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CORE CAPABILITIES AND CORE RIGIDITIES: A PARADOX IN MANAGING NEW PRODUCT DEVELOPMENT

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This paper examines the nature of the core capabilities of a firm, focusing in particular on their interaction with new product and process development projects. Two new concepts about core capabilities are explored here. First, while core capabilities are traditionally treated as clusters of distinct technical systems, skills, and managerial systems, these dimensions of capabilities are deeply rooted in values, which constitute an often overlooked but critical fourth dimension. Second, traditional core capabilities have a down side that inhibits innovation, here called core rigidities. Managers of new product and process development projects thus face a paradox: how to take advantage of core capabilities without being hampered by their dysfunctional flip side. Such projects play an important role in emerging strategies by highlighting the need for change and leading the way. Twenty case studies of new product and process development projects in five firms provide illustrative data.

INTRODUCTION

Debate about the nature and strategic importance of firms' distinctive capabilities has been heightened by the recent assertion that Japanese firms understand, nurture and exploit their core competencies better than their U.S.-based competitors (Prahalad and Hamel, 1990). This paper explores the interaction of such capabilities with a critical strategic activity: the development of new products and processes. In responding to environmental and market changes, development projects become the focal point for tension between innovation and the *status quo*—microcosms of the paradoxical organizational struggle to maintain, yet renew or replace core capabilities.

In this paper, I first examine the history of core capabilities, briefly review relevant literature, and describe a field-based study providing illustrative data. The paper then turns to a deeper description of the nature of core capabilities and detailed evidence about their symbiotic relationship with development projects. However, evidence from the field suggests the need to enhance emerging theory by examining the way that capabilities inhibit as well as enable development, and these arguments are next presented. The paper concludes with a discussion of the project/capabilities interaction as a paradox faced by project managers, observed management tactics, and the potential of product/process development projects to stimulate change.

THE HISTORY OF CORE CAPABILITIES

Capabilities are considered *core* if they differentiate a company strategically. The concept is not new. Various authors have called them distinctive

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competences (Snow and Hrebiniak, 1980; Hitt and Ireland, 1985), core or organizational competencies (Prahalad and Hamel, 1990; Hayes, Wheelwright and Clark, 1988), firm-specific competence (Pavitt, 1991), resource deployments (Hofer and Schendel, 1978), and invisible assets (Itami, with Roehl, 1987). Their strategic significance has been discussed for decades, stimulated by such research as Rumelt's (1974) discovery that of nine diversification strategies, the two that were built on an existing skill or resource base in the firm were associated with the highest performance. Mitchell's (1989) observation that industry-specific capabilities increased the likelihood a firm could exploit a new technology within that industry, has confirmed the early work. Therefore some authors suggest that effective competition is based less on strategic leaps than on incremental innovation that exploits carefully developed capabilities (Hayes, 1985; Quinn, 1980).

On the other hand, institutionalized capabilities may lead to 'incumbent inertia' (Lieberman and Montgomery, 1988) in the face of environmental changes. Technological discontinuities can enhance or destroy existing competencies within an industry (Tushman and Anderson, 1986). Such shifts in the external environment resonate within the organization, so that even 'seemingly minor' innovations can undermine the usefulness of deeply embedded knowledge (Henderson and Clark, 1990). In fact, all innovation necessarily requires some degree of 'creative destruction' (Schumpeter, 1942).

Thus at any given point in a corporation's history, core capabilities are evolving, and corporate survival depends upon successfully managing that evolution. New product and process development projects are obvious, visible arenas for conflict between the need for innovation and retention of important capabilities. Managers of such projects face a paradox: core capabilities *simultaneously* enhance and inhibit development.[1] Development projects reveal friction between technology strategy and current corporate practices; they also spearhead potential new strategic directions (Burgelman, 1991). However, most studies of industrial innovation focus on the new product project as a self-contained unit of analysis, and address such issues as project staffing or structure (Souder, 1987; Leonard-Barton, 1988a; Clark and Fujimoto, 1991. Chapter 9).[2] Therefore there is little research-based knowledge on managing the interface between the project and the organization, and the interaction between development and capabilities in particular. Observing core capabilities through the lens of the project places under a magnifying glass one aspect of the 'part-whole' problem of innovation management, which Van de Ven singles out as '[p]erhaps the most significant structural problem in managing complex organizations today. . . ' (1986:598).

Recent field research on 20 new product and process development projects provided an opportunity to explore and conceptually model the relationship between development practices and a firm's core capabilities. As described in the Appendix, four extensive case studies in each of five companies (Ford, Chaparral Steel, Hewlett Packard, and two anonymous companies, Electronics and Chemicals) were conducted by joint teams of academics and practitioners.[3] (Table 1). Before describing the interactions observed in the field, I first define core capabilities.

Dimensions of core capabilities

Writers often assume that descriptors of core capabilities such as 'unique,' 'distinctive,' 'difficult to imitate,' or 'superior to competition' render the term self-explanatory, especially if reference is also made to 'resource deployment' or 'skills.' A few authors include activities such as 'collective learning' and explain how competence is and is not cultivated (Prahalad and Hamel, 1990). Teece, Pisano and Shuen provide one of the clearest definitions: 'a set of differentiated skills, complementary assets, and routines that provide the basis for a firm's competitive capacities and sustainable advantage in a particular business' (1990: 28).

[1] According to Quinn and Cameron, '(t)he key characteristic in paradox is the simultaneous presence of contradictory, even mutually exclusive elements' (1988:2.)

[2] Exceptions are historical cases about a developing technical innovation in an industry (see for example, Rosenbloom and Cusumano, 1987.)

[3] Other members of the data-collection team on which I served are: Kent Bowen, Douglas Braithwaite, William Hanson, Gil Preuss and Michael Titelbaum. They contributed to the development of the ideas presented herein through discussion and reactions to early drafts of this paper.

Table 1. Description of projects studied

Company	Product/process description
Ford Motor Company	**FX15** Compressor for automobile air conditioning systems **EN53** New full-sized car built on carryover platform **MN12** All new car platform including a novel supercharged engine **FN9** Luxury automobile built on carryover platform with major suspension system modifications
Chaparral Steel	**Horizontal Caster** New caster used to produce higher grades steel **Pulpit Controls** Furnace control mechanism upgrade from analog to digital **Microtuff 10** New special bar quality alloy steel **Arc Saw** Electric arc saw for squaring ends of steel beams
Hewlett-Packard Company	**Deskjet** Low cost personal computer and office printer using new technology **Hornet** Low cost spectrum analyzer **HP 150** Terminal/PC linked to high-end computer **Logic Analyzer** Digital logic analyzer
Chemicals	Special use camera Large format printer for converting digital input to continuous images New polymer used in film 21st century 'factory of the future'
Electronics	New RISC/UNIX workstation Local area network linking multiple computer networks Software architecture for desktop publishing High-density storage disk drive

In this article, I adopt a knowledge-based view of the firm and define a core capability as the knowledge set that distinguishes and provides a competitive advantage. There are four dimensions to this knowledge set. Its content is embodied in (1) employee *knowledge and skills* and embedded in (2) *technical systems*. The processes of knowledge creation and control are guided by (3) *managerial systems*. The fourth dimension is (4) the *values and norms* associated with the various types of embodied and embedded knowledge and with the processes of knowledge creation and control. In managerial literature, this fourth dimension is usually separated from the others or ignored.[4] However, understanding it is crucial to managing both new product/process development and core capabilities.

[4] Barney (1986) is a partial exception in that it poses organizational culture as a competitive advantage.

The first dimension, knowledge and skills embodied in people, is the one most often associated with core capabilities (Teece *et al.*, 1990) and the one most obviously relevant to new product development. This knowledge/skills dimension encompasses both firm-specific techniques and scientific understanding. The second, knowledge embedded in technical systems, results from years of accumulating, codifying and structuring the tacit knowledge in peoples' heads. Such physical production or information systems represent compilations of knowledge, usually derived from multiple individual sources; therefore the whole technical system is greater than the sum of its parts. This knowledge constitutes both information (e.g. a data base of product tests conducted over decades) and procedures (e.g. proprietary design rules.) The third dimension, managerial systems, represents formal and informal ways of creating knowledge (e.g. through sabbaticals, apprenticeship programs or networks with partners) and of controlling knowledge (e.g. incentive systems and reporting structures).

Infused through these three dimensions is the fourth: the value assigned within the company to the content and structure of knowledge (e.g. chemical engineering vs. marketing expertise; 'open-systems' software vs. proprietary systems), means of collecting knowledge (e.g. formal degrees v. experience) and controlling knowledge (e.g. individual empowerment vs. management hierarchies). Even physical systems embody values. For instance, organizations that have a strong tradition of individual vs. centralized control over information prefer an architecture (software and hardware) that allows much autonomy at each network node. Such 'debatable, overt, espoused values' (Schein, 1984: 4) are one 'manifestation' of the corporate culture (Schein, 1986: 7).[5]

Core capabilities are 'institutionalized' (Zucker, 1977). That is, they are part of the organization's taken-for-granted reality, which is an accretion of decisions made over time and events in corporate history (Kimberly, 1987; Tucker, Singh and Meinhard, 1990; Pettigrew, 1979). The technology embodied in technical systems and skills usually traces its roots back to the firm's first products. Managerial systems evolve over time in response to employees' evolving interpretation of their organizational roles (Giddens, 1984) and to the need to reward particular actions. Values bear the 'imprint' of company founders and early leaders (Kimberly, 1987). All four dimensions of core capabilities reflect accumulated behaviors and beliefs based on early corporate successes. One advantage of core capabilities lies in this unique heritage, which is not easily imitated by would-be competitors.

Thus a core capability is an interrelated, interdependent knowledge system. See Figure 1. The four dimensions may be represented in very different proportions in various capabilities. For instance, the information and procedures embedded in technical systems such as computer programs are relatively more important to credit card companies than to engineering consulting firms, since these latter firms likely rely more on the knowledge base embodied in individual employees (the skills dimension).[6]

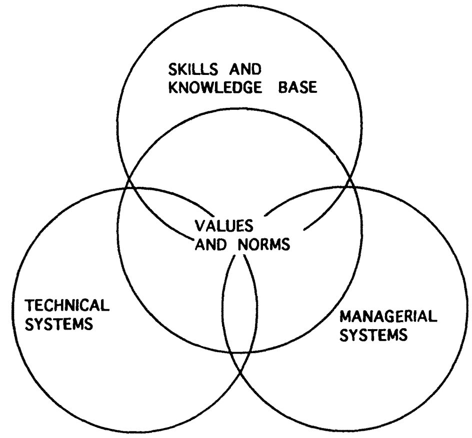

Figure 1. The four dimensions of a core capability.

Interaction of development projects and core capabilities: Managing the paradox

The interaction between development projects and capabilities lasts over a period of months or years and differs according to how completely aligned are the values, skills, managerial and technical systems required by the project with those currently prevalent in the firm. (See Figure 2). Companies in the study described above identified a selected, highly traditional and strongly held capability and then one project at each extreme of alignment: highly congruent vs. not at all (Table 2). Degree of congruence does not necessarily reflect project size, or technical or market novelty. Chaparral's horizontal caster and Ford's new luxury car, for instance, were neither incremental enhancements nor small undertakings. Nor did incongruent projects necessarily involve 'radical' innovations, by market or technological measures. Electronic's new workstation used readily available, 'state-of-the-shelf' components. Rather, unaligned projects

[5] Schein distinguishes between these surface values and 'preconscious' and 'invisible' 'basic assumptions' about the nature of reality (1984: 4).

[6] Each core capability draws upon only *some* of a company's skill and knowledge base, systems and values. Not only do some skills, systems and norms lie outside the domain of a particular core capability, but some may lie outside *all* core capabilities, as neither unique nor distinctly advantageous. For instance, although every company has personnel and pay systems, they may not constitute an important dimension of any core capability.

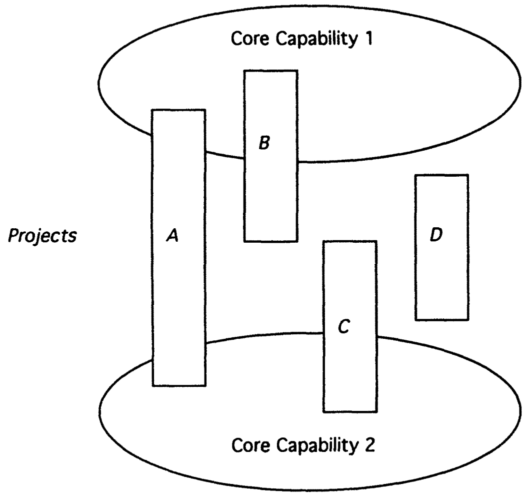

Figure 2. Possible alignments of new product and process development projects with current core capabilities at a point in time.

were nontraditional for the organization along several dimensions of the selected core capability.

For instance, Chemicals' project developing a new polymer used in film drew heavily on traditional values, skills and systems. In this company, film designers represent the top five percent of all engineers. All projects associated with film are high status, and highly proprietary technical systems have evolved to produce it. In contrast, the printer project was nontraditional. The key technical systems, for instance, were hardware rather than chemical or polymer and required mechanical engineering and software skills. Similarly, whereas the spectrum analyzer project at Hewlett Packard built on traditional capabilities in designing measurement equipment, the 150 terminal as a personal computer departed from conventional strengths. The 150 was originally conceived as a terminal for the HP3000, an industrial computer already on the market and as a terminal, was closely aligned with traditional capabilities. The attempt to transform the 150 into a personal computer was not very successful because different technical and marketing capabilities were required. Moreover, the greater system complexity represented by a stand-alone computer (e.g. the need for disk drives) required very untraditional cross-divisional cooperation.

Similar observations could be made about the other projects featured in Table 2. Chaparral's horizontal caster pushed the traditional science of molds to new heights, whereas the arc saw required capabilities that turned out to be

Table 2. Relationship of selected projects with a very traditional core capability in each company studied

		Degree of alignment	
Company name	Traditional core capability	Very high	Very low
Ford Motor Co.	Total Vehicle Architecture	luxury car built on carryover platform (FN9)	compressor for air conditioner system (FX15)
Chaparral Steel	Science of Casting Molds	horizontal caster	electric arc saw
Hewlett Packard	Measurement Technology	low cost spectrum analyzer	150 terminal/ personal computer
Chemicals	Silver Halide Technology	new polymer for film	factory of the future
Electronics	Networking	local area network link	stand-alone workstation

unavailable. The local area networks project at Electronics grew directly out of networking expertise, whereas the new RISC/UNIX workstation challenged dominant and proprietary software/hardware architecture. At Ford, the three car projects derived to varying degrees from traditional strengths—especially the new luxury car. However, the air-conditioner compressor had never been built in-house before. Since all new product development departs somewhat from current capabilities, project misalignment is a matter of degree. However, as discussed later, it is also a matter of kind. That is, the type as well as the number of capability dimensions challenged by a new project determines the intensity of the interaction and the project's potential to stimulate change.

THE UP SIDE: CAPABILITIES ENHANCE DEVELOPMENT

In all projects studied, deep stores of knowledge embodied in people and embedded in technical systems were accessed; all projects were aided by managerial systems that created and controlled knowledge flows, and by prevalent values and norms. That is, whether the projects were aligned or not with the prominent core capability identified by the company, *some* dimensions of that capability favored the project. However, the closer the alignment of project and core knowledge set, the stronger the enabling influence.

In order to understand the dynamic interaction of project with capabilities, it is helpful to tease apart the dimensions of capabilities and put each dimension separately under the microscope. However, we must remember that these dimensions are interrelated; each is supported by the other three. Values in particular permeate the other dimensions of a core capability.

Skills/knowledge dimension

Excellence in the dominant discipline

One of the most necessary elements in a core capability is excellence in the technical and professional skills and knowledge base underlying major products. The professional elite in these companies earn their status by demonstrating remarkable skills. They expect to 'achieve the impossible'—and it is often asked of them. Thus managers of development projects that draw upon core capabilities have rich resources. In numerous cases, seemingly intractable technical problems were solved through engineering excellence. For instance, although engineers working on the thin film media project at Electronics had little or no prior experience with this particular form of storage technology, (because the company had always used ferrite-based media) they were able to *invent* their way out of difficulties. Before this project was over, the geographically dispersed team had invented new media, new heads to read the data off the thin film media, as well as the software and hardware to run a customized assembly and test line for the new storage device.

Pervasive technical literacy

Besides attracting a cadre of superbly qualified people to work in the dominant discipline, time-honored core capabilities create a reservoir of complementary skills and interests outside the projects, composed of technically skilled people who help shape new products with skilled criticism. In the Electronics Software Applications project, the developers enlisted employees through computer networks to field test emerging products. After trying out the software sent them electronically, employees submitted all reactions to a computerized 'Notes' file. This internal field testing thus took advantage of both willing, technically able employees and also a computer system set up for easy world-wide networking. Similarly, Electronics Workstation developers recruited an internal 'wrecking crew' to evaluate their new product. Employees who found the most 'bugs' in the prototype workstations were rewarded by getting to keep them. At Chemicals, developers tested the special purpose camera by loading down an engineer going on a weekend trip with film, so that he could try out various features for them. In these companies, internal testing is so commonplace that it is taken for granted as a logical step in new product/process creation. However, it represents a significant advantage over competitors trying to enter the same market without access to such technically sophisticated personnel. Internal 'field testers' not only typify users but can translate their reactions into technical enhancements; such swift feedback helps development teams hit market windows.

The technical systems dimension

Just as pervasive technical literacy among employees can constitute a corporate resource, so do the systems, procedures and tools that are artifacts left behind by talented individuals, embodying many of their skills in a readily accessible form. Project members tap into this embedded knowledge, which can provide an advantage over competitors in timing, accuracy or amount of available detail. At Ford Motor Company, the capability to model reliability testing derives in part from proprietary software tools that simulate extremely complex interactions. In the full-sized car project, models simulating noise in the car body allowed engineers to identify nonobvious root causes, some originating from interaction among physically separated components. For instance, a noise apparently located in the floor panel could be traced instead to the acoustical interaction of sound waves reverberating between roof and floor. Such simulations cut development time as well as costs. They both build on and enhance the engineers' skills.

The management systems dimension

Managerial systems constitute part of a core capability when they incorporate unusual blends of skills, and/or foster beneficial behaviors not observed in competitive firms. Incentive systems encouraging innovative activities are critical components of some core capabilities, as are unusual educational systems. In Chaparral Steel, all employees are shareholders. This rewards system interacts with development projects in that employees feel that every project is an effort to improve a process they own. 'I feel like this company partly belongs to me,' explains a millwright. Consequently, even operators and maintenance personnel are tenacious innovation champions. The furnace controls upgrade (incorporating a switch from analog to digital) was initiated by a maintenance person, who persevered against opposition from his nominal superiors. Chaparral Steel also has a unique apprenticeship program for the entire production staff, involving both classroom education and on-the-job training. Classes are taught by mill foremen on a rotating basis. The combination of mill-specific information and general education (including such unusual offerings as interpersonal skills for furnace operators) would be difficult to imitate, if only because of the diversity of abilities required of these foremen. They know what to teach from having experienced problems on the floor, and they must live on the factory floor with what they have taught. This managerial system, tightly integrating technical theory and practice, is reflected in every development project undertaken in the company (Leonard-Barton, 1991).

Values dimension

The values assigned to knowledge creation and content, constantly reinforced by corporate leaders and embedded in management practices, affect all the development projects in a line of business. Two subdimensions of values are especially critical: the degree to which project members are empowered and the status assigned various disciplines on the project team.

Empowerment of project members

Empowerment is the belief in the potential of every individual to contribute meaningfully to the task at hand and the relinquishment by organizational authority figures to that individual of responsibility for that contribution. In HP, 'Electronics,' and Chaparral, the assumption is that empowered employees will create multiple potential futures for the corporation and these options will be selected and exercised as needed. The future of the corporation thus rests on the ability of such individuals to create new businesses by championing new products and processes. Since strategy in these companies is 'pattern in action' or 'emergent' rather than 'deliberate' (Mintzberg, 1990), empowerment is an especially important element of their core capabilities, and project members initiating new capabilities were exhilarated by the challenges they had created. The Hewlett Packard printer and the Electronics storage teams actually felt that they had turned the course of their mammoth corporate ship a critical degree or two.

High status for the dominant discipline

A business generally recognized for certain core capabilities attracts, holds, and motivates talented people who value the knowledge base underlying that capability and join up for the challenges, the camaraderie with competent peers, the status associated with the skills of the dominant discipline or function. Each company displays a cultural bias towards the technical base in which the corporation has its historical roots. For Chemicals, that base is chemistry and chemical engineering; for Hewlett Packard and Electronics, it is electronics/computer engineering and operating systems software. A history of high status for the dominant discipline enables the corporation and the projects to attract the very top talent. Top chemical engineers can aspire to become the professional elites constituting the five percent of engineers who design premier film products at Chemicals. At Hewlett Packard and Electronics, design engineers are the professional elite.

A natural outgrowth of the prominence of a particular knowledge base is its influence over the development process. In many firms, a reinforcing cycle of values and managerial systems lends power and authority to the design engineer. That is, design engineers have high status because the new products that are directly evaluated by the market originate in design engineering; in contrast, the expertise of manufacturing engineers is expended on projects less directly tied to the bottom line and more difficult to evaluate. The established, well-paid career path for product designers attracts top engineering talent, who tend to perform well. The success (or failure) of new products is attributed almost entirely to these strong performers, whose high visibility and status constantly reinforce the dominance of their discipline.

As the above discussion suggests, projects derive enormous support from core capabilities. In fact, such capabilities continually spawn new products and processes because so much creative power is focused on identifying new opportunities to apply the accumulated knowledge base. However, these same capabilities can also prove dysfunctional for product and process development.

THE DOWN SIDE: CORE RIGIDITIES INHIBIT DEVELOPMENT

Even in projects that eventually succeed, problems often surface as product launch approaches. In response to gaps between product specifications and market information, or problems in manufacture, project managers face unpalatable choices. They can cycle back to prior phases in the design process (Leonard-Barton, 1988a), revisiting previous decisions higher up the design hierarchy (Clark, 1985), but almost certainly at the cost of schedule slippage. Or they may ship an inadequate product. Some such problems are idiosyncratic to the particular project, unlikely to occur again in the same form and hence not easily predicted. Others, however, occur repeatedly in multiple projects. These recurring shortfalls in the process are often traceable to the gap between current environmental requirements and a corporation's core capabilities. Values, skills, managerial systems, and technical systems that served the company well in the past and may still be wholly appropriate for some projects or parts of projects, are experienced by others as core rigidities—inappropriate sets of knowledge. Core rigidities are the flip side of core capabilities. They are not neutral; these deeply embedded knowledge sets actively create problems. While core rigidities are more problematic for projects that are deliberately designed to create new, nontraditional capabilities, rigidities can affect all projects—even those that are reasonably congruent with current core capabilities.

Skills and knowledge dimension

Less strength in nondominant disciplines

Any corporation's resources are limited. Emphasizing one discipline heavily naturally makes the company somewhat less attractive for top people in a nondominant one. A skilled marketing person knows that she will represent a minority discipline in an engineering-driven firm. Similarly, engineers graduating from top U.S. schools generally regard manufacturing in fabrication industries less attractive than engineering design, (see Hayes *et al.*, 1988) not only because of noncompetitive salaries, but because of a lower level of expertise among potential colleagues.

In each of the nonaligned and hence more difficult projects (Table 2), specific nontraditional types of knowledge were missing. Chaparral Steel's electric arc saw project required understanding electromagnetic fields for a variety of alloys—a very different knowledge set than the usual metallurgical expertise required in casting.

The Hewlett Packard 150 project suffered from a lack of knowledge about personal computer design and manufacture. The company has a long history of successful instrument development based on 'next-bench' design, meaning the engineering designers based their decisions on the needs and skills of their colleagues on the bench next to them. However, such engineers are not representative of personal computer users. Therefore traditional sources of information and design feedback were not applicable for the 150 project. Similarly, the new workstation project of Electronics met with less than optimal market acceptance because the traditional focus on producing a 'hot box,' i.e. excellent hardware, resulted in correspondingly less attention to developing software applications. The knowledge relevant to traditional hardware development flows through well-worn channels, but much less knowledge exists about creating application software. Therefore, the first few working prototypes of the UNIX/RISC workstation were shipped to customers rather than to third-party software developers. While this practice had worked well to stimulate interest in the company's well-established lines of hardware, for which much software is available, it was less appropriate for the new hardware, which could not be used and evaluated without software.

Technical systems dimension

Physical systems can embody rigidities also, since the skills and processes captured in software or hardware become easily outdated. New product designers do not always know how many such systems they are affecting. For example, in the RISC/UNIX workstation project at Electronics, the new software base posed an extreme challenge to manufacturing because hundreds of diagnostic and test systems in the factory were based on the corporate proprietary software. The impact of this incompatibility had been underestimated, given the very tight 8 month product delivery targets.

Management systems dimension

Management systems can grow just as intractable as physical ones—perhaps more so, because one cannot just plug in a new career path when a new project requires strong leadership in a hithertofore underutilized role. Highly skilled people are understandably reluctant to apply their abilities to project tasks that are undervalued, lest that negative assessment of the importance of the task contaminate perceptions of their personal abilities. In several companies, the project manager's role is not a strong one—partly because there is no associated career path. The road to the top lies through individual technical contribution. Thus a hardware engineer in one project considered his contribution as an engineering manager to be much more important than his simultaneous role as project manager, which he said was 'not my real job.' His perception of the relative unimportance of project leadership not only weakened the power of the role in that specific project but reinforced the view held by some that problem-solving in project management requires less intelligence than technical problem-solving.

Values dimension

Core rigidities hampered innovation in the development projects especially along the values dimension. Of course, certain generic types of corporate cultures encourage innovation more than others (Burns and Stalker, 1961; Chakravarthy, 1982). While not disagreeing with that observation, the point here is a different one: the very same values, norms and attitudes that support a core capability and thus enable development can also constrain it.

Empowerment as entitlement

A potential down side to empowerment observed is that individuals construe their empowerment as a psychological contract with the corporation, and yet the boundaries of their responsibility and freedom are not always clear. Because they undertake heroic tasks for the corporation, they expect rewards, recognition and freedom to act. When the contract goes sour, either because they exceed the boundaries of personal freedom that the corporation can tolerate, or their project is technically successful but fails in other ways, or their ideas are rejected, or their self-sacrifice results in too little recognition, they experience the contract as abrogated and often leave the company—sometimes with a deep sense of betrayal.

Engineers in projects that fall towards the 'incongruity' end of the spectrum speak of 'betting their [corporate identification] badges,' on the outcome, and of having 'their backs to the cliff' as ways of expressing their sense of personal risk. One engineering project manager describes 'going into the tunnel,' meaning the development period, from which the team emerges only when the job is done. 'You either do it or you don't. . . You don't have any other life.' Such intrapreneurs seem to enjoy the stress—as long as their psychological contract with the company remains intact. In this case the manager believed her contract included enormous freedom from corporate interference with her management style. When corporate management imposed certain restrictions, she perceived her contract as abrogated, and left the company just 2 months before product launch, depriving the project of continuity in the vision she had articulated for an entire stream of products.

Empowerment as a value and practice greatly aids in projects, therefore, until it conflicts with the greater corporate good. Because development requires enormous initiative and yet great discipline in fulfilling corporate missions, the management challenge is to channel empowered individual energy towards corporate aims—without destroying creativity or losing good people.

Lower status for non-dominant disciplines

When new product development requires developing or drawing upon technical skills traditionally less well respected in the company, history can have an inhibiting effect. Even if multiple subcultures exist, with differing levels of maturity, the older and historically more important ones, as noted above, tend to be more prestigious. For instance, at Chemicals, the culture values the chemical engineers and related scientists as somehow 'more advanced' than mechanical engineers and manufacturing engineers. Therefore, projects involving polymers or film are perceived as more prestigious than equipment projects. The other companies displayed similar, very clear perceptions about what disciplines and what kinds of projects are high status. The lower status of nondominant disciplines was manifested in pervasive but subtle negatively reinforcing cycles that constrained their potential for contributions to new product development and therefore limited the cross-functional integration so necessary to innovation (Pavitt, 1991). Four of these unacknowledged but critical manifestations are: who travels to whom, self-fulfilling expectations, unequal credibility and wrong language.[7]

One seemingly minor yet important indication of status affecting product/process development is that lower status individuals usually travel to the physical location of the higher. Manufacturing engineers were far more likely to go to the engineering design sites than vice versa, whether for one-day visits, or temporary or permanent postings. Not only does such one-way travel reinforce manufacturing's lower status, but it slows critical learning by design engineers, reinforcing their isolation from the factory floor. The exception to the rule, when design engineers traveled to the manufacturing site, aided cross-functional coordination by fostering more effective personal relationships. Such trips also educated the design engineers about some of the rationale behind design for manufacture (Whitney, 1988). A design engineer in one project returned to alter designs after seeing 'what [manufacturing] is up against' when he visited the factory floor.

Expectations about the status of people and roles can be dangerously self-fulfilling. As dozens of controlled experiments manipulating unconscious interpersonal expectations have demonstrated, biases can have a 'pygmalion effect': person A's expectations about the behavior of person B affect B's actual performance—for better or worse (Rosenthal and Rubin, 1978). In the engineering-driven companies studied, the expectation that marketing could not aid product definition was ensured fulfillment by expectations of low quality input, which undermined marketers' confidence. In the Electronics Local Area Network project, the marketing people discovered early on that users would want certain very important features in the LAN. However, they lacked the experience to evaluate that information and self-confidence to push for inclusion of the features. Not until that same information was gathered directly from customers by two experienced consulting engineers who presented it strongly was it acted upon. Precious time was lost as the schedule was slipped

[7] Such cycles, or 'vicious circles' as psychiatry has labeled them, resemble the examples of self-fulfilling prophecies cited by Weick (1979: 159–164).

four months to incorporate the 'new' customer information. Similarly, in the Hewlett Packard printer project, marketing personnel conducted studies in shopping malls to discover potential customers' reactions to prototypes. When marketing reported need for 21 important changes, the product designers enacted only five. In the next mall studies, the design engineers went along. Hearing from the future customers' own lips the same information rejected before, the product developers returned to the bench and made the other 16 changes. The point is certainly not that marketing always has better information than engineering. Rather history has conferred higher expectations and greater credibility upon the dominant function, whereas other disciplines start at a disadvantage in the development process.

Even if nondominant disciplines are granted a hearing in team meetings, their input may be discounted if not presented in the language favored by the dominant function. Customer service representatives in the Electronics LAN project were unable to convince engineering to design the computer boards for field repair as opposed to replacing the whole system in the field with a new box and conducting repairs back at the service center, because they were unable to present their argument in cost-based figures. Engineering assumed that an argument not presented as compelling financial data was useless.

Thus, nondominant roles and disciplines on the development team are kept in their place through a self-reinforcing cycle of norms, attitudes and skill sets. In an engineering-dominated company, the cycle for marketing and manufacturing is: low status on the development team, reinforced by the appointment of either young, less experienced members or else one experienced person, whose time is splintered across far too many teams. Since little money is invested in these roles, little contribution is expected from the people holding them. Such individuals act without confidence, and so do not influence product design much—thus reinforcing their low status on the team.

THE INTERACTION OF PRODUCT/PROCESS DEVELOPMENT PROJECTS WITH CORE RIGIDITIES

The severity of the paradox faced by project managers because of the dual nature of core capabilities depends upon both (1) the number and (2) the types of dimensions comprising a core rigidity. The more dimensions represented, the greater the misalignment potentially experienced between project and capability. For example, the Arc Saw project at Chaparral Steel was misaligned with the core metallurgical capability mostly along two dimensions: technical systems (not originally designed to accommodate an arc saw), and more importantly, the skills and knowledge-base dimension. In contrast, the Factory-of-the-Future project at Chemicals challenged all four dimensions of the traditional core capability. Not only were current proprietary technical systems inadequate, but existing managerial systems did not provide any way to develop the cross-functional skills needed. Moreover, the values placed on potential knowledge creation and control varied wildly among the several sponsoring groups, rendering a common vision unattainable.

The four dimensions vary in ease of change. From technical to managerial systems, skills and then values, the dimensions are increasingly less tangible, less visible and less explicitly codified. The technical systems dimension is relatively easy to alter for many reasons, among them the probability that such systems are local to particular departments. Managerial systems usually have greater organizational scope (Leonard-Barton, 1988b), i.e. reach across more subunits than technical systems, requiring acceptance by more people. The skills and knowledge content dimension is even less amenable to change because skills are built over time and many remain tacit, i.e. uncodified and in employees' heads (see von Hippel, 1990). However, the value embodied in a core capability is the dimension least susceptible to change; values are most closely bound to culture, and culture is hard to alter in the short term (Zucker, 1977), if it can be changed at all (Barney, 1986).

Effects of the paradox on projects

Over time, some core capabilities are replaced because their dysfunctional side has begun to inhibit too many projects. However, that substitution or renewal will not occur within the lifetime of a single project. Therefore, project managers cannot wait for time to resolve the paradox they face (Quinn and Cameron, 1988).

In the projects observed in this study, managers handled the paradox in one of four ways: (1) abandonment; (2) recidivism, i.e. return to core capabilities; (3) reorientation; and (4) isolation. The arc saw and factory-of-the-future projects were abandoned, as the managers found no way to resolve the problems. The HP150 personal computer exemplifies recidivism. The end product was strongly derivative of traditional HP capabilities in that it resembled a terminal and was more successful as one than as a personal computer. The special-use camera project was reoriented. Started in the film division, the stronghold of the firm's most traditional core capability, the project languished. Relocated to the equipment division, where the traditional corporate capability was less strongly ensconced, and other capabilities were valued, the project was well accepted. The tactic of isolation, employed in several projects to varying degrees, has often been invoked in the case of new ventures (Burgelman, 1983). Both the workstation project at Electronics and the HP Deskjet project were separated physically and psychologically from the rest of the corporation, the former without upper management's blessing. These project managers encouraged their teams by promoting the group as hardy pioneers fighting corporate rigidities.

Effects of the paradox on core capabilities

Although capabilities are not usually dramatically altered by a single project, projects do pave the way for organizational change by highlighting core rigidities and introducing new capabilities. Of the companies studied, Chaparral Steel made the most consistent use of development projects as agents of renewal and organization-wide learning. Through activities such as benchmarking against best-in-the-world capabilities, Chaparral managers use projects as occasions for challenging current knowledge and for modeling alternative new capabilities. For instance, personnel from vice presidents to operators spent months in Japan learning about horizontal casting and in the case of the new specialty alloy, the company convened its own academic conference in order to push the bounds of current capabilities.

In other companies, negative cycles reinforcing the lower status of manufacturing or marketing were broken—to the benefit of both project and corporation. In the workstation project at Electronics, the manufacturing engineers on the project team eventually demonstrated so much knowledge that design engineers who had barely listened to 20 percent of their comments at the start of the project, gave a fair hearing to 80 percent, thereby allowing manufacturing to influence design. In the deskjet printer project at Hewlett Packard, managers recognized that inequality between design and manufacturing always created unnecessary delays. The Vancouver division thus sought to raise the status of manufacturing engineering skills by creating a manufacturing engineering group within R&D and then, once it was well established, moving it to manufacturing. A rotation plan between manufacturing and R&D was developed to help neutralize the traditional status differences; engineers who left research to work in manufacturing or vice versa were guaranteed a 'return ticket.' These changes interrupted the negative reinforcing cycle, signalling a change in status for manufacturing and attracting better talent to the position. This same project introduced HP to wholly unfamiliar market research techniques such as getting customer reactions to prototypes in shopping malls.

As these examples indicate, even within their 1–8-year lifetime, the projects studied served as small departures from tradition in organizations providing a 'foundation in experience' to inspire eventual large changes (Kanter, 1983). Such changes can be *precipitated* by the introduction of new capabilities along any of the four dimensions. However, for a capability to become *core*, all four dimensions must be addressed. A core capability is an interconnected set of knowledge collections—a tightly coupled system. This concept is akin to Pfeffer's definition of a paradigm, which he cautions is not just a view of the world but 'embodies procedures for inquiring about the world and categories into which these observations are collected. Thus', he warns, 'paradigms have within them an internal consistency that makes evolutionary change or adaptation nearly impossible' (1982: 228). While he is thinking of the whole organization, the caution might apply as well to core capabilities. Thus, new technical systems provide no inimitable advantage if not accompanied by new skills. New skills atrophy or flee the corporation if the technical systems are inadequate, and/or if the managerial systems such as training are incompatible. New values will not take root if associated behaviors are not rewarded. Therefore, when the development process encounters rigidities, projects can be managed consciously as the 'generative' actions characteristic of learning organizations (Senge, 1990) only if the multidimensional nature of core capabilities is fully appreciated.

CONCLUSION

This paper proposes a new focus of inquiry about technological innovation, enlarging the boundaries of 'middle range' project management theory to include interactions with development of capabilities, and hence with strategy. Because core capabilities are a collection of knowledge sets, they are distributed and are being constantly enhanced from multiple sources. However, at the same time that they enable innovation, they hinder it. Therefore in their interaction with the development process, they cannot be managed as a single good (or bad) entity.[8] They are not easy to change because they include a pervasive dimension of values, and as Weick (1979: 151) points out, 'managers unwittingly collude' to avoid actions that challenge accepted modes of behavior.

Yet technology-based organizations have no choice but to challenge their current paradigms. The swift-moving environment in which they function makes it critical that the 'old fit be consciously disturbed. . . ' (Chakravarthy, 1982: 42). Itami points out that 'The time to search out and develop a new core resource is when the current core is working well,' (1987: 54)—a point that is echoed by Foster (1982). Development projects provide opportunities for creating the 'requisite variety' for innovation (Van de Ven, 1986: 600; Kanter, 1986). As micro-level social systems, they create conflict with the macro system and hence a managerial paradox. Quinn and Cameron argue that recognizing and managing paradox is a powerful lever for change: 'Having multiple frameworks available. . . is probably the single most powerful attribute of self-renewing. . . organizations' (1988: 302).

Thus project managers who constructively 'discredit' (Weick, 1979) the systems, skills or values traditionally revered by companies may cause a complete redefinition of core capabilities or initiate new ones. They can consciously manage projects for continuous organizational renewal. As numerous authors have noted, (Clark and Fujimoto, 1991; Hayes *et al.*, 1988; Pavitt, 1991) the need for this kind of emphasis on organizational learning over immediate output alone is a critical element of competition.

[8] This observation is akin to Gidden's argument that structure is 'always both constraining and enabling' (1984: 25).

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APPENDIX: METHODOLOGY

Structure of research teams

Four universities (Harvard, M.I.T., Standford and Purdue) participated in the 'Manufacturing Visions' project. Each research team was composed of at least one engineering and one management professor plus one or two designated company employees. The research was organized into a matrix, with each research team having primary responsibility for one company and also one or more specific research 'themes' across sites and companies. Some themes were identified in the research protocol; others (such as the capabilities/project interaction) emerged from initial data analysis. In data collection and analysis, the internal company and outside researchers served as important checks on each other—the company insiders on the generalizability of company observations from four cases and the academics on the generalizability of findings across companies.

Data-gathering

Using a common research protocol, the teams developed case histories by interviewing development team members, including representatives from all functional groups who had taken active part and project staff members. These in-person interviews, conducted at multiple sites across the U.S., each lasted 1–3 hours. Interviewers toured the manufacturing plants and design laboratories and conducted follow-up interview sessions as necessary to ensure comparable information across all cases. The data-gathering procedures thus adhered to those advocated by Huber and Power (1985) to increase reliability of retrospective accounts (e.g. interviews conducted in tandem, motivated informants selected from different organizational levels, all responses probed extensively). In addition, the interviewers' disparate backgrounds guarded against the dominance of one research bias, and much archival evidence was collected. I personally interviewed in 3 of the 5 companies.

Data analysis

Notes compiled by each team were exchanged across a computer network and joint sessions were held every several months to discuss and analyze data. Company-specific and theme-specific reports were circulated, first among team members and then among all research teams to check on accuracy. Team members 'tested' the data against their own notes and observations and reacted by refuting, confirming or refining it. There were four within-team iterations and an additional three iterations with the larger research group. Thus observations were subjected to numerous sets of 'thought trials' (Weick, 1989).

Each team also presented interim reports to the host companies. These presentations offered the opportunity to check data for accuracy, obtain reactions to preliminary conclusions, fill in missing data and determine that observations drawn from a limited number of projects were in fact representative of common practice in the company. The examples of traditional core capabilities presented in Table 2 were provided by the companies as consensus judgments, usually involving others besides the company team members. While the 20 projects vary in the degree of success attributed to them by the companies, only two were clear failures. The others all succeeded in some ways (e.g. met a demanding schedule) but fell short in others (e.g. held market leadership for only a brief period).

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