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Managing radical innovation: an overview of emergent strategy issues

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Abstract

Despite differences in definitions, researchers understand that radical innovation within an organization is very different from incremental innovation [13,17,21] and that it is critical to the long-term success of firms. Unfortunately, research has also shown that it is often difficult to get support for radical projects in large firms [14], where internal cultures and pressures often push efforts toward more low risk, immediate reward, incremental projects. Interestingly, we know considerably less about the effective management of the product development process in the radical than in an incremental context. The purpose of this study is to explore the process of radical new product development from a strategic perspective, and to outline key observations and challenges that managers face as they move these projects to market. The findings presented here represent the results of a longitudinal (since 1995), multidisciplinary study of radical innovation projects. A multiple case study design was used to explore the similarities and differences in management practices applied to twelve radical innovation projects in ten large, established North American firms. The findings are grouped into three high-level strategic themes. The first theme, *market scope,* discusses the challenges associated with the pursuit of familiar versus unfamiliar markets for radical innovation. The second theme of *competency management* identifies and discusses strategic challenges that emerge as firms stretch themselves into new and unfamiliar territory. The final theme relates to the *people issues* that emerge as both individuals and the project teams themselves try to move radical projects forward in organizations that are not necessarily designed to support such uncertainty.

A breadth of subtopics emerge within and across this framework relating to such ideas as risk management, product cannibalization, team composition, and the search for a divisional home. Taken together, our observations reinforce the emerging literature that shows that project teams engaging in radical innovation encounter a much different set of challenges than those typically faced by NPD teams engaged in incremental innovation.

1. Introduction

The development of new businesses and product lines based on breakthrough innovations—which is critical for renewal of a firm's competitive position—requires management practices that differ substantially from those required for incremental innovation. While incremental innovations are typically extensions to current product offerings or logical and relatively minor extensions to existing processes [13,17], radical product innovations involve the development or application of significantly new technologies or ideas into markets that are either nonexistent or require dramatic behavior changes to existing markets. These radical innovations, in turn, provide the foundation upon which future generations of products are manufactured. Firms that hold the largest share in one product generation often fail to maintain leadership when there is a shift to a new technology [1,6,11,39,41,49]. Effectively developing radical innovations, therefore, is critical to the long-term survival of many of today's firms. The present research examines how firms manage the new product development process for potential game-changers. Using a multiple case study method, we explore and document the development process within twelve projects in nine manufacturing firms over the course of four years.

2. Radical innovation and the firm

Innovation is defined as a new technology or combination of technologies that offer worthwhile benefits. This definition does not delineate the *degree* of departure from existing technology and practices [13,17,18]. Major innovations require new skills, levels of market understanding, leaps in new processing abilities, and systems throughout the organization. The newly developed product or process is

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so distinct from current and existing activities within the firm that the process of bringing the product to market may not closely parallel that of any existing products within the firm. Examples of more radical innovations include the shift from piston aircraft engines to turbojets, the change from steam to diesel electric locomotives, or the move from core to semiconductor memory [49].

2.1. Definitions

Researchers are far from a consensus regarding a formal definition of radical innovation [13,15,17,21]. Recently, there have been attempts to understand and develop a consistent and reliable multidimensional measure of radical innovation. One reliable and valid measure developed by Green et al. [21] incorporates four dimensions: a) technological uncertainty, b) technical inexperience, c) business inexperience, and d) technology cost. The operational definition of radical projects used in this study was consistent with this definition.

Most breakthrough innovations require long-term (typically ten years or longer [38]) development time and millions of investment dollars. The project's longevity means that there is turnover among development team members and senior management that may typically be expected to protect such a risky project. With new management come changes in priorities. These, coupled with other exogenous events, add to the unpredictability of the process, and result in numerous stops and starts, deaths and revivals before such projects are ultimately commercialized [44].

2.2. Importance of understanding radical innovation

Despite differences in definitions, researchers understand that radical innovation within an organization is very different from incremental innovation [13,17,21] and that it is critical to the long-term success of firms. Unfortunately, research has also shown that it is often difficult to get support for radical projects in large firms [14], where internal cultures and pressures often push efforts toward more low risk, immediate reward, incremental projects. Interestingly, we know considerably less about the effective management of the product development process in the radical than in an incremental context. Much has been written regarding the integrated, cross-functional approach to new product development [12,18,20]. Concurrent engineering, Design-For-Manufacturability, and the Stage Gate Model [12] all aim to bring the functional areas together early and frequently in the new product development process. This stream of research has helped improve our understanding of the new product development (NPD) process but has implicitly focused on the development of products that are of an incremental, evolutionary nature.

It is unclear, however, what the landscape for radical NPD looks like, much less if these popular management practices are at all appropriate in developing radical products where uncertainty, risks, and potential rewards are much higher. In fact, there is growing evidence [2,31,45] that these common practices may be detrimental in some environments. In the search for speed to market, researchers and practitioners may have been too quick to generalize the utility of these practices across very diverse environments. Gaining a better understanding of the landscape of radical NPD is a critical first step in being able to judge the appropriateness of these common practices in this turbulent environment.

Since 1995, we have been engaged in a longitudinal study of the managerial processes associated with radical innovation. The specifics of the study are outlined below. Previously published works based on this research program study radical innovation from a variety of perspectives, including, among others, the role of manufacturing in radical innovation [30], market learning [40], and the radical innovation process compared to conventional stage gate approaches [24].[1] The discussion in the present paper outlines findings from a high-level, strategic perspective.

3. The study

The research presented in this article was conducted in cooperation with the Industrial Research Institute (IRI). This study presents the results of a longitudinal (since 1995), multidisciplinary study of the management of radical innovation. Projects were selected for observation while they were on-going and as a result, final outcomes of the projects were not yet known. We chose to collect data in real time rather than retrospectively to control for history effects that so often weaken case study research. While this design parameter was chosen to limit biases that might emerge from respondents tainting their comments in light of the ultimate success or failure of completed projects, it also ultimately limits the extent to which we can be prescriptive in our analysis, at least within the context of an academic audience. Our findings and analysis, therefore, to a large extent describe the managerial challenges and activities we observed in managing these projects.

Data were gathered at multiple times within each of the ongoing projects to effectively track both progress and learning that occurred as the project moved toward the marketplace. Most projects have not yet been introduced to the market and data collection will continue until they are introduced and market and financial performance can be measured.

For the purpose of this study, we defined discontinuous innovation as the creation of a new line of business, both for the firm and for the marketplace. To be selected as a study participant, R&D management in firms identified projects that were formed to the point of having a formal budget, an identifiable team and the potential to impact the market in at least one of the three following ways: offer an entirely new set of performance features, offer a five to 10-fold improvement in known performance features, or offer a significant (30–50%) reduction in costs. As such, the projects chosen for study tend to be new technologies (or previously untried combinations of technologies) focused on either latent or well-known needs, as opposed to new internal business systems innovations.[2] All but two of the projects studied emerged from the firm's R&D lab, having moved from the realm of pure scientific research to becoming a business case. They were viewed internally as products being developed for the market, facing both technical and business/market hurdles along the way. Thus we differentiate this activity from corporate support of basic research (for which there are few directed outcome requirements), which has greatly diminished in American firms in the past 15 years.

3.1. Participating firms

Nearly all the firms that participated in this research were members of the Industrial Research Institute (IRI), a consortium of Fortune 1000 Research and Development managers. IRI representatives volunteered projects on the basis of hearing a proposal about the study at their annual meeting. Volunteered projects were initially screened for appropriateness according to our operational definition described above. Ultimately, the development teams selected were from twelve ongoing projects within ten large, established firms, including Air Products, Analog Devices, Dupont, GE, GM, IBM, Northern Telecom, Polaroid, Texas Instruments and United Technologies Corporation. Researchers signed confidentiality agreements prior to the interviews, so that management practices tied to any specific project or firm are not so identified. The projects and firms span a variety of technologies, markets (consumer and industrial) and production environments (materials processing, fabrication and assembly, and both). This variety in the participating firms' technical and market base was a deliberate research design parameter chosen to increase the external validity of the study's findings, and to assure that our findings are generalizable and not specific to any one type of manufacturing process, market, or industry [29,53]. Each project is more specifically described in Appendix I.

Many of the projects we studied have been underway, in some form or another, for ten years or more. GM's hybrid electric vehicle, for example, has origins that can be traced back to the late 1960s. In an age where speed to market is an increasingly powerful competitive priority, these projects might appear to lumber slowly along like behemoths. This is due largely to the magnitude of newness in the projects themselves. In the hybrid vehicle, for example, GM clearly recognized the appeal of the product, yet needed to work patiently until both technologies and market infrastructures became receptive. While other competitors strove toward the same goals, they also faced the same stumbling blocks along the way. It is important to acknowledge the fact that the high levels of uncertainty surrounding these projects drive them to be extremely long term. Even Nortel's NetActive Channelware product, purely software based, has not yet recouped any financial rewards after more than six years. Simply put, negotiating the uncertainties takes time [7,9]. Funding stops and starts, senior management and corporate contexts change, technical setbacks occur, and market infrastructures must be built [33]. Not one of these projects arose in response to a customer response or a direct competitive threat. They persist on the basis of the nature of the 'big idea' and what it can offer to the marketplace [40]. This is one of the characteristics of these projects that makes them so different from their incremental counterparts, and in turn makes their effective management so difficult.

3.2. Methodology

A multiple case study design was used to explore the similarities and differences between management practices across radical projects within the sample of large firms. The study of radical innovation in large firms is rather early in its development, and as such there exists little theoretical background upon which to draw. Case study research is especially appropriate for this type of exploratory research, with a focus on 1) documenting a phenomenon within its organizational context, 2) exploring the boundaries of a phenomenon, and 3) integrating information from multiple sources [16,29,34]. McCutcheon and Meredith [29] argue that case studies are a powerful tool for gathering information and understanding the real conditions that are occurring in organizations.

To learn about each case, we interviewed senior management (including Directors and Vice Presidents of R&D and Corporate Development), project managers, and individual team members. Using multiple interviewees in such a way reduces the risk of undue influence that an individual interview may have on the case study, and brings a richer portrait of each case [16,19].

3.3. Data analysis

Academics from several functional areas within management were involved in conducting this research, including manufacturing, marketing, strategy, organizational behavior, entrepreneurship, and technology policy. Observations were compared among members of the research team at the conclusion of each visit. Developing a convergence of opinions from the various researchers involved can enhance confidence in the findings: as conflicting views can keep the research from premature closure [16]. Multiple investigators made visits to case study sites in teams; this allowed the case to be viewed from different perspectives. To uncover and examine the key themes in the data, we used the approach outlined by Miles & Huberman [35], Yin [53] and McCutcheon and Meredith [29]. We used a cross case or multicase method for exploring and describing themes. This approach allows us to understand the phenomena beyond

Table 1
Summary of strategic themes

Theme	Issues
Strategic choice regarding market scope	Existing markets • Delivering perceptible benefit • Threat of cannibalization • Overcoming market resistance New markers • Finding a divisional home • Identifying an appropriate business model
Competency management	Competency stretching as part of radical innovation Managing project risk Project management tools and interfaces
The people side of radical innovation	Leadership roles Team composition Role of informal networks

each individual firm's context and increases the generalizability of our observations [16].

The interview data were transcribed and a representative set of the interviews was used to establish common themes emerging from the data. From the themes, seven general categories emerged in which to classify the data. Each interview was then reduced, analyzed, and coded separately by one of the authors and a doctoral student. The results of each independent analysis were then compared. This pattern of coding and data reduction was repeated two more times. This process followed the procedure suggested by Miles and Huberman (35], pg. 57). These codes were then used to retrieve and organize the groupings of data within each firm. Following the same approach described by Miles and Huberman [35], the second author independently developed a set of themes from the data set that were then merged with those developed by the first. Observations and emerging themes were cross-checked with other researchers involved in the innovation study. It is important to note that, as the study continues to evolve due to the ongoing nature of the projects, themes will continue to emerge and evolve as well.

4. Findings

The findings from the study are framed by the three overarching themes, summarized in Table 1. First, we describe issues that emerge as a result of the project's choice of *market scope*. Projects can be directed at markets that are familiar territory to the firm, or may require the creation of entirely new ones. Secondly, the firm's approach to *competency management* drives a number of strategic issues. Radical innovations stretch firms beyond their current scope of capabilities. Third, we identify that *people issues* at a number of levels emerge as critical strategic challenges in managing Radical Innovation in the large established organizational context. Because careers advance, for the most part, on managing efficiency and meeting clearly stated goals, the development of people who understand and thrive in the more chaotic world of radical innovation, fraught with uncertainty and risk, is foreign to the large established organization. Thus each of these issues, and the choices firms make within those domains, become key strategic concerns in managing RI. Within each of these themes, a variety of observations emerge, that, we hope, can enlighten the reader regarding challenges and opportunities associated with creating a context wherein RI can be more effectively managed.

4.1. The choice of market scope

The issue of whether or not a market exists for an innovation is an early, critical differentiator in the challenges that project teams face in managing this process. We observed two kinds of radical innovation. The first serves to strengthen the firm's position with *familiar markets* by bringing breakthrough technologies to them and advancing the state of the art with big leaps. The appropriate SBU home is clear, and the infrastructure for contacting customers, understanding markets, and developing sales forecasts is understood. Five of the twelve projects were directed at existing markets in which the firm either already participated or had the infrastructure in place to enter. The second type of project is an innovation for which the *market is not clearly identified or developed.* While these are the riskier and more uncertain efforts, they are the ones with the potential to move the organization in new directions that provide rich platforms for growth. Seven of the twelve cases fit into this set. See Table 2.

4.1.1. The challenge of familiar markets

Projects targeted at familiar markets face three sets of challenges, all of which revolve around countering resistance and breaking down barriers, both within and outside the organization's boundaries. These include 1) ensuring delivery of a perceptible benefit, 2) managing the threat of cannibalization, and 3) overcoming market resistance to the technology.

In two of the five projects that have been commercialized so far, the benefit that was delivered did not measure up to the promised level, or was not immediately perceptible by customers. In both cases the technology was incorporated into an existing platform as the next incremental innovation in the natural progression of a product family. Depending on how the technology is presented by R&D in terms of application market possibilities, this is the easiest course of action for the business unit. Rather than considering potential application markets that may benefit in discontinuous ways from the technical discovery, we observed in these

Table 2
Divisional homes for projects

	Natural home in a current operating unit	Force fit into a current operating unit	New division	New market targeted	Spin out	Unclear/not yet resolved
P1A		•		•		
P1B	•					
P1C				•		•
P2			•			
P3						•
P4	•					
P5		•		•		
P6						•
P7		•		•		
P8		•				
P9			•			
P10				•	•	
P11		•		•		
P12				•		•

cases that firms opted not to invest the additional resources to develop new potential markets, but rather allowed the potential of the technology to be suboptimally marketed as a next generation product in a familiar market.

Secondly, the project must manage the cannibalization of the current line of business and the associated resistance to the new technology by the operating unit designated to receive the project from R&D and bring it to market. Chandy and Tellis [10] show that a firm's willingness to cannibalize it's current investments in products, assets and organizational routines is, in fact, more important than a firm's size in determining its likelihood of successfully commercializing radical innovations. We noted in one case that the determination of which operating unit the project team elected to work with rested on their judgment regarding which one of several potential operating units would more readily adopt the project. In another case, the R&D team worked hard to convince the operating unit that there 'really wasn't that much new about this,' so as to diminish concerns among operating unit people that they'd have to adopt new procedures. Again, the risks associated with these activities lie in not fully exploiting the market opportunities associated with the innovation because of the fear of reprisal from the operating unit.

The final challenge we identified in this market scope category is the question of whether users will adopt the new technology. Are the benefits big enough to warrant the change and risks associated with adoption of new usage patterns and extreme price levels? We observed that the familiarity of markets breeds, in some cases, an assumption on the part of the project team that the market will clamor for the technology even given new usage requirements that are perceptibly less convenient than customers' current situations offer. In addition, there is a lack of understanding of the level of investment required to develop a market understanding to sufficiently build demand. In these cases, the promises of the big market potential that drove the project at the outset can fail to materialize, and the firm risks the withdrawal of the operating unit's support.

4.1.2. The challenge of market creation

We identified two challenges unique to project teams that chose market applications unfamiliar to the firm. In contrast to the challenges of familiar markets, in which project teams were required to counter resistance and barriers, the challenges of unfamiliar markets lie in requirements to proactively invest in building and creating new domains both within and outside the corporation. Specifically, these include 1) where to locate this business within the firm, given that it has no obvious operating unit home, and 2) how to build an effective business model that takes advantage of the potential the innovation offers.

Unlike most incremental new product development efforts, project teams on most of these radical innovation projects found the need to actively search for a divisional home for their products. Too often, they simply did not fit neatly within existing business structures. Some were avoided because they were a threat to existing operations, and others were viewed as an obligation for the potential host to take on short-term debt. Yet the projects pushed on.

> [Divisions] can't look away from us because they do recognize there is a competitive threat. They really wish that we would go away along with all the other competitors' R&D people, but we won't and our competitors won't. So they have to face the fact that there may be a paradigm change. When it comes time to try to transfer this technology to [the division], that technology had better be good and it better sell itself, because they don't understand it, they didn't develop it, they don't necessarily trust us.

Table 2 illustrates the divisional home for each project. (One project ended up with multiple product platforms, each fitting into a different part of the organization, and so this is indicated as 1a, 1b and 1c). There were new divisions created for two of the projects, and one was spun out of the organization, but the vast majority were either clear fits or force-fitted into an existing division.

We observed a gap in attention to this transition process. There was no recognized mechanism in place to move the development of the project forward to a level acceptable by the operating unit. Operating units typically require a focus on the development of the initial entry application, the development of the list of initial potential customers, the fleshing out of the business plan, complete with forecasts for which there is some comfort level, and some additional engineering development effort. Yet R&D was often primarily focused on technical feasibility. When transitions to the business unit were made before this market development effort is invested, we observed two consequences. One was that the project was allowed to wither in the operating unit because the level of effort required to further its development was not rewarded by conventional operating unit based performance metrics. The second was that the project manager is forced to comply with conventional SBU procedures and submit a business plan with a forecast that he had no confidence in. In one case we observed, the forecast numbers were not met, and the project manager (who had been associated with the project almost from its origin and was transferred with it to the business unit), was sidelined and ultimately left the company. While it is beyond the scope of this study to state conclusively what would help in such situations, our observations certainly tend to support the proposition that a formally recognized transition group of some form might provide assistance in bridging this gap.

The second critical issue that arises in moving into new markets is how the opportunity should be leveraged to make money, or the form that the business model should take. There are typically many choices and many unknowns. The initial promise of a large market may have driven the project, but how to develop it, capture it, and ensure that returns are worth the effort are not trivial issues. Seven of our twelve projects can be categorized as projects that were directed at creating new markets.

Deriving the best business model takes time and experimentation. One project is developing a product platform that will offer entirely new features to the entertainment industry. The project team's business model has changed four times. It has gone from the concept of selling its technology to the public via the internet and gaining revenue from internet merchants, to selling it to producers of music and video games on a contract basis, to creating a series of alliances that will allow the firm to collect a small fee every time a consumer uses their technology, and ultimately, returned to the first model as the infrastructure has developed to support it. Discovering how the market structure works, figuring out how the firm will participate in it in terms of what it will offer and how the firm will ally with other partners to complete the offering is a critical part of new market creation. Interestingly, many project teams did not recognize the significant investment of time and talent required to do this successfully. As one project team member told us

> "We've invested $60 million in developing this technology. I don't want to have to invest another $60 million to develop the market!"

Even when the project team did recognize these requirements, their expectations and those of the management of the ultimate business unit that would commercialize the technology frequently were misaligned regarding how much time and investment was required to build new markets.

4.2. Competency stretching and risk management

The second overarching strategic decision is how competency development is managed. The idea of competencies has been discussed extensively in the literature [26,42], and there is much debate about its definitions and key elements. Prahalad and Hamel [42] define core competence as the "collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams of technologies." (pg. 82) Two defining attributes of competencies are that they are not easily imitated and that they provide firms access to new markets. This idea of core competence is frequently used to explain the process by which firms extend product lines in an incremental way. However, this notion of core competence was also an observable phenomenon within our study. Consistent with the Prahalad and Hamel definition above, we observed the projects building extensively off their respective firms' unique scientific, manufacturing, and market knowledge to effectively move their radical products toward the marketplace.

In their popular work on the subject, Tushman and Anderson [47] suggest that competencies can either be *enhancing,* where they further a firm's leadership position through extension of strengths, or *destroying,* where they replace existing strengths and incumbent firms. While the projects we studied clearly provided support for these concepts, an additional phenomenon emerged as well, which we label competency *stretching.* This stretching took the form of moving to a new direction for the firm (either technologically or through markets). It was not strictly competency enhancing, because it required the creation of truly new abilities and knowledge within the firm. This is one of the key elements of radical innovation projects, and is one that distinguishes them from more incremental efforts. They are more than just enhancing or destroying. The very nature of many of the projects stretches the firm into new directions and ventures. Every project team we observed engaged in learning and stretching the firm into new competency domains.

Our observations imply that competency destruction, enhancing, and stretching are separate, yet critical activities for long-term growth and renewal of large established organizations. As we will discuss, we observed a number of

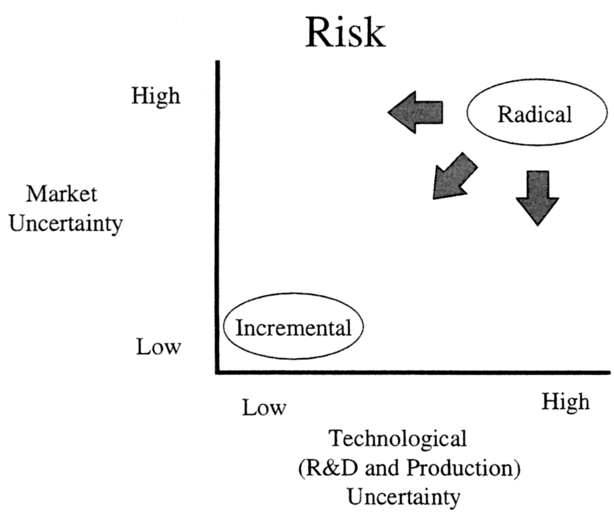

Fig. 1. Uncertainty reduction in radical innovation.

activities that were used to reduce the risk associated with stretching. Further research is needed to explore this relationship between competency destroying, competency enhancing and competency stretching more deeply. For example, the increasingly popular notion of "spinning out" breakthrough innovations poses significant questions when put in the light of competency stretching, as it might imply that this practice undermines long-term internal competency growth and development.

4.2.1. Managing risk associated with competency stretching

Fig. 1 depicts project characteristics classified along dimensions of technical and market uncertainty. This figure derives from a long history of researchers and consultants attempting to classify new product initiatives. Moriarty and Kosnik present a taxonomy of marketing [36] and NPD [37] situations based on technological and market uncertainty. The authors note that the quadrant of high uncertainty on both dimensions requires "high-tech" marketing principles, skills and tactics, which differ from the marketing strategies applied to the other three quadrants. Finally, Veryzer [50] classifies innovations along the dimensions of newness of product capability and newness of technological capability. He labels those innovation efforts that operate in the advanced technology and enhanced capability (as perceived by the market) as technologically and commercially discontinuous. Projects operating in this realm encounter high degrees of uncertainty, in that perceived value from the market may focus on features of the technology not anticipated by the developers [50].

This conceptual framework is useful not only to academic researchers, but also to those in industry as well. When presented with the generic form of this matrix, members of the Industrial Research Institute found it familiar, and labeled the upper right quadrant "suicide square,"[3] indicating their understanding of the risk in working in contexts characterized by high levels of uncertainty on multiple fronts.

We observed three approaches to reduce these risks. These include 1) leveraging from known capabilities, 2) outsourcing, and 3) choosing not to face all the issues of uncertainty concurrently.

4.2.1.1. Leveraging from known capabilities

Each firm's unique, historical knowledge of the enabling technologies served to lower their risk. All projects in the study built upon some form of strong technical competence (as opposed to innovating in a completely new area). By building off of existing strengths, firms effectively shifted their project's location on the grid in Fig. 1 away from the upper right quadrant (high technological **and** market uncertainty). Unique manufacturing knowledge and history in working with a material, for example, acted to make developing the project less uncertain for the innovating firm than it would be for a competitor. In one case, the firm had acquired a number of scientists with unique capabilities in ceramics research. When the firm went through a divestiture, these scientists were retained rather than retired, and were told to focus on a very specific problem for which the firm had no solution. Within a very short period, the project we studied was initiated, due to those unique capabilities that allowed for a wholly novel approach to the problem. R&D managers apply the label 'hinging' to the concept of leveraging the known in one area to strengthen one's prospects as they move into unknown territory.[4]

Outsourcing was a second approach we observed for managing risk. It is less and less common for firms of today to perform all of their critical development activities in house, yet this notion of outsourcing poses distinct challenges for more radical projects [10]. In every project we studied, alliances of some form or another were created to fill competency gaps deemed absolutely critical to the success of the project, yet not available in house. These gaps could be either technical or market based. Through the use of alliances, firms were able to progress their breakthrough projects without having all the skills internally, and were able to reduce their own risk and move out of suicide square, at least temporarily. In most cases, these were very tightly managed partnerships, to the extent that the team chose to use them to develop competencies and learn over time. In one project, for example, the team leader believed that the majority of value in the business his invention would enable would not be in manufacturing the novel computer chip, but rather in designing the newly enabled applications onto the chip. His team, therefore, strived to find a first customer/partner who would design the application, and who would fully disclose the know-how for creating that design to the project team. Other potential partners appeared to offer applications with bigger market promise earlier, but they were not chosen because the project team chose to strategically partner to maximize learning and competency development. In other cases, however, the teams managed the partners with a more hands off relationship, and depended on the partner to take on the risk and concomitant learning that resulted. This occurred in three of the projects we observed. In one project, the team recognized that the application possibilities for the technology they were developing were far removed from any markets the firm had previous experience with and, in fact, the project team recognized that they likely could not envision most of the more interesting ones. Rather than choosing to probe and learn [27,40] on their own, they hired an outside agency with marketing expertise to identify the most likely applications areas and the key potential customers in those arenas.

The third mechanism project teams used to manage risk was simply to *ignore* it and choose not to learn for a period of time, that is, to shelter the project team from some of the risks and issues by not attending to them. For example, one project team expected their technological innovation to result in a substantial cost reduction to the customer. The team worked for more than seven years on the assumption that the cost reduction would be realized, without ever testing it. By simply ignoring one set of uncertainties (or assuming them away), teams could focus their energies on addressing another. While, at many levels, this may seem like dangerous behavior, it was nonetheless a common mechanism we observed. Actively managing so much uncertainty was unpalatable, so they would choose to ignore an entire set so they could at least make progress on something.

The observation that radical innovation projects do not operate constantly in the high market, high technology uncertainty quadrant of Fig. 1 may seem surprising since we have used that conceptual framework to define radical innovation. But the dynamic nature of the project's evolution, and the management techniques applied to this chaotic environment are what we document here. What is reflected in the cases we observed is a way to temporarily suspend parts of the uncertainty so that attention can be focused on one or two problems at a time; not all of them simultaneously.

4.2.2. Project management tools and interfaces

The tools and techniques associated with good project management in incremental NPD could not be applied in the same manner in radical innovation projects. Traditional approaches are based on planning and controlling resources, based on clearly defined objectives, a set schedule and a known budget. Such techniques as PERT/CPM are staples of classic project management, yet seemed largely unworkable in environments wrought with such uncertainty and large-scale changes. Uncertainties that crop up are treated as exceptions to the well-defined development path, and are handled via appropriated "slack time" that's built in to the budget [43]. Various approaches have been proposed for managing innovation projects under conditions of high uncertainty [8,32,46]. Each of these writings defines a disciplined approach to innovation development, allowing for mistakes, discovery of false assumptions, and unexpected outcomes through actions described as 'recycle' or 'redirect.' Similarly, Leonard-Barton's [25] concept of 'failing forward' and Lynn, Morone and Paulson's [27] concept of 'probing and learning' are tools that require flexible, trial and error approaches to managing projects with high levels of uncertainty.

Consistent with these writings, managers in the projects we observed were oriented toward a different set of issues than allocating resources and controlling them towards predictable outcomes. In fact, many of them were concerned about protecting their team from scrutiny if and when they experienced failure. One team leader, for example, maintained two sets of Gantt charts. One he used to manage senior management's expectations, and the other he used to really track progress on the team. He did not put anyone's names next to the tasks listed, because he didn't want anyone to get targeted as failures if deadlines were missed. He knew his team was engaged in very highly uncertain technical development, and the only thing that was certain is that they couldn't predict with accuracy the pace at which progress would be made.

We also observed that, due to the critical contribution of alliance partners in radical innovation, project managers devoted significant time and effort to finding partners for the purpose of accessing competency based resources, and negotiating appropriate relationships. Beyond finding the partners, managing the relationships for competency development was a continuing challenge. In one case, the partnership and codevelopment work went extremely well, but in others, the project team found themselves oftentimes having to develop the intellectual property themselves and handing it off to the partner, or oversee the relationship very tightly such that there was no reduction in workload. In two cases where development was outsourced completely, project teams expressed regret because they not only had not gained the expertise they desired, but, in both cases, were unhappy with the result offered by the partner. In one of those cases, the project shut down completely due to the failure of the partner to deliver the necessary technology. Intellectual property concerns that previously caused firms to steer clear of alliances for breakthrough projects are now a critical challenge for RI project managers and their parent companies. Thus the well-intentioned desire to reduce uncertainty through outsourcing needs to be closely monitored, as it can result in a drain on managerial time and resources, as well as a potential loss of control and missed opportunity for competency stretching.

In addition to the project management challenges posed by external partners for accessing new competencies, we observed project leaders working to manage interfaces between the radical project and the mainstream organization for the same purpose. We noted a tension across the projects between the need to incubate them and the need to interact with the mainstream. Other writers have also noted that boundary-spanning activities vary widely across types of teams [4,5]. Isolation may protect the project from the counterproductive forces within the mainstream, but it also cuts the project off its most important sources of learning, competencies and resources. Further, projects that remained in protection mode too long had trouble gaining legitimacy when seeking a home. A key aspect of an RI project manager's job, we observed, was to manage this balance appropriately. Sometimes the environment was hostile, and other times apathetic. Both had to be overcome in order for the project manager to be able to leverage the firm's assets optimally.

4.3. The people side of radical innovation

Three issues emerge from the data with respect to the role of individuals in radical innovation. These include leadership roles, the composition of the team, and informal networks.

4.3.1. Leadership roles

There were two primary, critical groups of leadership roles we observed in these projects. In our discussion below, we discuss not only what function these Sponsors and Champions played in the development process, but also situations where the uncertain environment posed unique challenges or inefficiencies to these activities.

The sponsor's (a senior management level project supporter) position within each firm varied from the director level all the way up to CEO. Across cases, team members could point to an individual who provided encouragement from above, and financial backing for the projects when traditional measures would point to termination. This was a particularly critical factor in projects with long payback periods. Rather than base decisions on promises of specific economic payback hurdles, sponsors commonly cited continued investment based on a gut feel that the project could have significant impact on the *long-* term success of the firm. Many of the projects would "fall between the cracks" of the existing businesses of their corporations. The sponsor of each of these projects worked to keep them alive (even unofficially), and encouraged business units to adopt them. In five of our cases, senior management sponsors created new business units or spin-off companies to house the innovation. In our sample, we observed that it was critical that each project have someone willing (and in a position) to identify and promote these high-risk, high-potential projects within the firm.

While it is important to recognize the critical role of such sponsors to these projects' survival, it is also interesting to consider the effectiveness of this practice. Over time we began to term this the 'patronage model,' in reference to the artists of the Renaissance period who sought out wealthy patrons to support their ideas and efforts as they worked on their life's masterpieces. While patrons were critical to the artist's success, there was no system for connecting artists to patrons. The search for a patron was not a well-defined process, and there were no clear standards for convincing such a person to fund the artist.

This sponsorship model is similar in the radical innovation projects that we observed. First there is the issue of identifying the appropriate patron. Then there is the more difficult challenge of getting access to him. Finally, there is the challenge of convincing the sponsor of the importance of the project. Our observations suggest that this is not managed in a very systematic way, or with any prescribed set of tools.

Champions provided the operational level enthusiasm and persistence to keep these projects alive "in the trenches." In lieu of conventional financial projections that promise returns above accepted hurdle rates, we found across most projects that the patron had faith in the projects because of personal characteristics of its champion, a lengthy historical relationship between the two, and the champion's track record. Again, this raises obvious questions as to the effectiveness of this practice, both from a standard operating procedure perspective, and also because projects that are kept alive by a senior management patron are extremely vulnerable once the patron retires or moves on. Money, time and individuals' careers devoted to the project are wasted. Six of the twelve projects we studied were affected by senior management turnover. In two of those cases, the turnover resulted in increased attention and resources to the project, but in four of them, the result was in the opposite direction. Aside from finding and convincing a patron, the role of the champion was critical in other aspects as well. When funding went away, they worked on the projects on their own time, and lobbied extensively to get the project back on the map. When funding returned, they became project leaders, and were instrumental in creating and holding together a development team. Their enthusiasm for the projects was palpable. One champion boasted: "People go their whole career, 30 or 40 years, and never have a chance to work on things like this."

While the research on the importance of champions in innovation is inconclusive [22,28], their criticality to the projects we observed is undeniable. We expect that, where support systems, process and infrastructure are lacking for managing radical innovation systematically within a company, its success and drive is dependent on strong, persistent individuals, and thus the importance of individual champions for radical innovation is heightened.

4.3.2. Team composition

While much has been written about the importance of teams in traditional NPD projects, we were curious what practices we would observe in the more uncertain environment of radical innovation. Our findings in this area point to some interesting characteristics of the people on the projects and their backgrounds.

Our observations revealed that the people who sought to join radical innovation development teams were characterized by breadth of experience, in addition to depth. For example, former plant managers, or others who had spent significant time working on operational issues at the plant before moving on to other roles were selected for the team ahead of individuals who might have the greatest or most current knowledge of the operating system. It was clear that a combination of product development skills and functional sophistication (with an emphasis on the *former*) was what was sought after for this liaison position.

The role of marketing differed depending on whether the project was bound for an existing market with which the firm had experience, or for an as yet undeveloped market. For familiar markets, efforts were made to involve marketing people from the business unit in an informal way very early on, to validate the value of the innovation, and to provide links to customers that would provide input. Still, there was only one example of an individual from a business unit joining the team while the work was in being done within R&D. Scientists were the first ones to approach potential users in most cases. This observation is in alignment with Workman [52], who observed a limited role for Marketing in NPD activities in high-tech firms.

Projects directed at new, undeveloped markets added team members from outside the firm that had marketing experience in related markets, relied on scientists to initiate potential contacts in the earliest stages, or relied on the commercial development individuals within R&D to help drive the business related activities of the projects. Thus, the type of marketing expertise required, much like that of manufacturing expertise described earlier, is more broad-based in nature. This result supports Burgelman's [9] observation that this activity is less like New Product Development and more like New Business Development.

4.3.3. *The role of informal networks*

Individuals who operated most successfully in these positions had been with their firm for many (at least 15) years and had typically rotated through a number of positions in several business units before joining a business development group within R&D. The deep informal networks that they could access for information at any time, and experiential knowledge of most of their firms' businesses was invaluable. Said one manager "Because of the way in which managers have grown up around here, you have all these internal networks and webs, and you work them, and that's what makes the place work. It really does."

Team members on every project relied on the existence of large, informal networks of individuals, both inside and outside the company, which could be tapped into as needed to help the development process. These networks provided early validation of business opportunities, in some cases, or helped projects survive when shoestring budgets were in place [30]. Manufacturing networks allowed these projects to make pilot runs at very low costs, which was especially critical when budgetary belts were tightened. As the following quote shows, these networks also had strong ties to the firm's unique production expertise and knowledge—its manufacturing competencies.

> "I've developed a lot of links to discover whose equipment can I use. Well, a new [piece of equipment] is going to cost me 50- to $60,000. I'm not going to get money to do that on [this project], not until an SBU maybe takes it over and has ownership for it. . . . We're not there right now."

Others writer have noted the importance of these networks within the R&D setting, and the importance of professional networks of scientists [3]. We observed that 'communities of practice' [51] transcended laboratory boundaries. Technical experts found one another across organizational divisions, though this happened in an ad hoc manner. Most of these projects required the integration of multiple developing technologies from numerous divisions or research groups within the firm.

5. Discussion and conclusion

The findings of this study provide insight into key strategic issues faced by large firms as they develop radical products. The study describes a breadth of themes that we observed in our sample of projects relating to choice of market scope, competency creation and managemet, and people issues. While the design of our study prohibits prescription per se, our observations and analysis highlight emerging practice, and point to several propositions that appear worthy of further exploration. It is our hope that the themes that emerged from this study will help lay the foundation upon which later research on this important topic can be built. Specifically, this study provided unique insight in several key areas.

We observed that even though it may be that the driving technology is radical, the manner in which the project is managed, and the challenges that the team may expect to encounter, vary dramatically by whether the market exists or requires development. In the case of familiar markets, issues of threat of cannibalization or familiarity with the current business model may cause projects to be managed suboptimally because of inertia provided by mainstream operating units. In the case of completely new markets, the project may proceed more slowly than planned due to lack of attention to market development activities that neither the R&D based team nor the operating unit team are traditionally expected to perform.

The projects in this study extensively utilized existing competencies in the creation of radical products. Firms consistently built off *existing* internal knowledge of markets and technologies to launch into *radical* new product and process areas. In addition, they sought ways to *stretch* their competencies as the development of the invention into a commercial innovation pulled them technically or market-wise somewhat afield from completely familiar turf. Building on internal competencies together with the creation of alliances are methods firms use to reduce the overall risk associated with engaging in radical innovation. While conceptual frameworks used to define radical innovation indicate that it is set in the context of high technical and high market uncertainty [36,37], our observations of the dynamic nature of the process reveal that project teams work hard to reduce uncertainty on some dimensions so that they work on other aspects of the project. Whether or not this is appropriate, or what the decision criteria ought to be for choosing where to close off learning for a time, are clearly issues for future investigation.

The study also illustrates some mechanisms that helped projects, but that may not be explicitly recognized as NPD tools. For example, informal networks within the firm played a large role in the development of these radical projects. These networks were seen as a critical means to gain both market and technical insight, ultimately moving the project forward. The findings of the study as they relate to the integrated approach to NPD were also quite interesting. Interviews with team members across the sample gave credence to the proposition that the commonly held belief in the benefits of getting functional experts in manufacturing and marketing involved early and often in the NPD process might be less appealing in these radical products.

We noted that traditional project management priorities of evaluation, monitoring and control, take on a more minor role in comparison to the concerns about managing market, resource and organizational uncertainties along with the natural technical uncertainties associated with breakthroughs. This observation points to the need for rethinking appropriate management skill sets for radical innovation projects. It may be that negotiation, handling ambiguity, setting a course of action amid skepticism, and managing boundaries between the project team and outsiders (including senior management, the ultimate divisional home, alliance partners and funding sources) in order to set expectations and utilize available resources are among those critical skill sets.

This study also documented the unique difficulties these projects faced as they prepared to leave their respective firms' corporate R&D labs to become part of a division. The timetables, metrics, and people involved in these projects were often incongruent with those of existing divisions, resulting in a host of challenges for the project team. As a result of our observations, we identified a gap that might be filled by some form of interim incubating mechanism in organizations that would serve to bridge the transition from R&D and the business unit. As stated above, however, it is beyond the scope of this study to test this proposition, but it is our hope that this question does receive more research attention in the future.

Taking our observations as a whole, it appears the new insights we bring to light regarding the management of radical innovation point to key ideas. First, we've identified apparent gaps between *current* practice and what our study participants view as *effective* practice. In the big picture, it appears that large established firms too often assume the practices that have worked well for their incremental projects will be useful in more radical environments as well. Instead, our preliminary observations point to the idea that firms might need to create different sets of rules for the two types of innovation. Many incremental practices seem dysfunctional in this arena.

Similarly, these observations highlight the importance of the need to develop and test new practices that managers bringing radical projects along can use with confidence. Time and again, the individuals we studied decried their own lack of confidence in the practices they were using to move their projects forward in their firms. Unlike their incremental counterparts, these projects are rare in their firms, and the organization as a whole does not have the internal experience and expertise to move with confidence. In short, they appear to be pushing toward the need for developing a competency in managing radical innovation. The challenge goes beyond this. It appears important that firms' management recognize the need to build this competency while simultaneously excelling at incremental innovation, with its focus on current customers, speed to market, and intense competition. In our estimation, as well as that of many other writers [23,38,48], it is not an impossible task. Organizations have not been sensitive to the need for different systems, and instead have relied on maverick individuals, working with senior management patrons against the organizational context, to push these through, and then 'retroactively rationalizing' [9] them into the firm's strategy.

While this study highlights a number of important issues and observations regarding the conduct of radical innovation, it treats the issues at a high level. More research is needed in this area. Although our data are notable for its richness and longitudinal nature, it has its limitations. Because we observed ongoing projects, it was not possible to gather data regarding perceptions of product success. Such data would permit examination more akin to hypothesis testing, as opposed to exploratory analysis. The firms in the sample obviously do not represent all mature firms in their respective industries, and the projects clearly do not represent the population of discontinuous innovations. In addition, the process by which we selected these projects may introduce some bias to the findings. Since the projects were volunteered by their firms, for example, it is likely that they were of higher profile and more strategically critical to their respective firms than those that we might have studied through a random sampling process. This in turn, for example, may increase the likelihood of a sponsor in the organization. These limits may force constraints on the interpretation of the findings, and suggest topics for future research.[5]

Our observations about the importance of internal networks, generalists and business development experts on radical NPD teams also raise key questions. In what ways do these needs change in radical versus incremental NPD?

These observations regarding networks and generalists also raise questions about the extent to which firms need to do more work to actively develop the type of personnel who can become a part of radical NPD teams. For example, further research might explore whether activities such as job rotation effectively encourage both informal networks and act to create the type of generalists seen in these teams. In addition, there is much to be learned about the difficult process we observed relating to moving radical projects from R&D to the divisions. To what extent are these findings transferable to smaller firms pursuing radical NPD? How might incubating structures be created to effectively facilitate this transfer? These and similar questions are clearly worthy of more investigation.

It is our hope that these findings stimulate more research on the dynamic environment and challenges surrounding the development of radical products. Effectively managing radical innovation is absolutely critical to the *long*- term success of the firm, and, as echoed by the project members of the teams we studied, there is much to be learned.

Notes

1. For a complete listing of papers published from this research program, see the annotated bibliography at http:// radicalinnovation.mgmt.rpi.edu/ pubs_academ.asp
2. Our thanks to an anonymous reviewer for pointing out the need for this clarification.
3. These were R&D managers attending a meeting of the Industrial Research Institute in the Spring of 1995, at which we presented our original proposal for this research program.
4. These were R&D managers attending a meeting of the Industrial Research Institute in the Spring of 2000.
5. Again, we'd like to credit an anonymous reviewer for this helpful comment.

Appendix-case descriptions

- Air Products and Chemicals Corporation developed an ionic transport membrane (ITM) using ceramic materials for separating oxygen from air. AP was working on systems to meet the needs of three different application domains. The business model projects new to the world features in two of those application areas, and a greater than 30% cost savings in the third.
- Analog Devices has developed a microelectro-mechanical (MEMS) accelerometer, which is a small microchip that can measure changes in speed. While the application possibilities are nearly endless (e.g., virtual reality games, medical applications to detect changes in the rate of heart pulse), ADI initially used this technology to help move itself into the automotive market space. Even there, potential applications are numerous, but the initial market disruption was to replace current airbag sensors with accelerometers. The cost to the automotive market for the airbag system fell from approximately $500 to $100 per unit.
- Dupont's Biomax® is a polyester material that can be recycled or decomposed. It holds up under normal commercial conditions for a time period established through product specifications. The material decomposes at the right time and under the right conditions. It is environmentally safe at every stage of its decomposition. Chemically, Biomax® represents a new family of highly versatile polymers based on traditional polyethylene terephthalate (PET) technology. Its biodegradable qualities are made possible by the water soluble (hydrolyzable) linkages in its molecular chain. These linkages dissolve as they make contact with water, causing the entire molecular chain to break apart. The remnants are consumed by microbes, which convert them into carbon dioxide and water. The material itself can be made into fibers, films or resins. This makes it suitable for countless agricultural, industrial and consumer product applications: mulch containers, mulching film, seed mats, plant pots, disposable eating utensils, blister packs, yard waste bags, parts of disposable diapers, blown bottles. In the United States alone, where the average household creates over three tons of disposable waste each year, the number of potential applications for Biomax® is immense; its development represents a potentially huge business for DuPont and an important solution to the mounting problem of solid waste in developed countries.
- Dupont was also home to a second project of our study. This was the development on an electron emitting material with properties that made it attractive in electronic display applications.
- GE is well known for its advances in medical diagnostic technology, particularly with respect to imaging systems. One of the most controversial recent innovations in that industry is the advance of Digital X-ray technology. Digital X-ray not only allows for dramatic improvement in the specificity of the image, but also can be sent as a stream of data to a diagnostic bank. That alone allows for remote diagnosing, and has wide ranging implications for staffing of highly paid radiologists at local hospitals and clinics. GE has found a way to combine Digital X-ray technology with Fluoroscopy, a technology that allows the filming and digitization of movement within the body. The combined benefit provides a leap in benefits in the medical imaging field that GE believes will be the next "game-changer."

- GM's focus on alternative power systems for automobiles is widely known. One of the innovation paths down which they, and their counterparts, have been traveling for some time is that of the hybrid electric vehicle. The concept is that power comes from both electrical and conventional engines, each of which is drawn upon at the speeds at which it performs most efficiently. Those technologies, combined with several others such as regenerative braking, could serve to offer a vehicle capable of exceptional gas mileage (50–80 miles/gallon) and exceedingly low emissions of pollutants.
- IBM has commercialized a new microchip based on an alloy of Silicon and Germanium (SiGe), which promises to become the basis for high-performance new transistors with switching speeds up to four times faster than those of traditional semiconductors. SiGe chips also offer several other important additional benefits. First, they can operate using only a fraction of the normal power requirements for competing technologies, such as Gallium Arsenide (GaAs) based chips. Secondly, SiGe can be manufactured with the same costly fabrication equipment used to make conventional silicon chips, potentially avoiding billions in new capital investments. The most promising application arenas are in telecommunications, which is based on analog technology, an arena in which IBM had not previously participated.
- IBM was the second firm that entered two projects for study. The second project was the development and integration of display, memory and battery technologies to enable the creation of an 'electronic book,' though the development of utmost interest was the advance in the display technology.
- NetActive is a spin-off venture of Nortel Networks, though it began as an internal organizational innovation. The innovation is a software capability that allows NetActive to encode game publishers' software in such a way that a user could obtain the application for a fraction of the normal purchase price. The customer must then initialize its use over the internet, and choose from a variety of usage options that allow single use, usage for a specified period of time, or purchase, all with differing fee structures. The customer's credit card is then charged for the given usage selection. Game software and utility software such as tax filing programs are the current most promising applications.
- Polaroid applied highly innovative manufacturing technologies from its traditional product arena to the creation of low-cost, high-capacity computer memory storage devices.
- Texas Instrument's Digital Light Processor is based on the MEMS device described above. The TI projector creates a screen image by bouncing light off of 1.3 million microscopic mirrors squeezed onto a 1 square inch chip, each with the ability to angle itself independently in order to best reflect light. Potential applications exist in the hard copy markets, home movie projection systems, and large screen movie theaters, to name but a few. The first that TI is commercializing are large screen movie projection systems. Movie theater owners can now receive movies from Hollywood producers on Digital Video Disks or even by satellite rather than on heavy reels. Theaters will no longer be limited by a finite number of film prints, so they have increased flexibility in show times and the number of screens showing a particular movie.
- United Technologies' Otis Elevator division has devoted considerable energy to solving the problem of the "mile high building." In the commercial construction industry, limits on building height are not based on any technical constraints other than the problem of the elevator systems. Current systems are limited by the weight of the cable that pulls the elevator. Once the cable gets too long (more than 130 stories), it becomes too heavy to lift. Designing parallel elevator shafts and moving people from one shaft to the other is the current solution to very tall buildings, but at some point, that solution becomes uneconomic because the amount of the building's real estate needed to house the shafts is too high in proportion to the amount available for rent. Otis has developed a system of people movement that solves the problem. It allows for elevator cars to become separated from the shaft, and to move onto other shafts. A combination of horizontal and vertical movement allows for a conservation of shaft space, and opens up the opportunity for thinking about conveyance systems in a completely different light.

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Biographical Sketches

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