Knowledge and Process Management
Volume 13 Number 4 pp 239–251 (2006)
Published online in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/kpm.260

■ *Research Article*

The Effects of Ambiguity on Project Task Structure in New Product Development

P. Robert Duimering*, Bing Ran, Natalia Derbentseva and Christopher Poile

Department of Management Science, University of Waterloo, Waterloo, Ontario, Canada

New product development (NPD) projects are characterised by task ambiguity, whereby the set of tasks necessary for project completion and the relationships between tasks are initially unknown and only emerge as the development process unfolds. This paper uses interview data from NPD project managers in a large telecom firm to examine the influence of product requirements ambiguity on NPD task structures. The findings are used to propose a taxonomy outlining four generic patterns by which NPD task structures change during the product development process as a result of requirements ambiguity—task expansion, contraction, substitution and combination. The results also highlight in general terms the role of communication, coordination, knowledge and problem solving as distributed NPD project teams struggle to resolve ambiguity. Knowledge of how NPD project task structures evolve can lead to improved strategies for managing projects with ambiguous requirements. Two general types of strategies are suggested, decomposition of project tasks to minimize interdependence between tasks and the flexible adaptation of NPD task structures as new forms of task interdependence are recognised during the development process. Copyright © 2006 John Wiley & Sons, Ltd.

INTRODUCTION

The new product development (NPD) process begins with a set of more or less ambiguous statements defining required product characteristics and features. As the NPD process unfolds, product requirements gradually become precisely specified as a concrete product takes shape over time. Researchers have increasingly recognised the limitations of traditional project management strategies to cope adequately with requirements ambiguity (Gupta and Wilemon, 1990; Bailleti *et al*., 1994; Moenaert *et al*., 1995; Khurana and Rosenthal, 1997; Becker, 2001; Pich *et al*., 2002; Becker and Zirpoli, 2003) but the influence of requirements ambiguity on NPD projects is still poorly understood. This paper uses findings from a field study of NPD at a large telecommunications firm to examine the influence of ambiguity on the tasks performed by individuals involved in NPD projects. Since project tasks are defined in relation to project objectives, requirements ambiguity results in changes in the structure of tasks during the course of product development. We use results from interviews with NPD project managers first to describe the general properties of the NPD project task situation in the firm and then to propose a taxonomy outlining specific ways project task structures change over the course of NPD projects. The paper contributes by providing a framework for understanding the effects of requirements ambiguity on the structure

*Correspondence to: P. Robert Duimering, Department of Management Sciences, University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada.
E-mail: rduimering@uwaterloo.ca

Copyright © 2006 John Wiley & Sons, Ltd.

of NPD project tasks. Although ambiguity arguably results in inevitable task changes during NPD projects, we propose that these changes can be understood in terms of a finite set of predictable and, therefore, potentially manageable patterns.

Requirements ambiguity in NPD projects

Complexity, uncertainty and ambiguity associated with product and project requirements all influence the difficulty of managing NPD projects. Project complexity refers to the number of different activities that must be performed to complete the project (Bailleti *et al*., 1994; Pich *et al*., 2002). Traditional project management strategies handle complexity through hierarchical decomposition (Simon, 1962, 1996), whereby a complex project is decomposed into progressively simpler and more manageable component tasks that are processed separately and later integrated into a finished product. We refer to the network of interrelated project tasks resulting from such a decomposition process and the allocation of these tasks to individuals and groups as the project task structure. For projects with uncertainty but little ambiguity, the hierarchical decomposition of tasks works quite well, and the literature provides useful analytical methods such as the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) to support project success (Bailleti *et al*., 1994; Pich *et al*., 2002; Ward and Chrisa, 2003). These approaches are less helpful for projects with significant ambiguity, such as those dealing with NPD. NPD projects are often completed behind schedule or over budget and often result in products that are below desired quality or lacking in functionality (Gupta and Wilemon, 1990; Tatikonda and Rosenthal, 2000).

The difference between uncertainty and ambiguity has been discussed by several authors (Minkler, 1993; Schrader *et al*., 1993; Tsoukas, 1996; Globerson, 1997; Pender, 2001; Pich *et al*., 2002; Becker and Zirpoli, 2003). Uncertainty refers to cases where all decision variables relevant to the completion of project tasks are assumed to be known in advance, although the eventual values taken by particular variables may be unknown[1]. To handle project uncertainty, tools like CPM and PERT assume a fixed network of known project tasks connected to one another according to known sequential precedence relationships (Pich *et al*., 2002). These tools further assume (at least implicitly) that the time and cost associated with task completion are the only variables of concern to project managers and that uncertainties associated with the values of other decision variables can be adequately managed in terms of their effects on project time and cost.

Ambiguity exists when relationships between project decision variables and even the variables themselves are unknown. NPD tasks are usually ambiguous since the full range of tasks required to complete the project is likely to be unknown at the outset, and the full range of decision variables that must be specified to satisfy the completion of each task is also unknown. Furthermore, because of functional interdependencies among decision variables associated with different tasks, ongoing communication and coordination are needed so that detailed product specifications and associated task requirements can be gradually determined (Griffin and Hauser, 1992; Moenaert *et al*., 1995). Thus, interactions between tasks are likely to be characterised by complex patterns of reciprocal influence rather than strictly sequential precedence relations (Thompson, 1967). Numerous researchers have highlighted the difficulties of cross-functional communication and coordination in NPD due to the distribution of tasks to individuals with specialist knowledge located in different departments (Becker, 2001; Becker and Zirpoli, 2003), restrictive organisational routines (Hlavacek and Thompson, 1973; Dougherty, 1990), and different departmental objectives, jargons and interpretative schemas (Dougherty, 1992; Dougherty and Hardy, 1996; Tucker and Leonard, 2001). Tools and methods to support NPD project management under conditions of ambiguity include the stage gate process (Cooper *et al*., 2002) and milestone charts (Bailleti *et al*., 1994). Although these tools require fewer assumptions about project tasks than PERT or CPM, they essentially treat the NPD task structure as a black box and only track projects in terms of designated organisational events marking the completion of certain stages of the project (e.g. final approval of design specifications.) In this paper, we explicitly investigate how task structures evolve during the NPD process as a result of requirements ambiguity.

The remainder of the paper is organised as follows. In the next section, we discuss the interview methodology and the data codification process. We then summarize the interview results first by describing the general properties of the NPD task situation in the firm studied and second, by presenting a detailed taxonomy outlining patterns of task structure change during the NPD process

[1]The literature further distinguishes uncertainty from risk, where uncertainty refers to cases in which the set of possible outcomes (i.e. the potential values of decision variables) is known but their associated probabilities are unknown, and risk refers to cases in which both possible outcomes and their associated probabilities are known (Schrader *et al*., 1993).

DOI: 10.1002/kpm

associated with requirements ambiguity. The paper concludes with a discussion of the implications of the findings for future research and practice in NPD project management.

METHOD

The study was conducted in a large North American telecom firm with over 10 000 employees and operating in a range of high-tech industries such as ISP, internet security, wireless technology products, text messaging, voice services, etc. The firm introduced approximately 200 new industrial and consumer products to the market each year and the effectiveness of the NPD process was a major focus of management attention.

The NPD process began in the firm when an idea for a future product was proposed by a Product Manager within the marketing department who wished to 'sponsor' its development. New product ideas would then undergo an 'idea assessment' process that estimated the market value of the proposed product. If the market value was perceived to be satisfactory by an executive committee then a Project Manager was assigned and the product idea further assessed in terms of its fit within the firm's product portfolio and the availability of resources for a successful product launch. If this feasibility assessment was also satisfactory, product specifications would be produced and resources allocated for development. Product development projects relied on the participation of so-called 'subject matter experts' (SMEs), who were specialists with diverse expertise working in various functional departments throughout the firm. Technical development of the product was mainly performed by members of the Information Systems/Information Technology (IS/IT) department, but SMEs from various other groups performed numerous tasks necessary to launch new products successfully. These included the design and implementation of operational processes, the specification of customer support procedures, the development of financial billing and accounting systems, marketing plans, advertising campaigns and various other tasks. When the development process was complete, the product was launched into the marketplace and maintained on an ongoing basis by the Operations department.

Open-ended interviews based on the 'echo' method of Bavelas (1942) were used to investigate the NPD task situation. This method is designed to examine social network interactions significant to an interviewee's job situation and has been used for analysing social networks in various organisational settings (Barthol and Bridge, 1968; Barthol and de Mille, 1969; Safayeni *et al*., 1992; Duimering *et al*., 1998). Each interview begins by asking the subject to describe his/her work situation in general terms and to identify other individuals or groups in the organisation with whom s/he interacts on the job. As a result, a diagram in the shape of a star is formed with the subject in the middle surrounded by other nodes representing individuals or groups comprising the subject's immediate task-related social network. 'Echo questions' are then used to examine interactions between the subject and each of the identified nodes. The subject is asked to provide concrete examples of behaviours performed by other nodes that are *helpful* from the subject's point of view, and examples of behaviours that are *not helpful*. By asking for specific examples of positive and negative behaviours, subjects are encouraged to provide descriptive information about actual events experienced on the job rather than ungrounded opinions or stereotypes about the behaviour of others. By conducting interviews with people in each of the identified nodes, multiple perspectives on a given situation can be obtained.

Interviews were conducted with members of the four major groups involved in the NPD process at the firm: Project Managers, Product Managers, IS/IT and Operations. Due to the specific objectives of this paper, we will focus on the results of interviews with NPD Project Managers. Twelve interviews were conducted ranging from 2 to 3 hours in length. Individuals were selected by our management contact within the firm's Project Management Office to represent different divisions of the company and different levels of experience in order to obtain a relatively comprehensive picture of the Project Managers' task situation. All interviews were audio taped and transcribed for coding.

The coding of interview responses was done collaboratively by the research team members through an iterative process of coding, discussion and recoding using the QSR N6 (QSR International Pty Ltd, 2002) qualitative data analysis software. The unit of analysis was the individual example of a helpful or unhelpful behaviour. Comments describing specific examples of behaviours were categorised based on the similarity of the behaviours described. Comments and examples were also categorised according to the group in the organisation to which they referred, and helpful and unhelpful behaviours were coded separately for each group.

After the basic properties of the NPD task situation as experienced by Project Managers was established through the preceding method, an additional theme-based interpretive analysis of the interview data was completed. This second pass through the data focused on identifying specific comments related to the general theme of product requirements ambiguity and its influence on NPD task structures. From these theme-specific data, several patterns of task-structure change associated with product requirements ambiguity were identified.

Two types of results will be presented corresponding to these two analyses. First, we briefly summarise the major categories of behaviour identified from the analysis of interview comments to provide a general characterisation of the NPD task situation as experienced by Project Managers. For brevity, we focus on the Project Managers' comments about their interactions with Product Managers, IS/IT and Operations, although several other groups were also discussed by interviewees. Second, we present the findings of the theme-based analysis of the effects of product requirements ambiguity on NPD task structures. The latter will be presented in the form of a taxonomy in which particular patterns of task changes will be defined and illustrated using examples from the study.

RESULTS

General characteristics of the NPD task situation

Table 1 summarises interview results indicating Project Managers' perceptions of helpful and unhelpful behaviours on the part of Product Managers, IS/IT and Operations. Four major themes dominated the results: communication, coordination, knowledge and problem solving. Within each of these general categories, a variety of specific behaviours were identified. The communication category included comments related to the timeliness, accuracy and completeness of information communicated between project team members. For example, Product Managers provided information about product requirements, and it was helpful if this was accurate so SMEs could structure their tasks appropriately. When problems were encountered during development, it was helpful if SMEs from IS/IT and Operations informed Project Managers quickly so other groups could be notified and their input obtained to find solutions. On the other hand, vague product requirements, the failure to provide status information or slow responses to requests for information were regarded as unhelpful by Project Managers. The coordination category referred to behaviours related to the quality of SME cooperation during the NPD process. Poor coordination resulting from conflicting departmental objectives, poor time and resource management and disagreements over project scope were seen as unhelpful to Project Managers. Effective budget management by different departments, agreements about project scope and cooperative teamwork were seen as helpful. Budget and workload transparency were also valued, while the 'padding' of budget and workload estimates by SMEs was seen as unhelpful.

The knowledge category included several different kinds of comments about how the knowledge of SMEs contributed to, or detracted from, project success. SMEs who were experienced and knowledgeable in their domain were seen as helpful, while those with little experience or who lacked required knowledge were seen as unhelpful. For example, Product Managers were expected to be knowledgeable of customer needs and engineers were expected to understand product or process technology. Besides such domain-specific knowledge, social network knowledge about who to contact within the firm to obtain specific information, knowledge of project management procedures and knowledge of administrative procedures within the firm were all valued by Project Managers. Sharing of domain-specific knowledge in the form of advice or by training other team members was also helpful. The category of problem solving referred to comments about SMEs' contributions to project problem solving as product requirements were gradually refined during the NPD process. Project Managers appreciated SMEs who proactively identified problems and solutions, who were creative and flexible in developing solutions, and who consulted with others. They disliked it when SMEs were inflexible or not proactive, did not consult with others, made erroneous assumptions, or proposed inadequate or overly expensive solutions. Besides these four major categories of behaviour, Project Managers also appreciated it when SMEs were available to respond to requests for information or assistance, or to clarify, discuss and negotiate product requirements. They also said it was helpful when SMEs demonstrated a positive attitude towards their job and leadership with respect to their own domains of responsibility within the project.

This brief summary of interview results suggests that requirements ambiguity influenced the properties of the NPD task situation in several ways. Since NPD tasks were distributed across SMEs in different departments, project success depended on effective coordination, communication, knowledge sharing and cooperative problem solving

DOI: 10.1002/kpm

Table 1 Project Managers' perceptions of the behaviour of product managers, IS/IT and operations

	Number of behaviour examples by group			
	Product managers	IS/IT	Operations	Total
Helpful behaviours				
Communication	26	15	16	57
Coordination	18	29	8	55
Knowledge and experience	12	18	15	45
Problem solving	8	12	15	35
Availability	4	2	2	8
Positive job attitude	0	4	1	5
Leadership	3	1	0	4
Total no. of examples	71	81	57	209
Unhelpful behaviours				
Lack of coordination	36	23	17	76
Poor communication	40	11	16	67
Lack of problem solving	9	9	20	38
Lack of knowledge and experience	10	13	6	29
Unavailability	6	2	3	11
Negative job attitude	1	2	1	4
Total no. of examples	96	58	60	214

among team members responsible for performing various project tasks. Product requirements ambiguity demanded the availability of SMEs to respond quickly to the queries of other team members, as key product variables were defined and their values determined during the product development process.

Effects of ambiguity on the NPD task structure

We now examine the relationship between ambiguity and NPD task structure more explicitly, based on a thematic analysis of interview comments. From our data, we identified four basic patterns of task change encountered in the NPD process: task expansion, contraction, substitution and combination. Before describing these patterns, however, we introduce a notation for representing NPD task structures and discuss two basic properties of these structures: hierarchical decomposition of a complex NPD project into a network of component tasks and the functional interdependence of task components.

Hierarchical decomposition and task interdependence
When an NPD project is sufficiently complex as to require the involvement of more than one person or organisational department, hierarchical decomposition and division of labour are necessary to deal with the complexity. To explore the implications of NPD task decomposition, we adopt the following notation. Let X represent the NPD task as a whole and x_i a component task that must be completed as part of a given NPD project. Thus, the NPD process involves the decomposition of X into various component tasks x_1, x_2, $x_3 \ldots x_n$, where each x_i can be further decomposed into progressively smaller components (x_{ij}, x_{ijk}, etc.), the addition of which upon completion is presumed to result in a fully developed new product:

$$\begin{aligned} &X \Rightarrow \{x_1, x_2, x_3 \cdots x_n\}, \text{ where} \\ &x_i \Rightarrow \{x_{i1}, x_{i2}, x_{i3} \cdots x_{im}\}, \text{ etc., and} \\ &X = \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \end{aligned} \quad (1)$$

For example, for a given NPD project (X) in the firm studied, the responsibility for software development work (x_i) was delegated to the IS/IT department. Some portions of this work were then outsourced by IS/IT to a third party software developer while other portions were performed by various sub-units within the department (x_{ij}). Ultimately specific programming tasks were assigned to individual programmers (x_{ijk}), implying at least three hierarchical levels of decomposition distinguishable within the NPD task structure. It is worth noting that this degree of task decomposition would not be established immediately at the outset of a project. Rather, because of requirements

DOI: 10.1002/kpm

ambiguity, tasks were defined in fairly abstract terms at the beginning of the project and further decomposed over some period of time as detailed project requirements were identified and ambiguity reduced during the NPD process.

The decomposition of a complex project into such a distributed network of task components provides a kind of operational definition of how the project is to be completed by each operating unit of the organisation. Three assumptions underlie this decomposition process: (1) that the overall NPD task is indeed decomposable; (2) that the set of subtasks resulting from decomposition provides an appropriate operationalisation of the overall NPD task and (3) that after all relevant parties have completed their component tasks, the resulting product components can be reintegrated to yield the new product as originally conceived.

With respect to the first assumption, Simon (1962, 1996) argued that complex systems often exhibit the property of 'near decomposability', which refers to the idea that there tends to be a much higher degree of functional interdependence between component parts within the same subsystem than between the components of different subsystems. More precisely, variability in the degree of interdependence among component parts provides the basis for perceiving a complex system as a set of hierarchically organised, relatively independent subsystems. From a project management perspective, the property of near decomposability provides a basis for dividing a complex project into relatively independent component tasks that can be efficiently processed and managed separately, since relatively little coordination between tasks is required. Thus, the extent to which an NPD project can be considered decomposable depends on the extent to which it can be mapped onto a task structure characterised by relatively independent clusters of interdependent component tasks.

Research in the product design literature has used such concepts to investigate properties of product architecture, defined by Ulrich (1995) as the scheme by which product functions are mapped to product components, ranging from modular to integral. Highly modular architectures have a near one-to-one mapping of product functions to product components (i.e. each product component performs one function) and use standardised interfaces to decouple interdependent components such that products are easily and efficiently decomposed hierarchically. Integral architectures have more complex (e.g. one-to-many, many-to-one, many-to-many) mappings of product functions to components and tighter coupling among interdependent components, making hierarchical decomposition more difficult and less efficient. Our focus in this paper is on NPD project task decomposition, not product decomposition *per se*, though a clear relationship exists between the two. Sosa *et al*. (2003) provide evidence from a case study of aircraft engine design suggesting correlations between product architecture and interactions between teams responsible for the design of specific product components. Thus, functional relations among product components are a significant source of interdependence among NPD task components, but many other potential sources exist as well. In the firm we studied, project teams included individuals from diverse groups (operations, marketing, advertising, finance, etc.) whose tasks were not directly related to product design and interdependencies among these tasks were largely unrelated to product architecture. Product component interdependencies associated with product architecture, therefore, represent a subset of the complete set of task interdependencies associated with NPD task structures. However, it may be reasonable to speak about NPD project task structures in terms of *project architectures* ranging from modular to integral, and the extent to which project tasks can be modularised as a set of relatively independent subtasks should influence project management efficiency. When no decomposition strategy can be found that avoids a high degree of interdependence between separate tasks (i.e. an integral project architecture), project management efficiency is likely to decline.

With respect to the second assumption discussed above, regarding the appropriateness of a given decomposition strategy, coordination difficulties are likely to increase when decomposition is based on criteria other than the functional interdependence of component tasks (Thompson, 1967; Galbraith, 1973; von Hippel, 1990). In the firm studied, decomposition was based primarily on the pre-existing departmental structure of the organisation, which grouped people according to their functional specialisation. That is, rather than decomposing NPD tasks on the basis of what might be most appropriate for effective task coordination, decomposition was in accordance with the pre-existing division of labour in the organisation and associated standard operating procedures, a situation that is likely typical of many other firms. The result was significant functional interdependence among the component NPD tasks performed by different units of the organisation. In terms of our notation, satisfactory completion of task x_1 might depend on decisions made about task x_2, x_3 might be a function of x_1 and x_2 and so on.

Such interdependencies increase project management difficulty in a complex NPD task network

DOI: 10.1002/kpm

since each relevant party must continually coordinate activities with others in the network. Task changes at one node must be communicated to other interdependent nodes, which may then need to revise their own tasks accordingly, resulting in complex patterns of influence and feedback cycles throughout the task network. To ease the coordination burden in the present case, the organisation used a hierarchical project management structure, whereby each functional unit assigned a liaison person to act as a kind of second-tier project manager responsible for coordinating NPD tasks within their respective units and interfacing with the Project Manager. Such a two-tier project management structure is likely to be most effective when task decomposition is along the lines suggested above, resulting in relatively independent, modular clusters of interdependent component tasks. In the present case, the use of second-tier Project Managers facilitated departmentally based project budget tracking, but also complicated the overall NPD task structure by adding a layer of nodes in the network through which all task coordination must be processed.

The preceding discussion suggests three variables by which the complexity of NPD task networks can be evaluated: the number of hierarchical levels of task decomposition, the average number of other tasks to which each task is linked via some form of functional interdependence and the proportion of links among interdependent component tasks that cross the boundaries of different organisational units relative to the proportion within the same organisational units. In general, as any of these three variables increase, the more demanding the coordination task is likely to be for project managers.

Changes in task structure during new product development

The validity of the third assumption identified above that the outcome of decomposed tasks can be reintegrated after completion to yield the originally conceived product, depends on the extent to which component tasks change during the NPD process and on the effectiveness of coordination among the individuals performing these tasks. When all tasks can be precisely specified in advance, the degree of change during development is likely to be minimal, requiring relatively little coordination among participants. For NPD tasks, however, requirements ambiguity implies that the magnitude of change is likely to be significant, and indeed most of our interviewees mentioned that by the end of the product development process, the finished products were often substantially different from the original product idea. That is, NPD task X is decomposed into component tasks x_i, which later add up to X' at the end of the project:

$$X \Rightarrow X' \quad (2)$$

Changes in the project task structure result from changes in component tasks during development. In the study, changes resulted from both internal factors, such as unanticipated technological constraints encountered during development, and various external factors related to the organisational or competitive environment of the NPD process, including cuts to the development budget, market pressures to accelerate product launch due to the introduction of a competitor's product, etc. Based on our interview findings, we identified four generic ways that component tasks changed during the NPD process: expansion, contraction, substitution and combination.

Project and component expansion. One of the most common task structure changes encountered in NPD is the gradual increase in project scope during the course of development. This phenomenon, referred to as 'scope creep' by study participants, has been discussed in the popular literature of project management. We distinguish two forms of scope creep: (1) expansion of the project as a whole and (2) expansion of a component task defined as part of the NPD task structure. Project expansion refers to cases where a new task (Y) is added to the original project (X), typically due to desires to enhance the functionality of the product in some way. Y is assumed to be beyond the scope of the original project and therefore, its addition results in a new overall conception of the project (Z). Since Y is added after the initial project X has already been operationalised as a set of decomposed tasks x_i allocated across the organisation, it is likely that Y will also need to be decomposed into a corresponding set of components y_i and allocated to organisational units which may or may not already be involved in the project. Assuming the need to integrate X and Y into Z as an organic whole, new interdependencies are likely to be established between the task components of X and Y, potentially necessitating the transformation of components x_i, such that X also becomes modified from what was originally conceived.

$$\begin{aligned} &X = \{x_1, x_2, x_3\} \Rightarrow Z \quad \text{where} \\ &Z = X'\{x'_1, x'_2, x'_3\} + Y\{y_1, y_2, y_3, y_4\} \end{aligned} \quad (3)$$

Component expansion occurs when a task component that has already been defined as part of the NPD task structure expands to include one or more additional sub-tasks. Since tasks may be defined at various hierarchical levels of analysis

DOI: 10.1002/kpm

(x_i, x_{ij}, etc.), component expansion can theoretically occur at any of these levels within the task structure. If the interdependence of tasks is assumed as above, the originally defined component tasks should change accordingly to accommodate the addition of a new component.

$$X = \{x_1, x_2, x_3\} \Rightarrow X' = \{x'_1, x'_2, x'_3, x_4\} \quad (4)$$

or:

$$x_i = \{x_{i1}, x_{i2}, x_{i3}\} \Rightarrow x'_i = \{x'_{i1}, x'_{i2}, x'_{i3}, x_{i4}\}$$

In the present study, such task additions usually resulted from the recognition during detailed product development of necessary requirements that were either overlooked or unanticipated at the outset of the project. While interviewees suggested that more detailed up-front planning might have identified these unexpected tasks in certain cases, they also acknowledged that it was impossible to plan all aspects of the project in advance. The nature of the NPD process is such that many design parameters remain ambiguous during the planning stages and requirements do not become fully specified until detailed development work is underway. In effect, the only complete and accurate specification of product requirements is the fully developed product itself at the end of the NPD process. Between the beginning and end of the project, detailed design parameters are gradually identified and product requirements gradually become fleshed out in progressively greater detail as the development work proceeds.

Project and component contraction. We also observed numerous cases where NPD projects changed due to the elimination of tasks. These typically represented cases in which organisational pressures either to reduce development costs or to speed up product completion led to a decision to delete certain desired functionality from the finished product. As with the preceding cases, assuming interdependencies between the deleted and retained components of the product, scope contraction is likely to lead to modifications to remaining task components.

$$X = \{x_1, x_2, x_3\} \Rightarrow X' = \{x'_1, x'_3\} \quad (5)$$

or:

$$x_i = \{x_{i1}, x_{i2}, x_{i3}\} \Rightarrow x'_i = \{x'_{i1}, x'_{i3}\}$$

In the organisation studied, the deletion of any discrete product component often had repercussions throughout the NPD task structure due to mismatches between product architecture and task decomposition. Specifically, although NPD task decomposition was based on the existing division of labour within the organisational structure, the deletion of product functionality was usually based on the inherent interdependencies among components of the product. A product component chosen for deletion was likely to be one that had relatively little functional interdependence with other product components, leaving the remaining product with as much of the originally planned functionality as possible. However, since the development of any given product component corresponded with a set of tasks distributed across diverse organisational units, the deletion of any product component would impact individual tasks across the organisation.

The Project Managers we interviewed discussed both scope expansion and contraction in relation to two other decision variables: project budget and completion time. Besides reducing scope to cope with reduced budgets or accelerated completion dates, they also manipulated these variables in other ways to cope with unexpected contingencies. For instance, pressures to expand project scope by adding new product functionality or the discovery of unanticipated tasks during development usually precipitated a request either to increase the project budget, to delay product launch dates or both. Pressures to speed up development similarly triggered negotiations to either reduce project scope or to increase the budget.

Substitution. Substitution refers to cases in which an NPD project task is replaced by another task during the course of development. Task substitutions were most often associated with the replacement of one product component with another, which occurred in response to both external and internal factors in the study. For example, technological advances in the middle of the project (e.g. an upgrade to a third party software package used in the product) often triggered this sort of change. Similarly, the unexpected launch of a competitor's product might force a rethinking of product requirements to incorporate improved functionality exceeding that of the competitive product. Internally, Project Managers also blamed the Product Managers sponsoring product development projects for poor planning and for simply changing their minds about requirements during the development process. However, as previously noted, many technical design parameters were impossible to specify up front, since they were only understood by the technical specialists responsible for developing specific product components. When it became clear during development that a decision was required about a given design parameter, such decisions often necessitated a certain amount of task substitution rework elsewhere in the NPD structure due to the functional

DOI: 10.1002/kpm

interdependencies involved. Another internal reason for component substitution that we observed was miscommunication about product requirements between various groups in the NPD task network. For instance, in one project, an advertising campaign was initiated in anticipation of a new product launch, but the advertisements misrepresented actual product functionality due to a misunderstanding on the part of the advertising department. The result was a significant amount of NPD rework to modify the product in accordance with advertised claims. In all these cases, component substitution is likely to impact interdependent tasks throughout the NPD task structure, resulting in a finished product different from that originally conceived:

$$X = \{x_1, x_2, x_3\} \Rightarrow X' = \{x_1', x_2', x_4\} \tag{6}$$

Task combination. Finally task combination, which is the opposite of task decomposition, may become necessary as task interdependencies not recognised at the start of the project become apparent during the development process. For example, when two separate tasks are recognised to be highly interdependent during development, they may be combined into a single task to improve coordination and efficiency.

$$\{x_1, x_2\} \Rightarrow x_3 \tag{7}$$

Similarly, if a single task is discovered during development to incorporate two sets of relatively independent activities related to two product subsystems that have been organised as separate task components, it may be more efficient to decompose the task and merge its components with the other two. In this case, the initial task essentially disappears as a discrete unit of activity in the NPD task structure, while the other two expand due to component addition.

$$\begin{gathered} x_1 = \{x_{11}, x_{12}\} \text{ where } x_{11} = f(x_2), x_{12} = f(x_3) \\ x_1 \Rightarrow \{\} \\ \{x_2, x_{11}\} \Rightarrow x_2' \\ \{x_3, x_{12}\} \Rightarrow x_3' \end{gathered} \tag{8}$$

Task combination occurred both within and across projects in the study. Because the firm launched about 200 new products per year, there was often a lack of coordination among the various Product Managers sponsoring NPD projects. Although two Product Managers were unlikely to promote functionally identical products, different products targeted at different marketing applications often shared common underlying component technologies, which if not recognised would result in the duplication of development efforts and a lack of product standardisation as different development teams solved similar problems in different ways. When such similarities between the requirements of two projects were recognised during development, attempts were made to combine the component tasks from each project in ways that satisfied the requirements of both. Entire projects with significant functional similarities were sometimes combined to form a single project satisfying the market needs of both original product concepts.

Magnitude and rate of change in component tasks

The preceding discussion has identified four ways that tasks change during NPD projects. NPD task structures are also affected by the magnitude and rate of change in component tasks. The relationship between the magnitude and rate of component change and NPD task structures is complex and reciprocal, however. First, tasks that experience relatively larger or more frequent changes will have a greater relative impact on other interdependent tasks than those experiencing smaller, less frequent changes. This suggests that magnitude and rate of change influence perceptions of task interdependence, since the former would be regarded as having a higher degree of interdependence than the latter. To the extent that task decomposition strategies reflect attempts to contain functional interdependencies within the same tasks, as previously discussed, such perceptions are likely to influence how project tasks are divided.

On the other hand, once the overall NPD task has been divided into component tasks and allocated to organisational units, the particular decomposition strategy adopted is likely to influence subsequent perceptions of the magnitude and rate of task change. This is because interdependent tasks performed within the same organisational unit will generally be coordinated more effectively than those performed by different units since the impacts of task changes are contained within the bounds of the same unit (Galbraith, 1973; Thompson, 1967). Thus, when interdependent tasks are grouped together, changes are likely to be dealt with and resolved relatively quickly regardless of the magnitude or rate of change. By contrast when interdependent tasks are split across different units, as they were in the present study, small task changes may not be recognised as relevant to other units until sometime later in the NPD process, at which time the magnitude of the change would have become much larger in terms of the amount of rework required. Similarly, frequent small changes tend to be overlooked or ignored until they 'add up' to a larger change requiring significant rework.

DOI: 10.1002/kpm

Thus, perceptions of task interdependence are influenced by the magnitude and rate of change of project task components, which then influence choices of how the overall NPD task is decomposed into components. However, the NPD task structure resulting from a particular decomposition strategy then influences subsequent perceptions of the magnitude and rate of change of component tasks.

Organisational influences on the perception of NPD tasks

There are other factors that influence the perception and interpretation of NPD task structures. We have noted that in the current study, the distribution of tasks was based on the formal distribution of technical knowledge to functional departments that housed SMEs. Meanwhile, functional departments also operated as cost centres within the firm, responsible for their own departmental budgets. NPD Project Managers, therefore, essentially played the role of general contractors within the firm, sub-contracting with each department to perform given amounts of work in exchange for specific budget allocations. The correlation between the distribution of technical knowledge and the allocation of budgets by departments created incentives for functional managers to misrepresent the magnitude of NPD tasks, in terms of both the amount of time and budget required for completion, since Project Managers and other outsiders lacked the technical knowledge needed to challenge the accuracy of their time and budget estimates. Similarly, functional managers were accused of 'scope padding', whereby their cost and time estimates would be based on a technical specification that significantly exceeded the actual functional requirements of the product. Given these three forms of padding, the magnitude of any NPD task component or task change was likely to be overstated and the subject of much negotiation.

Meanwhile, the padding of time and budget estimates was considered necessary by the functional managers themselves, who did so as a means of hedging against task requirements ambiguity and corresponding cost and development time uncertainty. The practice of scope padding similarly allowed for the possibility of a scope reduction without substantial loss of functionality in the event of a budget cut during the product development process. Furthermore, although Project Managers complained about padding on the part of functional managers, they also padded their own overall time and budget estimates when negotiating with the Product Managers who sponsored the NPD projects. Thus, while outsiders regarded padding as a misrepresentation of the magnitude of project tasks by functional managers or the Project Manager, these actors themselves regarded it as necessary to cope with contingencies resulting from requirements ambiguity.

In the study, two other organisational factors aggravated the effects of NPD task ambiguity perceived by SMEs and Project Managers and influenced the tendency of functional managers to pad budget, time and scope estimates. First, the organisation had a high rate of internal employee turnover, to the extent that it was common for employees to change jobs within the firm at least once every 2 years. This high rate of 'churn' meant that most project teams included a number of SMEs with very little experience in their field. Other things being equal, SMEs with relatively less experience were likely to perceive project requirements as relatively more ambiguous and project time, budget and scope estimates as relatively more uncertain than those with more experience.

Second, a rather inflexible budgeting and capital allocation system within the firm required Product Managers sponsoring NPD projects to request funding approval a year or more before the actual start of a project. Since product concepts were extremely vague and ambiguous at this early stage of planning, Product Managers complained that this bureaucratic constraint forced them to estimate budgets by 'picking numbers out of the air'. The inflexibility of the budgeting system also made it difficult to obtain budget increases at later stages of the NPD process so, like Project Managers and functional managers, Product Managers also hedged their bets by padding cost estimates significantly. In cases where the resulting budget slack was used up and further funding was still needed to meet development goals, functional managers often dealt with the situation by 'shuffling' costs between budgets, charging activities related to an over-budget project to another project that was under-budget. To make matters worse, budgeting was performed on an annual basis, creating pressures to complete projects before the fiscal year end since incomplete projects required special approvals to carry budgets forward to the next year. Thus, budget shuffling occurred most often at the end of the year, when managers with incomplete projects traded unspent budgets in exchange for informal options to use money from future budgets to complete their projects during the next fiscal year. Like padding, budget shuffling was difficult for outsiders to detect due to their lack of technical knowledge in a department's area of speciality. Budget system inflexibility, therefore, amplified perceptions of project ambiguity during the early planning stages and also made it difficult to identify and track actual NPD tasks later during development.

DOI: 10.1002/kpm

DISCUSSION AND CONCLUSION

This paper has used interview findings from a study of NPD within a large telecom firm to examine the influence of requirements ambiguity on NPD task structures. Ambiguity implies that NPD tasks cannot be defined precisely, and that interdependencies and precedence relationships between tasks are unknown in advance. The results indicate that NPD projects in the firm were characterised by constant communication, coordination, knowledge sharing and problem solving among project team members from different functional departments, who each possessed specialised knowledge necessary for project completion. SMEs needed to be available for consultation and to adapt flexibly as requirements ambiguity was gradually resolved over the course of the NPD process.

We have also used the study findings to propose a taxonomy and corresponding notation for describing NPD task structures and the changes they undergo during the product development process in generic terms. The proposed framework highlights certain properties of the situation in ways that traditional NPD and project management strategies overlook. For example, we noted earlier that Project Managers discussed project scope adjustments in relation to project budget and completion time as a set of three inter-related control variables. Project Managers tended to speak about such adjustments as if project scope was a continuous linear variable (i.e. ranging from small to large), just as budget and completion time can be treated as continuous linear variables. However, such a view glosses over the underlying complexity of NPD task structure changes associated with scope adjustments and is based on misleading metaphors of NPD tasks as simple, independent, additive building blocks of activity and project expansion and contraction as balloon-like growth and shrinkage. The proposed framework provides a more realistic model of NPD task change resulting from ambiguity. Task ambiguity implies that component task boundaries are not fixed and interactions among interdependent tasks consist of complex reciprocal (i.e. non-linear) patterns of influence. Task expansion, contraction, substitution and combination correspond with the addition, deletion and reorganisation of tasks at multiple levels of analysis within the NPD task structure. Task decomposition that is arbitrarily based on an organisation's existing department structure rather than criteria related to task interdependence amplifies the complexity and nonlinearity involved.

The taxonomy and notation proposed here provide a framework and language for discussing NPD tasks that can serve as the basis for future managerial practice and research. In terms of practice, the study illustrates how ambiguity influences task change in the NPD process. Although change is inevitable in ambiguous task environments, we would argue that it also occurs in recognizable and predictable patterns, suggesting that it is manageable. The four patterns of task change identified are likely to vary in magnitude and frequency of change, depending on the degree of ambiguity present when the project is initially decomposed into a network of distributed tasks, and depending on the degree to which this network corresponds with underlying patterns of task interdependence.

Strategies for managing NPD task changes, therefore, can be divided into two groups: those that minimize the likelihood of necessary task change and those that support the flexible adaptation of task structures when change is required. The first strategy aims at defining task structures in ways that correspond as closely as possible to the pattern of task interdependence (von Hippel, 1990). This means that managers need to evaluate the degree of ambiguity present and to identify known interdependencies prior to task decomposition. Since complete knowledge of interdependencies is not available until much later in the development process, some degree of change is unavoidable and must be expected. In the study, the main coping strategy was the systematic padding of cost, time and scope estimates. Not only are such approaches likely to be inefficient but they also aggravate the coordination difficulties associated with task ambiguity by reducing the quality of communication among SMEs. More effective coping strategies would involve the flexible adaptation of task structures as project requirements emerge during the product development process. As new task interdependencies are identified during development, managers should be prepared to redefine and adapt task boundaries accordingly.

Existing organisational structures and routines constrain such adaptations, however, as the budgeting system and functional department structure did in the present study. The influence of such constraints likely depends on the degree of mismatch between the existing organisational structure and the optimal NPD task decomposition based on task interdependence criteria. When new products only vary incrementally from existing products, the degree of mismatch is likely to be much lower than for architectural innovations (Henderson and Clark, 1990) or for product development projects involving technologies entirely new to the firm. To prevent such constraints

DOI: 10.1002/kpm

from inhibiting innovation, some firms establish semi-autonomous new venture divisions to separate product development activities from routine operations (Burgelman, 1984). In the present study, many of the firm's new products were incremental in nature and it would have been inefficient to devote dedicated organisations to their development due to resource constraints. Other strategies for improving the adaptability of task structures were available however. For instance, reducing the rigidity of budgeting routines would have been a low cost means of helping managers adapt to task changes requiring budget adjustments and also might have reduced the tendency to misrepresent tasks in ways that amplified the effects of ambiguity. Similarly, the findings suggest perceptions of task ambiguity were partly a function of SME knowledge and experience level. Reducing the internal employee turnover rate in the firm should result in increased SME expertise, corresponding with both reduced perceived task ambiguity and quicker adaptation to changing task requirements.

The findings presented here also have implications for future research. The proposed framework is based on a qualitative analysis of interview data from a single organisation and further research is needed to examine its utility in other organisational contexts. The framework provides a potentially rich language for posing testable hypotheses about the relative influence of different degrees of interdependence on task structure change, the effects of task decomposition based on organisational structure versus product architecture, and various other issues. Research is also needed to investigate the potential implications of the proposed framework for the development of improved project management techniques and methods since traditional approaches have difficulty dealing with requirements ambiguity. Based on the findings and arguments presented here, it may be possible to develop analytical techniques that retain the time and cost tracking properties of traditional tools like PERT and CPM but incorporate more accurate models of ambiguous and changing project task structures. Although ambiguity, by definition, implies that key variables and relationships influencing project outcomes are unknown, we argue that because its effects on project task structures follow predictable patterns, strategies for dealing with these effects can be developed. By examining the influence of ambiguity on NPD task structures, we hope this paper can contribute to a better understanding of the effects of ambiguity and improved strategies for managing NPD projects.

REFERENCES

Bailleti AJ, Callahan JR, DiPietro P. 1994. A coordination structure approach to the management of projects. *IEEE Transactions on Engineering Management* **41**(4): 394–403.

Barthol RP, Bridge RG. 1968. The ECHO multi-response method for surveying value and influence patterns in groups. *Psychological Reports* **22**: 1345–1354.

Barthol RP, de Mille R. 1969. *Project ECHO*. General Research Corporation: Santa Barbara, CA.

Bavelas A. 1942. A method for investigating individual and group ideology. *Sociometry* **5**: 371–377.

Becker MC. 2001. Managing dispersed knowledge: organizational problems, managerial strategies, and their effectiveness. *Journal of Management Studies* **38**(7): 1037–1051.

Becker MC, Zirpoli F. 2003. Organizing new product development—knowledge hollowing-out and knowledge integration—the FIAT Auto case. *International Journal of Operations & Production Management* **23**(9): 1033–1061.

Burgelman RA. 1984. Designs for corporate entrepreneurship in established firms. *California Management Review* **26**: 154–166.

Cooper RG, Edgett SJ, Kleinschmidt EJ. 2002. Optimizing the stage-gate process: what best-practice companies do—I. *Research Technology Management* **45**(5): 21–27.

Dougherty D. 1990. Understanding new markets for new products. *Strategic Management Journal* **11**: 59–78.

Dougherty D. 1992. Interpretive barriers to successful product innovation in large firms. *Organization Science* **3**(2): 179–202.

Dougherty D, Hardy C. 1996. Sustained product innovation in large, mature organizations: overcoming innovation-to-organization problems. *Academy of Management Journal* **39**(5): 1120–1153.

Duimering PR, Purdy L, Safayeni F, Scala J. 1998. Applications of Ashby's Law of Requisite Variety to the practice of manufacturing. In *Proceedings of the World Multiconference on Systemics, Cybernetics and Informatics*, (Vol. 3). Orlando, FL; 749–756.

Galbraith JR. 1973. *Designing Complex Organizations*. Addison-Wesley Publishing Co.: Reading, MA.

Globerson S. 1997. Discrepancies between customer expectations and product configuration. *International Journal of Project Management* **15**(4): 199–203.

Griffin A, Hauser JR. 1992. Patterns of communication among marketing, engineering and manufacturing. *Management Science* **38**: 360–373.

Gupta AK, Wilemon DL. 1990. Accelerating the development of technology-based new products. *California Management Review* **32**(2): 24–44.

Henderson RM, Clark KB. 1990. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly* **35**: 9–30.

Hlavacek J, Thompson V. 1973. Bureaucracy and new product innovation. *Academy of Management Journal* **16**: 361–372.

Khurana A, Rosenthal SR. 1997. Integrating the fuzzy front end of new product development. *Sloan Management Review* **38**(2): 103–120.

Minkler AP. 1993. The problem with dispersed knowledge: firms in theory and practice. *Kyklos* **46**(4): 569–587.

Moenaert RK, Meyer AD, Souder WE, Deschoolmeester D. 1995. R-and-D marketing communication during the

DOI: 10.1002/kpm

fuzzy front-end. *IEEE Transactions on Engineering Management* **42**(3): 243–258.

Pender S. 2001. Managing incomplete knowledge: why risk management is not sufficient. *International Journal of Project Management* **19**(2): 79–87.

Pich MT, Loch CH, De Meyer A. 2002. On uncertainty, ambiguity, and complexity in project management. *Management Science* **48**(8): 1008–1023.

QSR International Pty Ltd. 2002. QSR N6.

Safayeni F, Yu A, Purdy L, Lee E. 1992. Assessing the potential of e-mail for engineers: case study. *Journal of Management in Engineering* **8**(4): 346–361.

Schrader S, Riggs W, Smith R. 1993. Choice over uncertainty and ambiguity in technical problem solving. *Journal of Engineering and Technology Management* **10**: 73–99.

Simon HA. 1962. The architecture of complexity. *Proceedings of the American Philosophical Society* **106**(6): 467–482.

Simon HA. 1996. *The Sciences of the Artificial* (3rd ed.) MIT Press: Cambridge, Mass.

Sosa ME, Eppinger SD, Rowles CM. 2003. Identifying modular and integrative systems and their impact on design team interactions. *Journal of Mechanical Design* **125**(2): 240–252.

Tatikonda MV, Rosenthal SR. 2000. Technology novelty, project complexity, and product development project execution success: a deeper look at task uncertainty in product innovation. *IEEE Transactions on Engineering Management* **47**(1): 74–87.

Thompson JD. 1967. *Organizations in Action*. McGraw-Hill Book Company Inc.: New York.

Tsoukas H. 1996. The firm as a distributed knowledge system. *Strategic Management Journal* **17**: 11–25.

Tucker D, Leonard R. 2001. An innovative approach for using the GRAI methodology for reengineering the new product introduction process. *International Journal of Flexible Manufacturing Systems* **13**: 177–193.

Ulrich K. 1995. The role of product architecture in the manufacturing firm. *Research Policy* **24**(3): 419–440.

von Hippel E. 1990. Task partitioning: an innovation process variable. *Research Policy* **19**: 407–418.

Ward S, Chapman C. 2003. Transforming project risk management into project uncertainty management. *International Journal of Project Management* **21**(2): 97–105.