DEEP INSIDE THE BLACK BOX: EARLY CASE STUDY FINDINGS ON TECHNOLOGY PLANNING IN PRODUCT DEVELOPMENT PROJECTS

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This paper presents case study findings on the technology planning process for individual new product development (NPD) projects. These findings were generated as part of a larger research project currently underway investigating effective management of risky product and process technologies in new product development projects. This topic is important since firms, in certain competitive environments, are pressured to employ risky technologies in product development projects. Risky technologies can lead to high variability in project outcomes including unit cost, product functionality, and time-to-market. Better understanding of effective means for planning and implementing risky technologies directly benefits practitioners facing such challenges. The case study findings presented support contributions to theory by assisting in characterization of development project types based on their technological requirements, and through determining archetypal technology implementation approaches which may be effective for given technology development project types.

Introduction

New product development (NPD) has become an increasingly important dimension for competition in many industries. Accordingly, in recent years, manufacturing firms have been placing greater emphasis on developing new products effectively. One issue in NPD that is not well understood is how firms should best go about selecting, planning for, and managing the appropriate product and process technologies in a proposed new product. This process is particularly difficult when firms have limited experience with some of the technology options.

In many industries, particularly those considered "high tech," some firms that choose to use well-understood, fully characterized technologies result in development projects that meet time, cost and quality objectives. However, these new products are sometimes not successful in the market since they are "me too" products lacking in product performance or other distinction. Alternatively, some firms choose unproven, but promising, new technologies for inclusion in their new product. These technologies are unproven due to a combination of general technological progress and the company's inexperience with that technology. Use of unproven, or "risky", technologies can lead to products that are highly successful in the marketplace due to product distinction, but can also lead problems during the development, leading to high unit cost, low product functionality, and/or late time-to-market.

The process of selecting and planning for the implementation of risky technologies is complex and does not appear to be well understood. Industry people at operational levels refer to it as a "black art." Senior managers call it one of the "mysteries" of new product development. In short, understanding and managing this process better would be of great benefit to firms involved in product development since it can greatly influence project success and company competitiveness. Accordingly, we are investigating effective management of risky product and process technologies in new product development projects, with special emphasis on understanding archetypal technology project challenges and effective technology implementation approaches.

Our objective is to develop and test a model of effective implementation approaches for given technology project types. As a first step, we have conducted substantial exploratory, descriptive, field-based work to understand better the overall process of technology management in NPD. As a second step, we compiled several highly in-depth descriptive case studies of the early technology planning stage in product development projects. This paper presents early findings from these case studies. Section 2 presents a descriptive framework of major task sets in NPD technology planning and management. The framework supports relatively detailed descriptive and analytical research questions about the process and context of technology planning in NPD. These questions are addressed in Section 3. The paper concludes with thoughts about moving from the exploratory and descriptive efforts described herein to explanatory research which would provide managerial prescription regarding effective technology management and theoretical contributions through characterization of technology project types and effective implementation approaches.

Task Sets In Technology Management For Product Development

This section presents a descriptive framework of technology planning and implementation tasks in industrial new product development projects. The framework aids product development professionals in conducting technology planning. Further, it serves as a foundation for the research findings presented in Section 3. This framework is based on close analysis of seven case study reports which describe, in an overview fashion, activities from product concept to full-volume production for an NPD project. These NPD projects were of a "moderate" level of innovation, that is, not radical, and were for assembled industrial products from diverse high-technology industries. An overview of the case documentation process is presented in [2]. The framework was constructed using the constant comparative method for cross-case analysis [4], what Glaser and Strauss [1] refer to as "grounded theory building."

Technology Management is the process of planning and implementing technological choice and development in new product development projects. We define "technology" broadly to include product technologies and the processes for manufacture of the product. Selecting a new motor and subsequently developing it for use in a new product is an example of technology management. Similarly, deciding to employ new surface-mount printed circuit board assembly equipment, and subsequently implementing this manufacturing technology, is another example of technology management. As illustrated by the new motor and assembly equipment examples, the overall process of technology management for NPD can be subdivided into technology planning and technology implementation activities.

Selection means choosing one or more technologies from an array of options. Continuing the use of an old product or process technology, with or without an explicit decision to do so, is also a selection, though of a default nature.

The descriptive framework models the technology planning process for an individual NPD project, and does so from an operational point of view. The technology planning process is modeled for NPD projects of "moderate" innovation. We believe "radical" NPDs would have different underlying processes for technology selection. Also, this model starts with technologies available for consideration for use in a given NPD project – this excludes the actual technology research process which is often conducted by a separate research department. The descriptive model is shown in Figure 1. The technology management process applies to both product and process technologies. This model emphasizes several related early activities in NPD: stating the product requirements, determining the technology options, and formulating implementation plans for development of the technologies. These three types of activities must be carefully conducted, compared, and finally matched, which is the crux of the technology selection process. After technologies are chosen, the remainder of the NPD process occurs. This includes detailed technology implementation of the selected technologies. The major activities are "task sets."

The technology options task set (I) addresses the technologies themselves and how their capabilities are assessed. The types of activities that happen in this task set include "collecting" all the ideas for what might be viable technologies, filtering the large list of possible technologies into a smaller number for closer consideration, and assessing the technological capabilities and risks associated with each technology. Such risks, or uncertainties, include whether the technology will work as desired, how long it might take to develop, or how much that technology might eventually cost.

An end result of this task set is a formal statement, or at least an informal understanding, of the final technology options, their capabilities and their risks.

The product requirements task set (II) identifies the parameters of the proposed new product and its development process. A central activity of this task set is determining the product features and requirements in terms of product functional performance, unit cost, operating cost, usability, upgradability, compatibility, reliability and aesthetics. Another primary activity in this task set is determining the priorities for the NPD development process. This requires stating which goals are most important: achieving cost objectives, product performance, or time-to-market. The final major activity, which is related to determining product requirements and NPD process priorities, is finding the appropriate level of risk that the organization feels it can and should take on for this new product development. The implementation plans task set (III) formulates the technology development plan for the new product. In this task set, the organization chooses how it will do detailed development of the various technologies. This includes planning the NPD project management and general organizational structure, personnel recruitment and other organizational resource levels, alternative development plans for risky technologies, levels of concurrent activities, and downstream NPD project control and review. The primary activity of the technology selection task set (IV) is the determination of which technologies to use for the NPD. In this task set, technology options are matched to product requirements, with simultaneous consideration of the implementation plans for those technologies. This process is typically iterative, and many trade-offs are made. Product requirements may be changed, different technology options may be brought into consideration, and implementation plans may be revised if it is felt that this might lead to a more feasible and optimal new product and development process. For this reason, this task set "feeds back" and interacts with the previous three task sets. An output of this task set is the "product spec" which lists the product requirements to be achieved and the major technologies to be used for the new product. Often, the project plan in terms of the organization and levels of resources for further development is also stated.

The technology implementation task set (V) deals with managing the development of the technologies once they are chosen. The types of activities involved in this task set include detailed design and development of the new product, monitoring the progress of the NPD, revising resources as needed in response to new risks and pressing needs, interacting with vendors and customers, implementing various tools that support the NPD process, and seeing the completion of the NPD. This is essentially a project management stage.

In summary, as shown in Figure 1, there are five task sets in technology management for new product development. The first four task sets have to do with technology planning, while the last task set is technology implementation. The descriptive framework is a generalized model, so for certain NPD projects various task sets will be emphasized and more active than others. The technology selection process is highly iterative, as are activities within individual task sets. Therefore, the descriptive framework may be seen as a dynamic model of the technology planning process.

The five task sets are rarely completely temporally or organizationally distinct. In addition, the degree to which the task sets are organizationally and temporally distinct will vary greatly across projects. The task sets are often, but not always, accomplished by different groups. For example, product requirements might be determined by a marketing group while an engineering group simultaneously lists technology options. The individual tasks, as listed in Figure 1, occur in each NPD project, though not always in some formal or managed way. The model reflects reality in that these are tasks that must, for the most part, be accomplished for an NPD to progress and eventually be completed. For a more detailed presentation of the full descriptive framework and its extensions, see [3].

In-depth Study of Technology Planning in Product Development Projects

This section builds on the descriptive framework by specifying and investigating detailed questions about the technology planning process.

Research Questions

Earlier we stressed the importance of pre-project planning, especially with respect to technology selection. The focus of this section is on technology planning, and in particular the technology selection stage and immediate inputs to it since this appears to be the crux of the technology planning process. Technology selection involves the matching and selection of not only technology options, but also product/project requirements and implementation plans.

The descriptive and analytical research questions about technology planning we investigate further are:

1. How are the technologies, product and project requirements, and implementation plans options communicated to those involved in technology selection?

2. Who is involved in the technology selection process? Who develops selection criteria? Who selects?

3. How does the selection process actually work? For example, are all major technologies selected at once, or at different times? What criteria are applied to the selection decision? What information is central to this decision? What is decided?

4. How is the subsequent implementation of technologies taken into consideration in the selection stage?

5. How are selected items communicated to others involved in the project?

6. How does a firm know it did the technology selection process well? Are there ways to measure this?

7. How is past NPD experience used to improve the technology selection process? Are there ways to increase organizational learning for this process?

We ask these questions with the hope of learning how selection processes vary in general, how they vary by different types of technology options or product/project requirements, and whether there are better selection processes and implementation plans for specific types of situations.

Methodology

A set of four in-depth, descriptive case studies of technology planning activities in product development efforts was compiled and analyzed. The four cases were from two major high-technology companies located along Boston's Route 128. We gained access to these firms by explaining our research intent and offering to critique their projects. The specific projects were chosen by the companies, based on dimensions of interest we provided them. Two cases illustrated new technology/new market situations, while the other two represented new technology/old market situations. For each case we determined what the product requirements, technology options, and project implementation plans were, and how these three sets of elements were traded-off and finally selected. Project outcomes data were also collected.

In conducting these case study efforts, we worked intensively within companies, interviewing individuals across company functions. Case data was collected through approximately 20 hours per project of one-on-one semi-structured interviews with project personnel, supplemented with on- and off-site document review. Explicit efforts at triangulation included asking similar questions to individuals from marketing, engineering and manufacturing perspectives, and comparing and prompting responses with respect to information contained in the documents. Primary project participants and substantial documentation were available since these projects had been completed within the year before our investigation. Representative interviewee titles included: research scientist, product manager, consulting engineer, program manager, advanced manufacturing engineering manager, director of R&D, engineering section head, purchasing manager, manufacturing engineer and plant manager. We also met with executive management.

Findings and Observations about Technology Planning

Below are selected findings from the case studies about various elements in technology planning in NPD projects. These findings help define the types of inputs to, and the inner workings of, the selection process. The findings listed here are presented in an observational vein, and are organized by the major task set boxes in technology management for NPD. Our next step is to synthesize these findings into a model of effective technology planning and management.

Requirements

Evolutionary Aspects of Functional Requirements

• Product and project requirements appear to be a function of time. They evolve throughout the project. "Freezing" the requirements is sometimes not necessary or desirable. Similarly, early freeze is not always appropriate.

• The firmness of requirements varies along "certainty" and "specificity" dimensions. A requirement is certain when the company knows it is unlikely to change. A requirement is specific if it is described exactly rather than roughly. A certain requirement can be unspecific (eg. "we must have the ability to produce color output, but we do not know at what sharpness level"). Similarly, an uncertain requirement can be stated very specifically (eg. "we are not sure if we will hold to this requirement, but for time being, shoot for product output of 5 inches per minute").

• In some cases, the product "requirements" are actually stated after the project is completed. This happens when there is a limited sense of what technological capabilities can actually be achieved, and so whatever happens is acceptable (this is an example of a "low certainty" requirement). This also happens when the market's desires are not well-known. Here, the market sets the product requirements after beta products are available, not before the project starts. Other influences which contribute to purposefully setting product requirements late include: changing federal and other regulations, issues having to do with integration of this product with other products, and late-breaking decisions regarding which market niches to enter.

How Functional Requirements are Stated

• There are several levels of functional requirements. We have identified three: strategic, within-project high, and within-project low. The strategic functional objectives are typically set by executives, and in very qualitative terms well-before the NPD project is initiated. Within-project high level requirements are set by project managers and those executives involved in the interface with the NPD project. These may be quantitative and qualitative. Within-project low level requirements seem to be set by project managers and team members. These are typically technical and quantitative. Since each level can be set by different and non-overlapping groups, special efforts must be taken to reduce communication problems and enhance translation from one level to another.

• Some functional requirements are stated as "functional primitives," that is, they are stated in relatively raw scientific terms (eg. "this product must achieve 4 million instructions per second" or "the laser width must be 3 microns"). Some functional requirements are stated as "embodiments," that is, they are stated at a higher level of aggregation or are translated into different metrics (eg. "use a 386 chip in this project" or "achieve 400 dots-per-inch"). It appears to be easier to assess technology uncertainty at the embodiment level.

Project Objectives

• There are three types of objectives that must be set: time, cost, and functionality. We have found that each of these objectives can be, and often are, set by different (groups of) people. Sometimes these individuals or groups overlap and integrate.

• Often, priorities among the different objectives are not explicitly considered when the objectives are set. These objectives are often not considered in an integrated fashion, either early or even during the project.

• We have found that the time objective is set with respect to many different factors. In some cases, but not all, the time objective is set with consideration of how long the project might take to implement. This objective is typically not set by project level people, though their input is sometimes solicited.

• The product unit cost objective is typically set by marketing. Most projects were driven by a market-determined selling price rather than driven by the estimation of aggregate direct costs. In the cases where direct costs were considered in setting cost objectives, the estimation efforts were quite rough and preliminary -- in no case were cost targets set as a result of rigorous cost estimation.

• We already know that different functional groups working on a project may have very different perspectives on the importance of various project objectives such as time-to-market or unit cost. We observed that this is true also at different levels in the organization. In some cases, executive management had a different perspective on priorities than the project-level people. This seems to happen due to different individuals being involved at different times in the project. This also happens when the priorities are communicated, but not explained or defended by executive management.

Technologies

• Individual technologies can be compared in terms of their "absolute" and "relative" risks. The absolute risk is simply how risky that technology choice is. The relative risk is how risky that technology choice is relative to the risks associated with the other technologies. We expected that absolute risk would be the primary means of comparison and evaluation, but found that relative risk was what was actually considered most often. Further, the nature of relative risk seems to indicate when the technologies can be frozen. For example, a technology with high absolute risk may be selected and frozen early in a project if all the other technology options have even higher absolute risk.

• The array of "product-system" or "architecture" options can vary greatly across projects. Two major dimensions for this variance are: quantity and dominance. In some projects, there was only one product-system option identified and seriously considered -- it, by default, dominates. In other projects, there were multiple options. In some cases, there were options that dominated, while in other cases, no option dominated. A "dominant" alternative is one that for strategic, political and other reasons is identified early on as a preferred option. We observed that dominance often had little to do with technological risk.

• The nature of the product-system array of options implies very different decision-making situations. Further, the nature of the array indicates to some degree when the "technology freeze" can occur.

• There are product-system level and module-level technologies. Choices must be made among options at each level. In almost all cases, the product-system level decisions received the bulk of evaluation and decision-making effort. Also, product-system decisions were made first, in turn dictating some module-level selection decisions.

• In some cases, new figures-of-merit needed to be developed to describe and assess different technologies and the capability of the product under development. For example, achieving "high reproducibility" was an objective in two different projects were observed. Both cases employed new technologies for whom old metrics for reproducibility made no sense. It appears the need to develop new metrics correlates highly with risky technology.

• We observed a number of techniques for avoiding and/or dealing with technology risk. These techniques can be classified on a temporal basis into five categories: strategic preceder, tactical preceder, project plan, contingent plan, and real-time action. The last three may be seen as categories of implementation plans. A strategic preceder technique would be one popularized by Sony, and observed in one company we studied. Here, a firm employs medium to long term technology forecasting and planning efforts to identify various new technologies they might employ in the future. For each technology identified, the firm undertakes intensive research effort to learn a great deal about that technology. This leads to "bins" of well-characterized technologies that are "ready" to be employed in a given NPD project. The upside is that what might otherwise be a risky technology is not. The downside is that this is a very expensive means of conducting R&D. A related technique employed is called the "bootleg" project. In this situation, individuals in R&D, without any strategic guidance, choose to work on a technology they believe is promising.

A tactical preceder situation arises when it is decided to delay a project start while research in conducted on risky technologies. Another example of a tactical preceder technique is the acquisition of a small start-up group that has experience with a new technology.

Implementation Plans

• Three of the five categories of techniques for reducing or dealing with technology risk are in the implementation plans domain. The implementation plans that are critical to the selection process in NPD technology planning are "project plans" Certain project plans, such as those requiring acquisition of additional personnel resources, reduce risk. As part of technology planning in NPD, the project team may identify problems that while of lower probability might arise during the project. Early on, they can develop "contingent plans" to deal with these problems should they arise (eg. an alternative technology approach might be identified as a fall-back). Finally, unanticipated technology problems may arise during the project. In this case, the firm must undertake "real-time actions" to deal with the crisis (eg. additional engineering resources may be added).

• In general, implementation planning efforts were significantly less rigorous than efforts for determining functional requirements or evaluating technology options. Typically, implementation planning was considered after, rather than simultaneously with, product requirements and technology options determination. In most cases, implementation planning did not really seem to exist -- the project team structure that was already in place was expected to work again essentially unchanged.

• No major contingency plans were employed to cope with potential product-system problems. However, we did observe many contingency plans for modules. These included identifying back-up vendors, identifying back-up technologies, keeping in mind that the product requirements for a given module can be "de-rated" (reduced), adding extra personnel, phasing the introduction of product, and using "slush" funds where additional capabilities for some modules were traded off with reduced capabilities for other modules (eg. cost trade-offs).

Selection

Selection Process Structure

• The selection processes we observed were not highly rational or structured. As indicated above, the inputs to the selection process are dynamic, highly varied, and often fuzzy. The selection process itself is distributed over time. Further, it involves different players and selection criteria at different levels and points in time. Nonetheless, selection happens. Admittedly, in some cases, a default option is "selected" only because there was no discussion or controversy about it.

• In no case was all the desired information available at once to serve a truly rational, optimized selection decision. We observed in several cases that as more information about the market and/or technologies became available, the criteria for selection changed. In one case, the cost target was increased when early technology investigations showed the preliminary cost targets to be inachievable.

• In no case were all the relevant technologies for a product chosen all at once.

• We observed no usage of quality-function-deployment (QFD) or other matrix techniques to support selection evaluation.

The Selectors

• The product-system technology choice and higher level product and project requirements were typically chosen by executive management. In some cases, the product-system alternatives were investigated by the project team before executive decisions were made.

• Module-level technology and requirements selection efforts were typically conducted by project level individuals. However, different individuals or groups were often involved in selecting different modules. In many cases, but not all, these groups would partially overlap in membership.

• Certain modules deemed strategically critical were chosen (mandated) by executives. These included modules that might introduce risk for a given project, but would support downstream product efforts and entry into new sub-markets.

• Design and manufacturing engineers were involved in technology selection activities. While manufacturing engineers did have involvement in aiding selection of process technologies, they appear to have little involvement in product-system or architecture choices.

Selection Criteria

• In a few cases the potential interactions of one module with another was considered during the selection process. In several cases, the interaction of the product and its modules with peripheral products was considered.

Project End-Outcomes

Tactical Outcomes

• In almost all cases, product unit cost objectives were not achieved.

• In almost all cases, time-to-market objectives were not achieved. However, in one exceptional case, first-customer-shipment and ramp-up occurred before the original time target. This happened due to infusion of extra resources during the project to achieve this objective. Further, this project was structured in a manner that additional resources would actually be beneficial.

• Product functionality objectives were achieved in all cases. And in some cases, functionality objectives were exceeded. Organizational Learning Post-audits were conducted in very few cases. In general, there appears to be little organization-level learning about specific technologies or management processes. However, individuals and small groups do appear to have "learned." They try to apply their new knowledge to successor activities.

Conclusions

This paper presented early case study findings on the technology planning process in individual product development projects. Our next step is to clarify and synthesize the findings into a model of effective technology management in NPD. Such an effort allows us to progress from exploratory, "grounded theory" efforts to explanatory, theory-testing research. Specifically, a simple model of effective technology implementation plans for given product development project types can be developed and tested in order to provide managerial prescription and contribution to theory. Product development projects can be categorized by technology and product/project requirements characteristics observed in the field and deemed important in the literature. Similarly, implementation plan types can be determined based on case observations such as those presented earlier and contributions from the literature. We aim to gather data across a number of development projects to test hypotheses regarding effectiveness of specific implementation plan approaches for given project types. This confirmatory analysis will be combined with qualitative detail already gathered to develop an integrated interpretation.

References

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FIGURE 1: TASK SETS IN NPD TECHNOLOGY MANAGEMENT