, RMA, and Ada. In fact, as we have indicated, it was this perception (that RMA was tied only to Ada) that prompted the project to change its name and adjust the nature of the RMARTS purpose statement. Nonetheless, at ComCo, RMA was perceived as a means to successfully deal with Ada systems, even though most recognized that the utility of the analytical approach extended beyond Ada.

For example, GP, software engineer, commented that initially he wasn't "sure that RMA was relevant." He said they "went along with [the change agent] because they were one of the first Ada programs. [DV's] model sounded like it would give us insight into tasking and priorities.... We were in the dark about Ada and saw this as a way to address tasking problems." The system that GP referred to was in high-level design when it was determined that they would switch to Ada from C. GP remarked that they had assumed that "they would get an Ada waiver; and they said 'help' when they needed to make the switch to Ada." SN, software engineer, referred to "one particular function—audio—[volume control] where we wanted a high-priority

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46. Codiffusion and standards development sometimes blur, so that the difference between these two efforts may depend on the intent of those who jump in. For example, SEI standards work sought leverage for the technology itself and also sought to ensure that new and existing standards did not preclude the use of RMA.

message, and the model [RMA] helped us." SN found that the "Ada compiler didn't have the interrupt capability, even though it was advertised as such." RB, manager (OCR systems), succinctly summarized his early impression of associations between RMA and Ada. When we asked him if he had been able to observe how RMA was helpful to others, he said, "Initially, no. We didn't see its usefulness early on. We did not apply it to what we were doing. If we weren't doing a real-time application, it wasn't to be applied. 'I don't have a need because I'm not using Ada' was a typical argument." Five of the ten individuals we interviewed mentioned Ada in some detail.

6.4 Transition Research

The case study on the transition of RMA represents a single effort to understand the complex processes of software technology transition and diffusion. To gain a full understanding of this area, researchers must consider both sides of the technology push-pull equation and attend to the full range of transfer conditions, from R&D, through new product development, to adoption and implementation in an organizational setting. Such an understanding of technology transition requires crossing boundaries between disciplinary communities and between the arenas of academia, industry, and government. The latter is a difficult task—each discipline and each arena speaks about and investigates technology transfer in a different way [Fowler & Levine, 1993; Rogers, 1983; Tornatzky & Fleischer, 1990].

Additional case study research on technology transition in general and software technology transition in particular is essential. Researchers must continue to explore the circumstances and surrounding conditions for transferring software tools, techniques, or practices, as opposed to other kinds of technologies. Such distinctions will become critical as more and more technology is layered—and as software is embedded within other technologies. Within the software transition arena, researchers must begin to focus on a taxonomy of technology types and consider distinctions between tools, techniques, integrated toolsets, and larger ill-defined process-based technologies. Because of its nature, software raises fundamental questions about process- and product-based technology. Understanding these relationships will help create new taxonomies for technology beyond current manufacturing operation distinctions, such as customer technology, small and large batch, mass production, etc. [Woodward, 1965; Khandwalla, 1974]

Case study research can provide the basis for understanding software technology transition issues generally and for exploring transition with respect to specific technology types and organizational settings. How does the transition of RMA compare to that of a

- CASE tool?
- Software development environment?
- Human behavior-intensive technology such as software inspections?

- Tool-based technology such as project management that also requires human behavioral changes in attention to detail?
- Grand-scale composite technology such as software process improvement?

Finally, how does the transfer of these technologies vary with respect to the nature of the receiving organization or environment?

In exploring these and other questions, researchers must be willing to innovate and to borrow methods of inquiry from the many disciplines that shed light on the process of technology transition. For example, the study of RMA raises interesting questions about the types of people involved and the communities that they represent. A full history and communication-network analysis might provide additional clues to issues of diffusion and influence.

Case study research offers us a way to understand, in depth, how software technologies can be effectively (or ineffectively) transitioned. Such studies support the goals of technology developers, their managers and funding sources, and researchers alike. They reflect and honor the complexity of real transition situations, and also, as their number increases, provide a basis for common understanding of a range of transition experience for software technologies.

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References

Ackerman, A., Fowler, P., & Ebenau, R. G. (1983). Software inspections and the industrial production of software. *Proceedings of the Symposium on Software Validation* (pp. 13-43). Darmstadt, FRG: GMD and SRI International, Elsevier Science Publishers.

Adler, P.S. & Shenhar, A. (1990). Adapting your technological base: The organizational challenge. *Sloan Management Review 32*(1), 25-37.

Augliere, R. (1994). Technology assessment: Old and new. *Software Engineering Technology Transfer Newsletter 2*, IEEE Computer Society Technical Committee on Software Engineering, Subcommittee on Software Engineering Technology Transfer (April), 2-4.

Botkin, J. & Matthews, J. (1992). *Winning combinations: The coming wave of entrepreneurial partnerships between large and small companies*. New York: John Wiley & Sons, Inc.

Bouldin, B. (1989). *Agents of change: Managing the introduction of automated tools*. Englewood Cliffs, N.J.: Yourdon Press.

Chadwick, B.A., Bahr, H.M., & Albrecht, S.L. (1984). *Social science research methods*. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Conner, D.R. & Patterson, R.W. (1982). Building commitment to organizational change. *Training and Development Journal*, April 1982, 18-30.

Deal, T.E. (1991). Developing a quality culture. In R.H. Kilmann (Ed.), *Making organizations competitive* (pp.156-175). San Francisco, Calif.: Jossey-Bass.

Dean, J.J. (1987). *Deciding to innovate: How firms justify advanced technology*. Cambridge, Mass.: Ballinger Publishing Company.

Downs, G.W. & Mohr, L.B. (1976). Conceptual issues in the study of innovation. *Administrative Science Quarterly 21*, 700-714.

Eason, K. (1988). *Information technology and organizational change*. London: Taylor & Francis.

Fagan, M. (1976). Design and code inspections to reduce errors in program development. *ComCo Systems Journal 15*(3), 182-211.

Fichman, R.G. & Kemerer, C. (1993). Adoption of software engineering innovations: The case of object orientation. *Sloan Management Review*, Winter 1993, 7-22.

Fiman, B. (1989). *Implementing change*. Training course licensed by Implementation Management Associates, Inc. IMA, Golden, Colorado.

Fliegel, F.C., Kivlin, J.E., & Sekhon, G.S. (1968). A cross-national comparison of farmers' perceptions of innovations as related to adoption behavior, *Rural Sociology 33*, 437-449.

Fowler, P. & Levine, L. (1992a). Software technology transition: Life cycles, models, and mechanisms. Pittsburgh, Pa.: Carnegie Mellon University, Software Engineering Institute, *Bridge* (October), 3-8.

Fowler, P. & Levine, L. (1992b). Toward a problem solving approach to software technology transition. In J. Van Leeuwen (Ed.), *Proceedings of the IFIP 12th World Computer Congress, vol. 1* (pp. 57-64), Madrid, Spain. The Netherlands: North Holland, Elsevier Science Publishers.

Fowler, P. & Levine, L. (1994). From theory to practice: Technology transition at the SEI. In *Proceedings of the Hawaii International Conference on System Sciences*, Maui, Hawaii. IEEE Computer Society Press.

Fowler, P. & Maher, J. (1992). *Foundations for systematic software technology transition*. Software Engineering Institute Technical Review '92, 1-32.

Fowler, P. (1990). Technology transfer as collaboration: The receptor group. *Proceedings of the 12th International Conference on Software Engineering* (pp. 332-333), Nice, France. U.S.: IEEE Computer Society Press.

Geertz, C. (1973). Thick description: Toward an interpretive theory of culture. In *The interpretation of cultures: Selected essays.* New York: Basic Books, Inc.

Gibbs, W. (1994). Software's chronic crisis. *Scientific American 271*(3*),* September, 86-95.

Glynn, G. (1990). Semi-formal process model for technology transfer. *Proceedings of the 12th International Conference on Software Engineering* (pp. 334-335), Nice, France. U.S.: IEEE Computer Society Press.

Grady, R.B. & Caswell, D.L. (1987). *Software metrics: Establishing a company-wide program*. Englewood Cliffs, N.J.: Prentice-Hall, Inc.

Hefley, W.E., Foreman, J. T., Engle, C.B. Jr., & Goodenough, J. B. (1992)*. Ada adoption handbook: A program manager's guide* (CMU/SEI-92-TR-29, ADA258937). Pittsburgh, Pa.: Software Engineering Institute, Carnegie Mellon University.

Humphrey, W.S. (1988). Characterizing the software process, *IEEE Software 5*, 73-79.

Kanter, R. M. (1983). *The change masters*. New York: Simon and Shuster.

Khandwalla, P.N. (1974). Mass output orientation of operations technology and organizational structure. *Administrative Science Quarterly 19*, 74-97.

Kim, D.H. (1993). The link between individual and organizational learning. *Sloan Management Review*, Fall, 37-50.

Klein M. et al. (1993). *A practitioner's handbook for real-time analysis: Guide to rate monotonic analysis for real-time systems.* Boston, Mass.: Kluwer Academic Publishers.

Leonard-Barton, D. (1988a). Implementation as mutual adaptation of technology and organization. *Research Policy 17*, 5 (Oct. 1988), 102-110.

Leonard-Barton, D. (1988b). Implementation characteristics of organizational innovations. *Communication Research 15*, 603-631.

Leonard-Barton, D. (1990). The intraorganizational environment: Point-to-point versus diffusion. In F. Williams & D.V. Gibson (Ed.), *Technology transfer: A communication perspective*. Newbury Park, Calif.: Sage Publications.

Levine, L. (Ed.). (1994). *Diffusion, transfer and implementation of information technology. Proceedings of the IFIP TC8 Working Conference*. Pittsburgh, Pennsylvania, Amsterdam: North-Holland, Elsevier Science.

Liu, C.L. & Layland, J.W. (1973). Scheduling algorithms for multiprogramming in a hard real-time environment. *Journal of the Association for Computing Machinery 20,* 46-61.

Moore, G. (1991). *Crossing the chasm: Marketing and selling technology products to mainstream customers*. Harper Business.

Morgan, G. (1986). *Images of organization*. Beverly Hills, Calif.: Sage Publications.

Nord, W.R. & Tucker, S. (1987). *Implementing routine and radical innovations*. Lexington, Mass.: D.C. Heath.

Orlikowski, W. J. (1993). CASE tools as organizational change: Investigating incremental and radical changes in systems development. *MIS Quarterly 17*(3), 309-340.

Orlikowski, W. J. (1992). The duality of technology: Rethinking the concept of technology in organizations. *Organization Science 3*(3), 398-427.

Paulk, M. et al. (1991). *Capability maturity model for software*. (CMU/SEI-91-TR-24, ADA240603). Pittsburgh, Pa.: Software Engineering Institute.

Peters, T. & Waterman, R. (1982). *In search of excellence.* New York: Harper & Row.

Pollak, W. (1993). Standards: Leverage for new technologies. Pittsburgh, Pa.: Carnegie Mellon University, Software Engineering Institute, *Bridge* (October), 1-7.

Pressman, R. S. (1988). *Making software engineering happen: A guide for instituting the technology*. Englewood Cliffs, New Jersey: Prentice-hall, 1988.

Przybylinski, S., Fowler, P., & Maher, J. (1991). *Software technology transition*. Tutorial presented at the 13th International Conference on Software Engineering, Austin, Texas, May 1991.

Redwine, S.T., Becker, L.G., Marmor-Squires, A.B., Martin, R.J., Nash, S.H., & Riddle, W.E. (1984). *DoD related software technology requirements, practices, and prospects for the future*. (Technical Report IDA Paper P-1788). Alexandria, Va.: Institute for Defense Analysis.

Roberts, E. (1991). *Entrepreneurs in high technology: Lessons from MIT and beyond*. New York: Oxford University Press.

Rogers, E.M. (1983). *Diffusion of innovations*. New York: Free Press.

Rothman, J. (1974). *Planning and organizing for social change: Action principles from social science research*. New York: Columbia University Press.

Roussel, P.A., Saad, K.N., & Erickson, T.J. (1991). *Third generation R&D: Managing the link to corporate strategy*. Boston: Harvard Business School Press.

Santosus, M. (1994). Down to earth. *CIO*, April 15, 54-60.

Sha, L. & Goodenough, J.B. (1990). Real-time scheduling theory and Ada. *IEEE Computer* *23*(4): 53-62, April 1990.

Sha, L., Klein, M.H. & Goodenough, J.B. (1991) *Rate monotonic analysis for real-time systems* (Technical Report CMU/SEI-91-TR-6, ADA235641). Pittsburgh, Pa.: Software Engineering Institute, Carnegie Mellon University.

Smith, G. N., Cohen, W.M., Hefley, W.E., & Levinthal, D.A. (1989). *Understanding the adoption of Ada: A field study report* (Technical Report CMU/SEI-89-TR-28, ADA219188). Pittsburgh, Pa.: Software Engineering Institute, Carnegie Mellon University.

Souder, W.E. (1987). *Managing new product innovations*. New York: Lexington Books.

Souder, W.E., Nashar, A.S., & Padmanabhan, V. (1990). A guide to the best technology transfer practices. *Journal of Technology Transfer 15*, 5-16.

Tornatzky, L. G., Eveland, J. D., Boylan, M. G., Hetzner, W. A., Johnson, E. C., Roitman, D. & Schneider, J. (1983). *The process of technological innovation* (Productivity Improvement Research Section, Division of Industrial Science and Technology Innovation). Washington, DC: National Science Foundation.

Tornatzky, L. G. & Fleischer, M. (1990). *The processes of technological innovation*. Lexington, Mass.: Lexington Books.

Tornatzky, L. & Klein, K. (1982). Innovation Characteristics and innovation adoption-implementation: A meta-analysis of findings. *IEEE Transactions on Engineering Management EM 29*(1), February 1982, 28-45.

Tyre, M. J. & Orlikowski, W. J. (1993). Exploiting opportunities for technological improvement in organizations. *Sloan Management Review*, Fall 1993.

Walton, R.E. (1989). *Up and running*. Boston: Harvard Business School Press.

Williams, F. & Gibson, D.V. (Eds.). (1990). *Technology transfer: A communication perspective*. Newbury Park, Calif.: Sage Publications.

Willis, R. (1983). Technology transfer takes 6 +/- 2 years. In R. Morton (Ed.), *Proceedings of the IEEE Computer Society Workshop on Software Engineering Technology Transfer* (pp. 108-117), Miami Beach, Fla. IEEE Computer Society Press.

Woodward, J. (1965). *Industrial organization: Theory and practice*. London: Oxford University Press.

Yin, R.K. (1984). *Case study research: Design and methods*. Beverly Hills, Calif.: Sage Publications.

Zmud, R.W. & Apple, L.E. (1992). Measuring technology incorporation/infusion. *Journal of Product Innovation Management 9*, 148-155.

Appendix

Interview Questions, ComCo, Woodville
April, 1993

Name:
Project:

Job Title:
Job Description:

No. Years at ComCo:

1. When did you first hear about rate monotonic analysis? Where were you? What was the source?

   Did you hear about it in a journal? Specify.

   Did you read about it in a ComCo document? Specify.

   Did you hear about it at an external event? Specify.

   Did you hear about it at an internal event? Specify.

   Did you read about it on the Internet?

   Did you hear about it from a colleague (in your group, outside your group, or outside ComCo)? Specify.

2. When did you realize that RMA was relevant to your work (to your problem or to your project, etc.)? How did you know it was relevant? What did you consider? (This question is about the possibility of use because of perceived relevance.)
3. Were you able to observe how RMA was helpful to others? (This question is about observability.)
4. When did you *decide* to use RMA? Why?
5. When did you begin using RMA? Why then? For what? How did you use it (in design, analysis, trial use)?
6. How well did RMA fit in with how you do your work? (This question is about compatibility.)
7. Does RMA help you to do things better than you've done before? (This question is about relative advantage.)
8. How easy or difficult was it to use RMA in your work? (This question is about complexity.)

9. Did you try it out? Describe. (This question is about trialability.)
10. Did you continue using RMA? Describe.
11. Are you using RMA now? Describe.
12. Will you continue to use RMA? Why or why not?
13. Are there other technologies that you've explored or used on a trial basis? Specify.
14. Is there anything else related to RMA that you'd like to talk about?

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This case study reports on efforts to introduce a software technology, rate monotonic analysis, into several software-intensive programs at one site within a multinational firm. We describe lessons learned and success factors in the early use of rate monotonic analysis (RMA). We also present evidence that supports the requirement for an internal capability—in the form of technical expertise and infrastructure—to adopt and assimilate this new technology. Finally, the study applies the "whole product" concept for understanding technology adoption and use, showing how one firm compensated for lack of a whole product in its adoption of RMA.

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