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Faster, better, cheaper: A study of NPD project efficiency and performance tradeoffs

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Abstract

In this paper, we develop a theory of efficiency and performance tradeoffs for new product development (NPD) projects. Data from 137 completed NPD projects are analyzed for evidence pointing to tradeoffs in performance patterns manifested in the data. In addition, we investigate hypothesized relationships between certain NPD practices and a holistic, efficiency based measure of NPD performance. We demonstrate a new approach to the operationalization of holistic new product development (NPD) project performance, employing a sequential data envelopment analysis (DEA) methodology that simultaneously incorporates multiple factors including new product development cost, product cost, product quality, and project lead time.

The results of the data analysis support our hypothesis that tradeoffs among NPD performance outcomes are manifested more strongly in highly efficient projects when compared to inefficient projects. The presence of three distinct subgroups in highly efficient projects is suggestive of several modes of efficiency which appear to achieve equally effective market success. The absence of such patterns in less efficient projects supports a theory of performance frontiers that may impose the need for tradeoffs more strongly as NPD projects achieve higher levels of efficiency. The findings also point to the importance of project management experience, balanced management commitment, and cross-functional integration in achieving high levels of NPD project efficiency. We discuss the implications of the findings for practice and for future research.

Keywords: Product development; Project management; Data envelopment analysis; Empirical research methods

1. Introduction

Researchers have frequently highlighted potential performance tradeoffs in NPD project management, suggesting the need for research that addresses multiple project outcomes in a more holistic fashion (Gupta et al., 1992; Bayus, 1997; Smith and Reinertsen, 1998). While researchers and practitioners agree that there are potential tradeoffs between respective pairs of NPD performance outcomes: speed-quality (Calantone and Di Benedetto, 2000; Harter et al., 2000); time–cost (Graves, 1989); and time-quality (Karlsson and Ahlstrom, 1999), arguments for these tradeoffs have been articulated, but not tested.

In addition, numerous research studies have examined various new product development (NPD) practices related to project organization and management (Montoya-Weiss and Calantone, 1994; Brown and Eisenhardt, 1995; Calantone et al., 1996; Henard and Szymanski, 2001; Krishnan and Ulrich, 2001). Most have focused on one or a few project objectives, seeking to uncover effective practices associated with that objective. For example, many studies have examined antecedents and drivers of NPD time (Clark, 1989; Griffin, 1993; Ali et al., 1995; Eisenhardt and Tabrizi, 1995; Datar et al., 1997). At the same time, these types

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of studies have suggested that certain practices serve to mitigate tradeoffs in NPD project management. Thus, the existing literature raises questions regarding the existence of tradeoffs, and the role of changes in project execution processes in affecting the nature of such tradeoffs.

The first contribution of the research described in this paper is to develop and test a theory of performance tradeoffs in NPD project performance. We employ a theory of performance frontiers in order to merge two divergent perspectives of performance tradeoffs found in the literature. An investigation of data from 137 completed NPD projects provides evidence pointing to tradeoffs in performance patterns manifested in the data. Prior empirical evidence of such tradeoffs has been limited. Thus, the results of our analysis have important theoretical and practical implications for NPD performance improvements and optimal resource allocations.

Our second contribution is a study of relationships between NPD practices, levels of NPD project efficiency, and market-based project success. By using efficiency as a measure of project performance, the analysis is able to test the associations of NPD practices with a more holistic assessment of project performance than prior research has provided. This analysis provides insights into the breadth of benefits associated with the practices, and whether or not such practices serve to create or to mitigate tradeoffs in NPD project performance.

The operationalization of NPD project performance has in the past posed a challenge for researchers seeking to address the questions alluded to above. Industry and other contextual differences across projects make comparability an important issue (Griffin and Page, 1996; Shenhar et al., 2001). In addition, there is the question of how to appropriately aggregate information on various performance outcomes in different dimensions into a holistic representation of overall project performance.

As a third contribution of this paper, we demonstrate a novel approach to the operationalization of holistic NPD project performance, employing a sequential data envelopment analysis (DEA) methodology. We utilize DEA to evaluate efficiencies of NPD projects by considering multiple dimensions of NPD project performance, including aspects of development cost, product cost, product quality, and project lead time (Smith and Reinertsen, 1998). We consider development cost and product cost as inputs to the DEA model since they represent the resources spent on product development and production. Dimensions of product quality and project lead time are considered as outputs since they characterize performance outcomes derived from the utilization of resources. This categorization of inputs and outputs is consistent with DEA since higher levels of these inputs generate higher levels of performance in the outputs.

The rest of the paper is organized as follows. Section 2 draws upon the literature to develop theory and related hypotheses. Section 3 describes the data collection and methodology used to investigate empirical support for the hypotheses. Section 4 presents the analysis and results. The paper concludes in Sections 5 and 6 with discussion of limitations and implications of the findings and future research directions.

2. Theory development

2.1. Tradeoffs in NPD project performance

A sizeable literature discusses tradeoffs among dimensions of NPD project performance. Smith and Reinertsen (1998) identify four key objectives in NPD project management: project timeliness, product performance, development expense, and product cost. They argue that tradeoffs exist between each pair of performance dimensions, requiring that objectives in these areas be balanced. Interestingly, they suggest that the relationship between project time and development expense is u-shaped (Smith and Reinertsen, 1998, p. 13; Gupta et al., 1992; Murmann, 1994). A given project's position on this tradeoff curve is determined by the "effectiveness" of the project, that is, the degree to which the managers of the project have made use of "techniques" which improve the efficiency of project execution. Thus, NPD projects which are relatively naïve in their use of techniques have low efficiencies, and thus have the potential to reduce both project time and project expense by better utilization of techniques and resources available to them. However, projects that already have high levels of execution competence are more likely to face a tradeoff; faster product development will require greater development expense.

Such issues are ignored in classical project management theory, which maintains that the project time–cost relationship is negative and non-linear; thus efforts to reduce project duration will require increasingly greater levels of cost. For example, Graves (1989) explains that as people are added to a project in order to speed up work, their marginal contributions decline. He further argues that attempts to reduce NPD lead time by overlapping activities in the project create denser, more complex networks which raise coordination costs.

Scherer (1966) demonstrates how the probabilistic nature of NPD project activities contributes to cost increases under acceleration. Teece (1977) established negatively sloped time–cost elasticities for manufacturing plant launch projects and argued that they were similar to tradeoffs in innovation projects.

In similar ways, researchers have also studied tradeoffs among other pairs of the aforementioned NPD project performance dimensions. Calantone and Di Benedetto (2000) provide an analytical model of the relationship between product performance quality and NPD lead time. Other analytical studies identify conditions in which NPD project acceleration techniques may actually increase time to market or negatively affect product performance (Ulrich et al., 1993; Ha and Porteus, 1995; Terwiesch and Loch, 1999). Researchers have also studied the product performance-development time tradeoff empirically, with mixed findings (Krubasik, 1988; Gupta et al., 1992; Cohen et al., 1996; Karlsson and Ahlstrom, 1999; Sethi, 2000; Everaert and Bruggeman, 2002); some studies support the existence of a performance-time tradeoff, others do not. Similarly, support for a performance-development cost tradeoff has also been mixed (Griffin, 1993; Levesque, 2000; Everaert and Bruggeman, 2002).

Overall, the literature identifies many mixed findings regarding tradeoffs, suggesting the need for a broader theory which explains the nature of tradeoffs and their relationships to NPD practices in a more comprehensive way. In developing such a theory, it is first important to note that the literature contains two important perspectives regarding inter-performance relationships. On the one hand, researchers assume that tradeoffs exist. According to Bayus (1997), most NPD managers also intuitively know that tradeoffs exist. For example, Gupta et al. (1992) studied how technology-based companies in Germany and the US make tradeoffs among development schedule, development cost, and product performance. They concluded that German companies place greater emphasis on meeting schedules than on meeting development budgets, whereas US firms place greater emphasis on budgets and product performance.

On the other hand, researchers also suggest that tradeoffs can be reduced by using new techniques, by project restructuring, and by reduction in wasteful activities (Clark and Fujimoto, 1991; Bayus, 1997; Kessler et al., 2000; Roemer et al., 2000; Hoque and Mondon, 2002; Everaert and Bruggeman, 2002). For example, Harter et al. (2000) argue that NPD quality, lead time and cost can all be simultaneously improved by reducing defects, waste, and rework in NPD project activities. They provide empirical evidence indicating that process maturity may contribute to greater project performance.

In order to integrate the first perspective, which is based on classical project management theories, with the second perspective, which is based on project efficiency related arguments, we draw upon the theory of performance frontiers (TPF). The TPF is based in microeconomics theory which suggests that technical realities form constraints on the capabilities of a production system, thereby forcing tradeoffs among various dimensions of performance in the short term. A number of researchers have developed this theory as it applies to manufacturing and service operations management (Clark, 1996; Hayes and Pisano, 1996; Schmenner and Swink, 1999; Vastag, 2000; Lapré and Scudder, 2004). We apply the arguments of TPF to the case of NPD projects.

Fig. 1 illustrates a two dimensional performance space for NPD projects (as a simplification of the larger multidimensional space). A TPF based view of individual NPD projects places them along various points within the overall performance space. Any given project is subject to *local tradeoffs* imposed by the technology, organizational structure, and other practices which define the process by which the project is executed. Project "A" shown in Fig. 1, for example, operates on a *local performance frontier* which is created by the technical constraints embedded in its overall execution process. Without making a significant change in the execution process, the managers of project A are faced with a choice of improving in performance dimension Y1 at the expense of performance dimension Y2, or vice versa. As shown in the literature review, there is conceptual and empirical support for a non-linear relationship between Y1 and Y2. That is, continuing increases in performance in one dimension would cause increasingly greater detriments to performance in another dimension. These hypothesized relationships are consistent with classical project management theory.

However, efficiency based arguments suggest that the managers of project A may indeed achieve performance improvements in multiple dimensions simultaneously through a significant process change, a fundamental change in the technology used to transform inputs into outputs. This type of change is illustrated in Fig. 1 by the arrow showing a trajectory from the position of project A to the position of project B. Once such a change is implemented, the project is now subject to a new local performance frontier, and a new set of tradeoffs. Thus, both projects A and B are

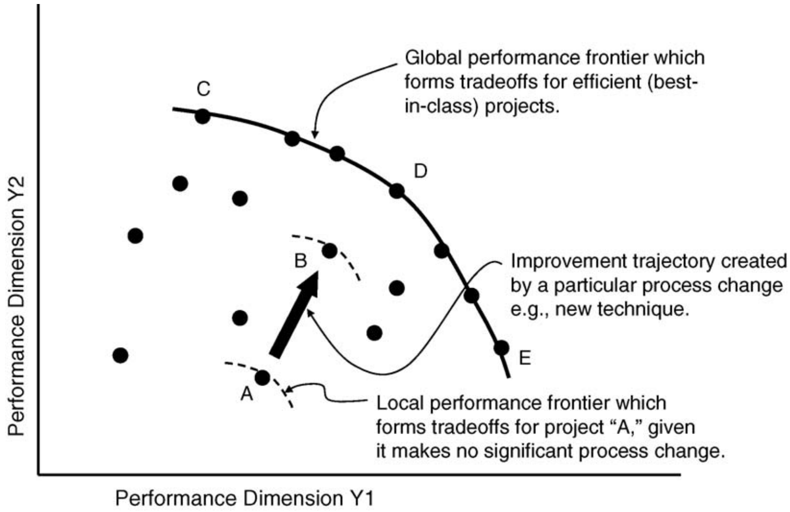

Fig. 1. Theory of performance frontiers applied to NPD project management.

subject to tradeoffs, but in absolute terms project B is able to attain higher levels of performance than project A in both performance dimensions.

Another important tenet of the TPF is that this type of performance improvement cannot be extended indefinitely. One reason for this limitation is that the benefits of such process changes are subject to diminishing returns (Schmenner and Swink, 1999). For example, Calantone and Di Benedetto (2000) maintain that there are diminishing benefits to greater and greater degrees of overlap among NPD activities (an example of project restructuring). Secondly, at any point in time there are a finite number of known possibilities for significant process changes. Once an organization has exhausted many or most of the known possibilities for process change, fewer opportunities for improvement become readily apparent. Ultimately, a *global performance frontier* is established by the state-of-the-art in NPD project management. Managers of projects which have reached this position in the performance space will face *global tradeoffs*. These global tradeoffs are ''harder'' than local tradeoffs in the sense that they are seemingly inescapable in the short term, whereas local tradeoffs may be allayed by relatively abundant opportunities for process change. Hence, while pursuit of new techniques and project restructuring opportunities push out the boundaries formerly imposed on a given project by local tradeoffs, these process changes inevitably move a project closer to an ultimate performance frontier, and thus closer to a point where global tradeoffs are in force.

In the language of microeconomics, a project which is closer to the global performance frontier is more *efficient* than other projects. Efficiency is a function of the degree to which the project can economically transform inputs into outputs. A project residing on the global performance frontier can be viewed as being the most efficient given the current state-of-the-art. The foregoing logic would suggest that projects in this class would experience global tradeoffs to a higher degree than less efficient projects. Managers of inefficient projects will be less inclined to experience hard tradeoffs in performance because boundary extending process changes are more available and hold greater potential. This leads us to our first hypothesis:

H1. Global tradeoffs in NPD project performance are more evident in efficient projects than in inefficient projects.

In considering the implications of H1, it is important to note another key distinction between local and global tradeoffs. Global tradeoffs explain performance differences across projects at a given point in time, whereas local tradeoffs describe choices confronting a single project over time (Schmenner and Swink, 1999). Studies of global tradeoffs therefore require a different focus and methodology than studies of local tradeoffs. The remainder of this paper deals with global tradeoffs.

In Fig. 1, projects C, D, and E occupy three different positions along the global performance frontier. These positions represent different combined levels of achievement in the two performance dimensions. However, the three projects are equally efficient since they lie on the efficient frontier; they are all supremely efficient given the state-of-the-art. Thus, the three positions occupied by these projects represent different *modes of efficiency*. Differences across the efficient modes result from goal choices and levels of achievement which are imposed by the technical constraints embodied by the global performance frontier.

Seen from a productivity perspective, efficient NPD projects which pursue different modes of efficiency are equally adept at converting inputs to outputs. Since efficient projects represent the state-of-the-art in this capability, they create value at rates that are superior to those of inefficient projects. The value propositions created by efficient NPD projects which occupy different positions on the global performance frontier may be equally effective in the marketplace, depending on the technological and market context (Bayus, 1997). For example, Krubasik (1988) discusses the need to customize product development efforts to market and competitive conditions. However, if we assume that issues such as market opportunity cost and technical risk are incorporated into the strategic planning for a NPD project, then we would expect that efficient projects which occupy different positions on the global performance frontier should produce similar levels of market success, and these levels should be superior to the success levels achieved by inefficient projects. Efficient NPD projects offer rare levels of value creation that ultimately should be rewarded by markets. This discussion leads to two hypotheses:

H2. The market success of efficient NPD projects is greater than that of inefficient projects.

H3. There is no significant difference in market success across efficient NPD projects which pursue different modes of efficiency.

2.2. Drivers of NPD project efficiency

The TPF as we have described it suggests that NPD project efficiency is improved through the implementation of changes to project execution processes. Such process changes might apply new technologies, operating procedures, organizational structures, or other practices that remove waste (inefficiency) from design and development activities. The literature describing relationships between NPD project practices and performance is quite large (see reviews in Balachandra and Friar, 1997; Brown and Eisenhardt, 1995; Montoya-Weiss and Calantone, 1994; Damanpour, 1991; Shenhar et al., 2001; Krishnan and Ulrich, 2001). We focus our attention on three process areas pointed up in the literature as having significant potential to affect overall NPD project efficiency: experience, project leadership, and cross-functional integration. As was mentioned earlier, most studies of practice-performance relationships in NPD project management have tended to be focused on one or a few dimensions of performance. Where possible, we review the findings from these studies in support of arguments for more holistic, efficiency oriented performance expectations.

An interesting contextual factor posited to affect NPD project efficiency is NPD process experience. Organizational learning theory suggests that economies of learning are achieved as an organization applies process improvement knowledge gained through repeated execution of similar tasks (Yelle, 1979). Graves (1989) reasoned that NPD project management experience, especially in a related field of products, gives the firm the ability to safely bypass steps and reduce costs, thereby lowering time–cost elasticity in NPD. Harter et al. (2000) showed empirically that process maturity, reflected by level of investment to improve process capability, led to higher product quality, but not to NPD cycle time reduction. Pisano (1997) found that experienced workers are more often able to identify what is practical and compatible with development goals. Thus, learning which results from greater NPD process experience is thought to lead to greater efficiency.

H4. NPD project management experience is positively associated with project efficiency.

A large number of NPD research studies addressing the role of management leadership provide clear evidence of its perceived importance. An important aspect of leadership is management's ability to balance its interests and commitment with the need to allow the project team to have proper levels of decision making authority. For example, Kessler (2000) found that the number of product champions in a project was associated with lower product development costs. At the same time, top management involvement and *interest* was associated with higher NPD cost. Top management support is seen as necessary for the project to secure important resources and to provide leadership in uncertain circumstances (Pate-Cornell and Dillon, 2001; Eisenhardt and Tabrizi, 1995). However, over-involvement by managers can stretch out decision making time (Zirger and Hartley, 1996). Hence, a balance between "appropriate" top management involvement and project team empowerment is thought to be a key to achieving excellence in multiple dimensions of project performance (Anthony and McKay, 1992).

H5. Balanced top management commitment is associated with NPD project efficiency.

A related leadership issue has to do with the establishment of NPD project objectives, goals, and rewards. Kessler (2000) found clarity of product concept to be associated with lower development cost. Others have associated explicit goals with reduction in project lateness and in development lead time (Zirger and Hartley, 1996; Swink, 2002), especially in high market growth environments (LaBahn et al., 1996). However, Harter et al. (2000) found no significant impact of requirements ambiguity on cycle time or development effort (man–months).

The logic relating goal clarity to NPD project efficiency stems from a waste reduction perspective, where waste is observed as non-value adding activities. NPD projects often involve high levels of uncertainty (Moenaert and Souder, 1990). Left unresolved, uncertainty creates ambiguity and equivocality in the project that can lead to many false starts and wasted efforts (Daft and Lengel, 1986). This reasoning leads us to expect that NPD projects which have explicit goals established at the outset are likely to be executed in a better organized and more expeditious manner.

H6. The establishment of explicit project goals is associated with NPD project efficiency.

A host of organizational approaches and infrastructural programs are aimed at fostering or enhancing the integration of cross-functional concerns in problem solving activities (Atuahene-Gima, 2003). An important prerequisite to cross-functional integration is a working environment which supports collaboration among project team members (O'Leary-Kelly and Flores, 2002). A collaborative working environment contains fewer barriers to information exchange such as functional silos, team member inaccessibility, and incompatible information systems.

Knowledge sharing in a collaborative environment has been found to positively affect innovation performance (Nonaka, 1991; Leonard-Barton, 1992), as it facilitates problem solving and reduces the inefficiency of re-inventing already existing solutions. Interactions among team members are also thought to stimulate better quality solutions in the design process. Thus, we expect a positive association between a collaborative environment and NPD project efficiency.

H7. A collaborative work environment is positively associated with NPD project efficiency.

A key infrastructural element of team operation in NPD is the degree to which project members are collocated. The benefits of collocation have been touted, and in some cases, empirically supported (Pate-Cornell et al., 2001). However, researchers have also uncovered detriments of collocation, including increased time-to-market (Datar et al., 1997) and higher product development costs (Kessler, 2000; Kessler et al., 2000). Kessler suggested that team member proximity induces too many meetings that detract from productive work.

Collocation of project members reduces the physical distances between them. We would expect that the removal of distance as a barrier would improve overall project efficiency, as information transactions and other communications are made easier. In addition, collocation increases the likelihood of serendipitous solution generation via informal contacts among project members who represent different, yet interdependent, functional concerns. The foregoing literature suggests that these benefits may be offset by increased operating costs (e.g., travel and relocation) and the potential for inefficient bureaucratic behaviors (e.g., excessive meetings). While the total effect of collocation on NPD project efficiency is unclear, we tentatively forward the following hypothesis:

H8. Project team collocation is positively associated with NPD project efficiency.

Design manufacturing integration is one of the most important cross-functional linkages within the NPD process. A new product often requires adjustments, and possibly major changes, to the manufacturing process. Early cooperation of design and manufacturing personnel in the NPD project provides consideration of dependencies between product and process design decisions which reduces the cost and time associated with wasteful redesigns of products. In addition, use of methods such as design for manufacturing (DFM) to encourage the integration of product and process design decisions has been associated with lower product costs and better conformance quality (Youssef, 1994; Swink, 2002; Sanchez and Perez, 2003). Ulrich et al. (1993) demonstrate how an overly rigid and formulaic use of design-for-manufacture (DFM) methods might increase NPD lead time due to the selection of long lead time manufacturing tools, creating a tradeoff between NPD lead time and product manufacturability. However, we expect that if product design and manufacturing personnel act in truly cooperative ways, overall project efficiency should increase.

H9. Design manufacturing integration is positively associated with NPD project efficiency.

A final important area of project execution related to cross-functional integration is NPD project scheduling, specifically, the degree to which managers schedule upstream and downstream activities to be overlapped. Concurrent engineering, an approach involving the overlap of product and process development activities, is one of the most highly cited techniques to reduce NPD time. Analyses of empirical data have associated activity overlap with higher development speed, yet other empirical analyses and analytical models also suggest that overlap can lead to higher development costs and increased product quality risks (Ha et al., 1995; Krishnan et al., 1997; Smith and Eppinger, 1997; Calantone and Di Benedetto, 2000; Kessler, 2000; Pate-Cornell and Dillon, 2001). Overlap of design activities may require greater coordination costs (Roemer et al., 2000). Overlap may also be riskier since it requires that work be done using assumptions or preliminary data (Browning and Eppinger, 2002). However, it is expected that these additional costs are more than repaid by benefits in product quality and downstream launch efficiencies.

H10. Project activity overlap (concurrency) is positively associated with NPD project efficiency.

3. Methodology

3.1. *Project efficiency via data envelopment analysis*

In order to evaluate NPD project tradeoffs and efficiency in a manner consistent with TPF, we utilized DEA, considering multiple performance outcomes. DEA is a linear programming based technique that that evaluates the relative efficiencies of a homogenous set of decision making units in the presence of multiple input and output factors. Efficiency is defined as the ratio of weighted outputs to weighted inputs. In DEA, each unit selects input and output weights that maximize its efficiency score subject to constraints that prevent the efficiency scores of all the units when evaluated with these weights from exceeding a value of 1. Some of the strengths of DEA are that it does not require limiting assumptions of many parametric methods such as normality and equal variance. It does not need *a priori* factor weights to be specified in the evaluation process, and it is based on best practice, not average (mean) practice.

DEA has extensively been utilized in efficiency evaluation of homogenous units such as schools, bank branches, hospitals, and manufacturing plants (Charnes et al., 1994). DEA applications in project efficiency evaluation have targeted both project selection and project development and maintenance. Cook et al. (1996) developed and applied a DEA model that effectively considered both ordinal and cardinal factors in efficiency evaluation and selection of projects. Linton et al. (2002) utilized DEA to categorize R&D projects into subgroups (accept, consider further, and reject) for assisting managers in identifying potential projects for selection and execution. Banker et al. (1991) utilized stochastic DEA to evaluate variables affecting the productivity of software maintenance projects. They estimated marginal impacts of various factors which managers can utilize to improve productivity in software maintenance. In a related study, Banker and Slaughter (1997) utilized DEA to estimate the relationship between software project maintenance inputs and outputs and evaluated the returns to scale for the projects. They concluded that it is possible to reduce software maintenance costs by batching smaller projects into larger planned releases. While DEA has been utilized for evaluating project efficiencies in a variety of areas as discussed above, it has not been utilized in the area of NPD project performance, which is the focus of our study.

In evaluating project efficiencies, we utilized the variable returns to scale model proposed by Banker et al. (1984). It is well established in project management literature that as more resources are invested in a project the performance outcomes do not improve proportionally, thus indicating variable returns to scale (Graves, 1989; Griffin, 1993; Calantone and Di Benedetto, 2000). The BCC (Banker et al.) model is shown below as Model I:

Model I:

$$\text{Minimize} \quad \theta_h - \varepsilon\left[\sum_i S_{ih}^+ + \sum_r S_{rh}^-\right]$$

$$\text{s.t.} \quad \sum_{j=1}^{n} x_{ij}\lambda_j + S_{ih}^+ = \theta_h x_{ih} \quad \forall i$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - S_{rh}^- = y_{rh} \quad \forall r$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$S_{ih}^+ \geq 0,\ S_{rh}^- \geq 0, \text{ and } \lambda_j \geq 0$$

where x_{ij} and y_{rj} indicate the ith input and rth output of the jth project, respectively; x_{ih} and y_{rh} are the ith input and rth output of the project h that is being evaluated, respectively; λ_j's are the dual variables utilized to construct a composite project that is utilized in dominating project h; S_{ih}^+ and S_{rh}^- are the slack and surplus variables, which are maximized to allow the composite project to effectively dominate project h; θ_h is the efficiency score of project h; and ε is a small positive scalar.

The above model is run n times to obtain the efficiency scores for each of the n projects. If a project achieves an efficiency score of 1 (slack = 0) it is considered to be efficient, and a score of less than 1 indicates that it is inefficient. Since we are utilizing the dual problem, the objective function minimizes the efficiency score of project h. The first two constraint sets in the model try to identify a composite project, constructed from some projects in the dataset, which utilizes less input than project h while generating at least the same output levels. The third constraint is the convexity constraint that limits the summation of the λ values to 1 in imposing the variable returns to scale assumption. For more details on the model development, see Banker et al. (1984).

We utilized the BCC model sequentially in categorizing projects into various groups. For illustrative purposes the concept of sequential DEA is demonstrated in Fig. 2, which considers two outputs and one input. We considered a more comprehensive set of project inputs and outputs as detailed later in conducting the DEA evaluations. Initially, all projects were simultaneously evaluated in determining the efficient and inefficient projects. The efficient projects, which we refer to as "Tier 1 Efficient," were then removed from the dataset and the DEA evaluations were repeated on the remaining projects. This second run DEA evaluations identified "Tier 2 Efficient" projects, and the remaining projects were deemed "Inefficient" as shown in Fig. 2. Further tiers can be identified depending on the initial sample size of projects, but we limited our analysis to three groups, i.e., Tier 1 Efficient, Tier 2 Efficient, and Inefficient projects. A methodological advantage of the sequential DEA is that projects can be categorized into groups with minimum amount of subjectivity. Also, removing efficient projects from the dataset at each stage allows for better identifying the strengths of inefficient projects, which results in a more comprehensive and realistic evaluation of projects.

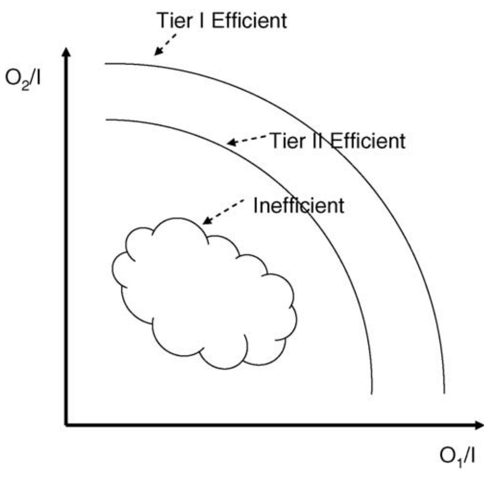

Fig. 2. Sequential DEA evaluations.

3.2. Data

We used data gathered by a survey of completed NPD projects in order to explore practice-performance relationships and possible performance tradeoffs. A total of 1362 surveys were mailed to firms randomly selected from Dun and Bradstreet's Decision Makers file for Research and Development Personnel. The firms were selected from manufacturing industries (SICs 20–39) located in the continental United States. A pre-notification of the survey was sent about 1 week in advance of the survey. The cover letter for each survey was addressed by name to an R&D executive, typically holding a rank of Director or Vice President. The letter specified that to participate in the research the firm must have recently developed a new product that was eventually produced and marketed. The survey instructed respondents to report on their most recent major product introduction to prevent them from offering only "success stories."

A total of 153 questionnaires were returned. Of these, 16 were eliminated due to missing data, yielding 137 usable responses (approximately 10% response rate). The low response rate resulted at least partially because the mailing list was somewhat dated and was not pre-screened. Instead, post-screening and an extensive evaluation of response bias were conducted. Phone contacts were made with 359 randomly selected non-respondents to establish the primary reasons for non-response. These results indicated that approximately 33% of those who received the survey and were eligible to participate eventually provided usable responses. In addition, the phone contacts indicated that the target sample subjects had high degrees of relevant knowledge. Only three of the contacted non-respondents said they were not familiar enough with the latest new product to adequately complete the questionnaire.

Further analysis revealed no substantial differences between respondents and non-respondents regarding geographic location, size, or industry. As a test for other response biases, responses of early and late waves of returned surveys were compared. This commonly used method is based on the assumption that the opinions of late responders are representative of non-respondents

(Armstrong and Overton, 1977). Scores from the first and last waves of surveys received were compared using *t*-tests. The tests indicated no significant differences across the two groups for any of the variables used in this study, or across any of the project characteristics such as project length, NPD experience, firm size, or level of project investment.

Appendix A provides a brief characteristic description of the sample. No respondents came from the furniture (SIC 25), leather (SIC 29), or petroleum refining (SIC 31) industries. However, when compared to published statistics (Troy, 1990), the sample represents all other manufacturing industry populations fairly well, with the exception of miscellaneous manufacturing (SIC 39), and measuring, analyzing, and controlling instruments (SIC 38). These two industries are somewhat over-represented. The sample includes firms from all major geographic regions of the country. The sample also contains a wide range of firm sizes, as indicated by net sales and number of employees. For more details on the industry representation in the sample see Swink (2003).

Respondents were mostly executive managers or project managers for the NPD efforts on which they reported. Over 75% of the respondents identified product design and development as the primary functional area in which they worked. The sample comprises a wide deviation of product life and project lengths, suggesting a wide variety of product types. At the time of the survey, the average time in production for the sampled products was 18 months, providing ample time for the respondents to have developed a good estimation of NPD performance.

3.3. Measures

Measures used in this research were provided by a questionnaire asking respondents to provide background information and NPD project characteristics, practices, and performance. Seven R&D managers from five different firms and five experienced survey researchers examined the initial questionnaire and cover letter in order to eliminate confusing questions and identify interpretation problems.

The NPD project measures are reported in Appendix B, along with sources for the measures and reliability metrics. Most of the constructs addressed in our hypotheses were operationalized by multi-item scales. All of the measures have been validated and used in prior research studies. The sources identified in Appendix B include both conceptual sources and studies which have used the measures before. The measures assessed project context and practice variables by using a combination of 5-point Likert type scales and ratio scale response formats. Anchors on the Likert scales were "strongly agree/strongly disagree" when questions asked for agreement with statements describing the project. Other questions asked respondents to rate the extent to which a given practice was employed on the project. Anchors for these questions were "not used/used extensively." Company size data (sales, number of employees) were provided from the Dun and Bradstreet file.

Project performance variables included nine items that addressed aspects of development cost, product cost, product quality, and project timeliness. The questionnaire items asked respondents to indicate on a 5-point scale the degree to which they had achieved their project or product target in each of the performance areas (not nearly achieved/fully achieved). In addition, respondents were asked to rate the aggressiveness of each of the performance targets (not very aggressive/very aggressive). The product of these two ratings indicates the performance for each project goal; the logic being that a project that achieves a very aggressive goal outperforms a project that equally achieves a less aggressive goal. Measures assessing development cost and product cost were reverse-coded in order to obtain a measure of budget or cost overruns.

This measurement approach addresses the possibility that goals themselves may be adjusted according to the characteristics of the project, such as technological novelty or organizational complexity. Few other studies using goal attainment performance measures have accounted for this measurement issue (Gerwin and Barrowman, 2002).

The nine performance measures provide multiple assessments of the four primary NPD project outcomes identified by Smith and Reinertsen (1998): development cost, product cost, product quality, and development time. Correlations among the measures were consistent with groupings in these four areas. For example, the individual product quality measures were highly intercorrelated. However, instead of averaging scores to create a reduced set of variables, we performed the DEA using all nine variables. We used this approach to preserve the greatest degree of granularity in the analysis, and thus provide greater information for interpretation and insight.

4. Analysis and results

In accordance with the sequence of our hypotheses, our analysis of the data involved four stages: (1)

formation of efficiency groups, (2) analysis of tradeoffs indicated by subgroups within each efficiency group (test of H1), (3) analysis of market success differences across and within the efficiency groups (test of H2 and H3), and (4) analysis of differences in practices across projects in different efficiency groups (tests of H4–H10).

4.1. Use of DEA to form efficiency groups

We defined NPD performance elements related to product quality and development time as outputs. The quality dimensions utilized addressed product manufacturability, quality, performance, innovative features, and the degree to which the product met specific customer needs. The time dimensions used were on-time performance and reduced development time. Thus, a total of seven aggressiveness-adjusted goal achievement scores were treated as outputs in the DEA evaluations. Reverse-coded development cost and product cost goal achievement scores served as the inputs to the DEA model. A high score in one of these cost measures indicates a budget or goal overrun, that is, the degree to which a relatively non-aggressive cost goal was not achieved. This conceptualization employs a total product lifecycle cost view of resources, in which the total resources required to develop and produce the product are inputs in the model, while the quality attributes and timeliness of the product are outputs.

As discussed earlier, we implemented the sequential DEA evaluations with the BCC model in identifying the three project groups. A total of 137 projects were analyzed with respect to the above specified inputs and outputs. With two inputs and seven outputs, the sample of projects being evaluated using DEA must be significantly greater than 14 (the product of inputs and outputs) for effective discrimination (Boussofiane et al., 1991). Each of the DEA evaluations that we performed met this requirement effectively. We identified 46 projects as being Tier 1 Efficient, 42 projects as being Tier 2 Efficient, and 49 projects as being Inefficient.

One-way ANOVA with post hoc multiple comparison tests were used to analyze differences in performance variables across the three groups. Table 1 indicates that group means for all of the project performance variables were nominally higher for Tier 1 Efficient projects than for Tier 2 Efficient projects. Similarly, all project performance means were higher for Tier 2 Efficient projects than for the Inefficient projects. About three-fourths of the mean differences across the different groups and performance outcomes were significant at $p < 0.05$. The pattern of significant differences in Table 1 indicates that Tier 2 Efficient projects are distinguished from Inefficient projects by better performance in cost and quality elements, but not timeliness elements. Tier 1 projects are distinguished from Tier 2 projects by better project performance in cost elements, timeliness, product quality (defects reduction), and product performance. Tier 1 projects' mean scores are significantly better than Inefficient projects' scores for manufacturability, innovative features, and meeting specific customer needs.

We expected that the approach we used to operationalize project performance outcomes and to establish efficiency scores should have standardized and controlled for differences across project groups due to situational factors such as size, new product novelty, and complexity. As a confirmation, we conducted ANOVA in order to evaluate potential differences in these variables across the three efficiency groups. Table 2 indicates that none of the differences were significant. Thus, memberships in the efficiency groups appear not to be dependent on these aspects of the projects. The lack of discrimination based on these criteria is seen as a positive attribute of the methods utilized in this study, as it indicates with reasonable confidence that the results are not biased by these situational variables.

4.2. Evidence of tradeoffs in NPD performance

We were intrigued by the question of how Tier 1 Efficient projects might be relatively positioned along the global performance frontier, and how this might differ from groupings of projects elsewhere in the overall project performance space. To investigate these questions, we performed a hierarchical cluster analysis of the Tier 1 project performance data, using Ward's method and the Euclidean squared distance metric. The percentage change in agglomeration scores and an examination of the dendogram strongly suggested that the Tier 1 projects clustered into three distinct projects groups (Aldenderfer and Blashfield, 1984). Furthermore, the differences in performance variables indicated by ANOVA and multiple comparison tests across these three clusters provided good interpretability regarding group definitions. Examinations of the 2-group and 4-group cluster solutions solidified our confidence in the 3-group solution. The 2-group solution was formed by combining groups two and three, yet these two groups differ significantly on five of the nine performance dimensions. The 4-group solution was formed by dividing group one into two groups, yet these two groups differed significantly on only one

Table 1
Analysis of variance for project performance variables across three efficiency groups

Degree to which project met aggressive goals in each area	Group 1: Tier 1 Efficient ($N = 46$)	Group 2: Tier 2 Efficient ($N = 42$)	Group 3: Inefficient ($N = 49$)	Total	F (Sig)
Cost variables					
Development cost					
Mean	17.93	12.26	9.65	13.23	29.53 (0.000)
S.D.	6.86	4.9	3.87	6.36	
		1 > 2 > 3*			
Product cost					
Mean	20.07	15.40	10.44	15.19	46.74 (0.000)
S.D.	5.84	4.6	3.95	6.27	
		1 > 2 > 3			
Time variables					
On-time performance					
Mean	16.85	13.65	11.65	14.01	8.61 (0.000)
S.D.	6.74	6.04	5.62	6.48	
		1 > 2, 3			
Reduced development time					
Mean	13.54	11.78	10.82	12.03	2.04 (0.067)
S.D.	7.81	6.5	5.49	6.7	
		1 > 3+			
Quality variables					
Manufacturability					
Mean	19.04	18.94	14.35	17.33	13.12 (0.000)
S.D.	5.26	4.87	5.12	5.53	
		1, 2 > 3			
Product quality (defects reduction)					
Mean	19.37	16.83	13.45	16.47	14.25 (0.000)
S.D.	5.52	5.57	5.2	5.93	
		1 > 2 > 3			
Product performance					
Mean	21.93	18.79	15.89	18.81	18.93 (0.000)
S.D.	4.76	4.97	4.65	5.38	
		1 > 2 > 3			
Developing innovative features					
Mean	17.82	16.03	14.08	15.93	4.02 (0.010)
S.D.	6.75	6.95	5.64	6.58	
		1 > 3			
Meeting specific customer needs					
Mean	19.37	18.07	15.35	17.53	6.75 (0.001)
S.D.	6.47	4.45	5.15	5.67	
		1, 2 > 3			

* Indicates which group means are significantly different.
\+ Indicates differences significant at $p < 0.10$, other differences are significant at $p < 0.05$ (Tukey multiple comparison, 1-tail test).

dimension. The three group solution also provides an interpretable pattern that is consistent with the assertions of previous conceptual frameworks (Krubasik, 1988; Smith and Reinertsen, 1998).

Table 3 provides an analysis of mean differences in project performance variables across the three high performing groups. Fig. 3 displays the means for each group in a ‘‘radar graph’’ format. We tentatively labeled the three groups as ‘‘Lean’’ projects, ‘‘Fast and Reliable’’ projects, and ‘‘100% Right’’ projects, respectively. The Lean projects group has the highest development cost and product cost mean performance scores (that is, they did the best job of achieving aggressive cost goals, on average). However, for each of the other performance dimensions, the Lean group’s average score is significantly lower than at least one of the other groups’ scores. The 100% Right group has the highest average scores for each of the product quality

Table 2
Analysis of variance for size, novelty, and complexity variables across three efficiency groups

	Group 1: Tier 1 Efficient ($N = 46$)	Group 2: Tier 2 Efficient ($N = 42$)	Group 3: Inefficient ($N = 49$)	Total	F (Sig)
Company sales ($1,000,000)					
Mean	1410	696	604	891	0.75 (0.48)
S.D.	4219	3219	1728	3185	
Company employees (1000)					
Mean	6.49	2.10	2.91	3.80	1.39 (0.25)
S.D.	19.09	6.78	8.59	12.61	
Technological uncertainty					
Mean	29.29	26.07	22.35	25.82	0.96 (0.193)
S.D.	28.47	25.12	19.37	24.48	
Project complexity					
Mean	1.6014	1.43	1.61	1.55	1.02 (0.166)
S.D.	0.59	0.58	0.80	0.67	

performance dimensions, and each of the group's means in these areas significantly differs from that of at least one other group. The Fast and Reliable group manifests a more balanced overall performance picture than the other two groups. Their mean scores suggest excellence in project timeliness (speed and on-timeness). They do not have the lowest mean score in any performance category. However, their mean score for product cost performance is lower than the Lean group mean, and their mean score for innovative features is significantly lower than the 100% Right group's mean score.

We performed the same cluster analysis procedure using the performance data from the Inefficient projects group. Again, the agglomeration statistic and analysis of variance indicated that three clusters provided the best solution. However, the clusters within the Inefficient projects groups did not manifest the same pattern of performance differences (see Fig. 4). One group was dominant or at least as good as the next best group in every dimension. Another group had the lowest mean performance in all dimensions, save one. The third group's mean scores were mostly in-between the other two. Thus, while the Tier 1 Efficient project groups manifested patterns suggesting performance tradeoffs, these tradeoffs were not as apparent in the Inefficient project groups. These findings provide evidence in support of Hypothesis H1.

4.3. Analysis of market success differences across the groups

In the next step we assessed respondents' ratings of product success variables across the three groups.

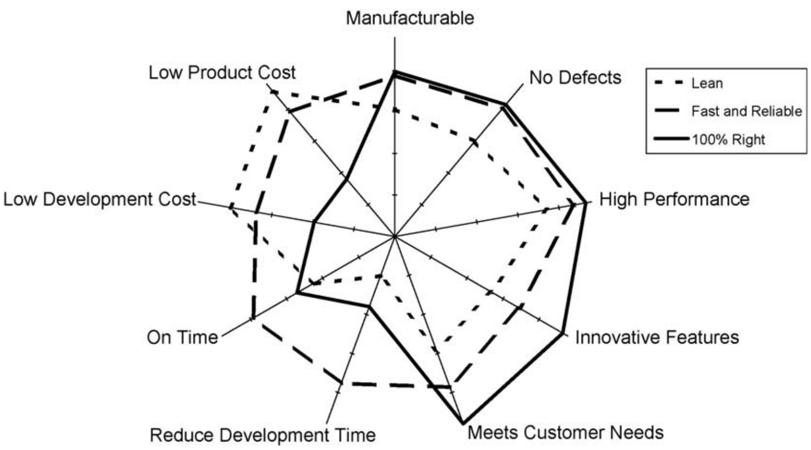

Fig. 3. Tier 1 efficient sub-groups.

Table 3
Analysis of variance for project performance variables: Tier 1 Efficient projects only

Degree to which project met aggressive goals in each area	Group 1: Lean ($N = 16$)	Group 2: Fast and Reliable ($N = 23$)	Group 3: 100% Right ($N = 7$)	Total	F (Sig)
Cost					
Development cost					
Mean	21.06	17.91	10.86	17.93	6.766 (0.003)
S.D.	5.37	6.95	4.38	6.86	
		$1 > 3^{*}$			
Product cost					
Mean	23.75	20.57	10.00	20.07	33.145 (0.000)
S.D.	2.24	4.25	4.69	5.84	
		$1 > 2^{+}$; $2 > 3$			
Time					
On-time performance					
Mean	12.44	20.61	14.57	16.85	10.565 (0.000)
S.D.	7.21	3.81	6.70	6.74	
		$2 > 1, 3$			
Reduced development time					
Mean	6.06	19.83	10.00	13.54	47.822 (0.000)
S.D.	5.13	4.14	3.61	7.81	
		$2 > 3$; $3 > 1^{+}$			
Quality					
Manufacturability					
Mean	16.31	20.39	20.86	19.04	3.729 (0.032)
S.D.	4.64	4.51	6.96	5.26	
		$2^{+}, 3^{+} > 1$			
Product quality (defects reduction)					
Mean	15.94	21.04	21.71	19.37	5.794 (0.006)
S.D.	5.20	5.07	4.31	5.52	
		$2, 3 > 1$			
Product performance					
Mean	19.56	22.87	24.29	21.93	3.678 (0.034)
S.D.	6.44	3.21	1.89	4.76	
		$3 > 1$			
Developing innovative features					
Mean	14.38	18.26	24.29	17.82	6.687 (0.003)
S.D.	6.88	6.16	1.89	6.75	
		$3 > 1, 2$			
Meeting customer needs					
Mean	15.56	20.30	25.00	19.37	7.232 (0.002)
S.D.	6.30	6.08	0.00	6.47	
		$3 > 1$			

* Indicates which group means are significantly different.
$^{+}$ Indicates differences significant at $p < 0.10$, all other differences are significant at $p < 0.05$ (Tukey multiple comparison, 1-tail test).

Table 4 shows the results of ANOVA for respondents' ratings of product profitability and financial success, respectively. As expected, the results suggest that on average Tier 1 efficient projects produced the most successful products, Tier 2 products were the next most successful, and products from Inefficient projects were least successful. These results support H2.

All projects in each of the three Tier 1 sub-groups have efficiency scores of 1; they all achieved high levels of overall performance. Furthermore, the ANOVA results in Table 5 indicate that product success ratings did not vary significantly across the Tier 1 sub-groups. Thus, the results suggest that these three performance patterns were equally effective, supporting H3.

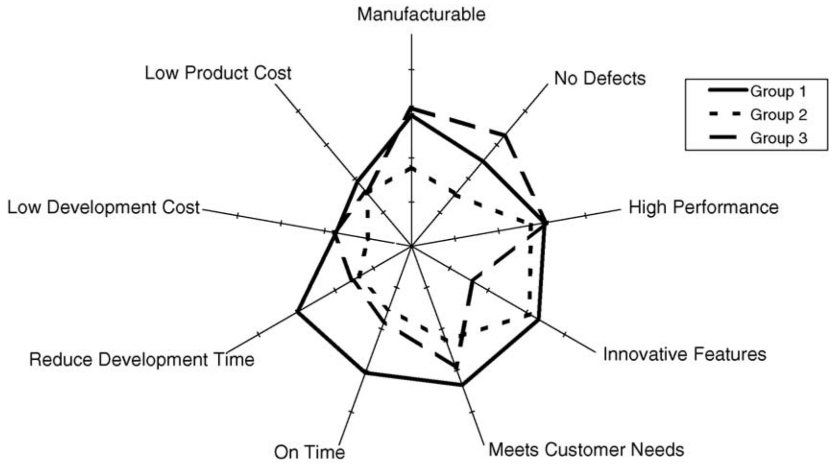

Fig. 4. Inefficient sub-groups.

Table 4
Analysis of variance for product success variables across three efficiency groups

	Group 1: Tier 1 Efficient ($N = 46$)	Group 2: Tier 2 Efficient ($N = 42$)	Group 3: Inefficient ($N = 49$)	Total	F (Sig)
Financial/market performance					
Mean	4.16	3.83	3.28	3.75	10.89 (0.000)
S.D.	0.92	0.89	0.94	0.98	
		1 > 3*			

* Indicates which group means are significantly different at $p < 0.05$ (Tukey multiple comparison, 1-tail test).

4.4. Differences in process variables across the three efficiency groups

Table 6 provides ANOVA results for project process variables. The results support H4, as NPD project experience varied across the three groups at a statistically significant level. Tier 1 projects were housed in organizations that on average executed almost three times more projects each year than Inefficient project organizations. Tier 1 project organizations also had more than twice the experience in attempting NPD time reductions, on average.

H5 and H6 were also supported. Tier 1 and Tier 2 projects had significantly higher perceived levels of balanced management commitment and goal specificity than the Inefficient projects group. These results possibly suggest diminishing returns. Balanced management involvement appears to be associated with moderate improvements in overall project performance. However, it appears not to play a strong role in differentiating highly efficient projects from their moderate performing counterparts.

Managers' perceptions of a collaborative environment were significantly higher on average for Tier 1 efficient projects as opposed to Inefficient projects, supporting H7. Collocation did not vary significantly across the groups in the expected direction. Thus, H8 was not supported.

Table 5
Analysis of variance for product success variables: Tier 1 Efficient projects only

	Group 1: Lean ($N = 16$)	Group 2: Fast and Reliable ($N = 23$)	Group 3: 100% Right ($N = 7$)	Total	F (Sig)
Financial/market performance					
Mean	4.02	4.24	4.21	4.16	0.285 (0.753)
S.D.	1.03	0.82	1.07	0.92	

Table 6
Analysis of variance for project process variables across three efficiency groups

	Group 1: Tier 1 Efficient ($N = 46$)	Group 2: Tier 2 Efficient ($N = 42$)	Group 3: Inefficient ($N = 49$)	Total	F (Sig)
H4: Experience—NPD projects per year					
Mean	14.09	9.41	4.95	9.42	3.44 (0.02)
S.D.	22.66	17.25	4.80	16.84	
		1 > 3*			
H4: Experience—time reduction					
Mean	8.67	6.95	4.26	6.56	2.28 (0.053)
S.D.	10.20	12.86	6.56	10.14	
		1 > 3			
H5: Balanced management support					
Mean	4.04	3.96	3.48	3.81	6.882 (0.001)
S.D.	0.86	0.63	0.84	0.82	
		1, 2 > 3			
H6: Explicit project goals					
Mean	4.24	4.17	3.78	4.05	3.51 (0.016)
S.D.	0.82	0.88	1.03	0.93	
		1 > 3; 2 > 3+			
H7: Collaborative environment					
Mean	4.05	3.94	3.64	3.87	3.75 (0.026)
S.D.	0.76	0.79	0.75	0.78	
		1 > 3			
H8: Collocation					
Mean	1.96	1.75	2.32	2.02	2.88 (0.059)
S.D.	1.23	0.90	1.24	1.16	
H9: Design—manufacturing integration					
Mean	3.74	3.57	3.35	3.55	2.38 (0.097)
S.D.	0.92	0.90	0.75	0.87	
		1 > 3+			
H10: Project activity overlap					
Mean	4.26	3.86	3.92	4.01	2.57 (0.040)
S.D.	0.80	1.12	0.81	0.92	
		1 > 2; 1 > 3+			

* Indicates which group means are significantly different.
+ Indicates differences significant at $p < 0.10$, other differences are significant at $p < 0.05$ (Tukey multiple comparison, 1-tail test).

H9 was supported. The degree of design and manufacturing integration differed across the project groups in the expected direction. H10 was also supported. Overlapping of activities (concurrency) was the only practice that differed significantly across Tier 1 and Tier 2 Efficient projects.

5. Discussion

Our analysis of the data yielded interesting results, provoking a number of propositions with implications for future research. One of the important outcomes of the research is the evidence of support for TPF as a suitable theory for describing performance tradeoffs in NPD project management. Hypothesis 1 was supported by the data, suggesting that efficiency based arguments might explain the presence of global tradeoffs in some, but not all, NPD projects. We view this as an important development in the synthesis of conflicting research studies that argue for and against the existence of tradeoffs. Further, the support for Hypothesis 2 and Hypothesis 3 suggests that markets reward project efficiency, and that multiple modes of efficiency can achieve equally effective market outcomes. Future research could extend this thesis by investigating highly efficient NPD projects which operate under varying levels of technical risk and market opportunity.

Most of the hypotheses regarding relationships between certain NPD management practices and overall project efficiency were supported. First, we found that Tier 1 Efficient projects operated in organizations/divisions with the highest amounts of experience, while

Inefficient project organizations had the lowest amounts of experience. Tier 2 Efficient projects' experiences were located in-between the Tier 1 Efficient and the Inefficient groups, suggesting a consistent association of performance with experience. Researchers have suggested that experience plays an important role in NPD project success (Graves, 1989; Harter et al., 2000). However, research studies addressing this factor, even as a control variable, are scant.

Management support and explicit goals significantly distinguished Tier 2 Efficient projects from Inefficient projects, thus suggesting that these attributes are important for achieving foundational, mid-level improvements in overall performance. Interestingly, differences in these variables between the Tier 1 and Tier 2 efficient groups were not significant, consistent with the possibility of diminishing returns on these practices. In fact, several studies have suggested detrimental effects of too much management commitment or involvement. Excessive commitment can lead to meddling or irrational pursuit of "pet" projects (Gersick and Davis-Sacks, 1990). Similarly, excessive resources can lead to lowered development efficiency, and higher costs (Kessler, 2000). Too much goal specificity has been thought to interfere with product innovativeness (Takeuchi and Nonaka, 1986).

The findings indicate that elements of cross-functional integration appear to be valuable in attaining high levels of efficiency. The fact that aspects such as collaborative environment and design manufacturing integration were significant leads us to posit that the effectiveness of structural changes such as team arrangements and collocation depends more on the behavioral aspects of *how* they are employed rather than the *extent* to which they are employed. Foregoing researchers have offered this same thesis, yet it remains relatively unexplored (Swink, 2003).

Again, the significant differences uncovered in our study mostly distinguished high and moderate performing projects from low performers. Project activity overlap (concurrency) was the only variable that significantly difference between Tier 1 and Tier 2 efficient groups. The implication for future research is that current management and practice variables may explain gross NPD project performance improvements to a substantial degree. However, these variables appear to be less powerful in explaining the performance differences among ultra-efficient projects. Variables that explain differences at this level may be largely unrecognized and represent an important opportunity for future research.

Along with these findings, our examination of the data in light of the associated theoretical framework led us to the following propositions for future research:

Proposition 1. *NPD project improvement trajectory manifests improvements in cost and quality performance dimensions first*; *improvements in project timeliness come later*.

This proposition stems from our inference of a step-wise performance improvement progression manifested in the data. In each dimension, the average Tier 1 Efficient project performance was at least as good, and nominally better, than the average Tier 2 Efficient project performance. Similarly, the Tier 2 Efficient group performed at least as well, and nominally better, than the Inefficient group in every dimension on average. When considering the statistical significances of these differences, however, one can infer a progression of performance improvements from the results. Tier 2 Efficient projects are distinguished from Inefficient projects by superior cost and quality performance, with no significant differences in time-related outcomes. Further improvements in cost and a few of the quality performance dimensions distinguish Tier 1 Efficient projects from Tier 2 Efficient projects, yet it is also at this level that significant differences in time-based performance are apparent.

We note that this interpretation of the results is speculative, as we are inferring a step-wise performance improvement progression from a study of cross-sectional data. One might suggest, for example, that an Inefficient project could simultaneously improve in all dimensions, thereby leaping to Tier 1 Efficiency status. Still, the progression that we speculated and described seems logical. Resource limitations for improvement programs, limits on organizational learning capacity, and the benefits of focused organizational learning argue for a sequenced improvement trajectory. In addition, our proposed improvement trajectory is interestingly similar to the manufacturing performance capability progression currently receiving debate in the manufacturing strategy literature, which suggests that quality is a foundational capability that precedes speed (Ferdows and De Meyer, 1990; Rosenzweig et al., 2003). As is the case in that line of research, our proposition suggests the need for more focused, longitudinal studies of performance improvement.

Proposition 2a. *Highly efficient projects make trade-offs that position them in the following ways*:

- "*Lean*" *projects trade product design and conformance quality*, *development speed and lateness*, *in return for development and product cost efficiency*.
- "*Fast and Reliable*" *projects trade product innovative features and lower product cost in return for development speed and on-time performance*.
- "*100% Right*" *projects trade lower product cost*, *lower development cost*, *development speed*, *and lateness in return for product design quality*.

This proposition is an extension of Hypothesis 1 flowing from our data analysis. The TPF theory developed in this study maintains that "performance frontiers" impose limitations on various dimensions of performance such that, once certain levels of performance are attained, limited resources and technological constraints prevent further simultaneous improvements across multiple performance dimensions. Once reaching the global performance frontier, managers have to make choices among performance dimensions. Our data suggests that these choices are manifested in three predominant performance patterns. An interesting question for future research is, do these patterns reflect intentional "strategies" (as Krubasik, 1988, would suggest), or are they realized outcomes that reflect choices made throughout the project execution? In addition, future research might explore NPD practices that are related to these different modes of efficiency.

Proposition 2b. *Low performing projects do not make performance tradeoffs in the same ways or to the same degree as high performing projects*.

In our data, clusters within the low performing projects (the Inefficient projects group) did not manifest performance patterns suggestive of tradeoffs, at least not to the same degree that was depicted in high performing projects. Our explanation, based on the TPF, is that tradeoffs were *not required* in the low performance projects because *they did not experience the resource or technological constraints imposed by performance frontiers*. The projects in each and every Tier 1 Efficient subgroup (Lean, Fast and Reliable, 100% Right) outperformed the Inefficient projects in every performance dimension, on average. In other words, even the lowest average performance of any Tier 1 subgroup was better than the average performance of the Inefficient group. Thus, it appears that at least some of the Inefficient projects could have made simultaneous improvements in multiple dimensions, unencumbered by resource or technology constraints. Indeed, it appears that projects in the lowest performing Inefficient sub-cluster could have improved in all dimensions, since projects in this group performed worse than at least one of the other Inefficient subgroups in every dimension, respectively. Clearly, additional research is needed to buttress our findings and to examine these propositions with a direct focus.

Finally, the results of our study indicate that the use of DEA as a tool for addressing NPD project performance in a more holistic fashion appears to have merit and holds promise for future research applications. None of the firm size, project complexity, or technical novelty variables varied significantly across the three performance groups. This suggests that our measurement approach and DEA operationalization of performance may be fairly robust to contextual factors. Thus, the technique could be a useful way to create "apples-to-apples" comparisons across projects. For researchers, this approach could prove useful in overcoming a major hurdle to the development of higher range theories in both NPD and more general project management. The inability to effectively deal with the idiosyncratic nature of specific NPD project efforts has long been a criticism of research in this area. For practitioners, further development of our approach could produce planning and decision making tools useful to project portfolio managers. Given a current set of NPD projects, they could effectively use such tools to make resource allocation decisions and to design project management improvement programs.

6. Conclusions and limitations

Our research makes two important contributions to the study of NPD project management. The primary contribution is a study of tradeoffs in NPD and relationships between NPD practices and NPD efficiency, with implications for tradeoffs among NPD performance dimensions. The results point to the importance of project management experience, management commitment, and cross-functional integration in achieving a high level of efficiency, i.e., holistic project performance. In addition, three high efficiency subgroups suggest performance patterns and alternative strategies that are likely to be successful. The lack of such patterns in low efficiency projects supports a theory of performance frontiers that imposes the need for tradeoffs as NPD projects achieve higher levels of efficiency. Our results are summarized by propositions that should stimulate future research.

Secondly, we demonstrate a new approach to the measurement and operationalization of holistic NPD project performance, employing a novel sequential

DEA methodology. Study of determinants of NPD performance has been hampered by limited performance measures, notably the lack of methods for assessing performance in a holistic manner. To our knowledge, this is the first such usage of DEA in NPD research. The approach holds promise for future research in the evaluation of NPD projects, and for practical use in the design and evaluation of NPD project performance improvement programs.

The limitations of this research should also be considered. First, our research focuses on immediate operational NPD project outcomes. Our examination of the market success of the new products was limited to managers' perceptions of overall financial performance. Other dimensions of market success were not addressed. Additional NPD project inputs and output could arguably be incorporated into the model as well. Second, while the DEA approach utilized in this paper has several advantages, it is not without limitations. DEA results are sensitive to the inputs and outputs used in the model. It is also possible in DEA for a unit to be efficient by emphasizing relatively few dimensions while completely ignoring other dimensions. This is not so much of an issue in our study, however, due to a fairly parsimonious set of inputs and outputs and relatively large sample size. This problem can further be alleviated by incorporating managerial preferences in terms of input and output weight restrictions in DEA. Third, the effects of contextual factors on performance appear to have been successfully mitigated by our performance operationalization approach. However, we ignored potential interaction effects among contextual, leadership, and project execution practices that might be important in explaining performance differences. Finally, while all of the measures have been validated in prior research, many of them are perceptual and self reported. Self reports are potentially subject to hindsight and common methods biases. Our post survey phone calls indicated that the respondents held high ranks and similar positions in large organizations, and that they possessed high degrees of relevant knowledge. In addition, measurement items were spread out over a fairly lengthy survey instrument. Mitchell's (1994) guidelines suggest that these attributes tend to mitigate biases. However, the potential for bias should be considered when reviewing the results of this study.

Appendix A. Sample statistics

Project characteristics	Mean	S.D.
Years in production	1.50	1.40
Product life cycle (years)	7.44	5.60
Project length (months)	15.68	14.92

Quartile maximums	Annual sales ($)	No. of employees
1	9 M	81
2	39 M	272
3	167 M	1200
4	21.6 B	89,300

Respondent's role	% of sample
Managing executive	25.7
Project manager	41.9
Functional manager	24.3
Project team member	8.1

Respondent' functional area	% of sample
Marketing/sales	6.8
Product design and development	76.4
Finance/accounting/corporate	3.1
Personnel/human resources	1.5
Manufacturing/operations	6.1
Combination of above	6.1

Appendix B. Description of measures

Construct	Items	Scale*	Cronbach's alpha	Sources
Financial performance	This product has been highly profitable	1	0.87	Swink (2000)
	This product is considered a financial success by our firm	1		
Technological uncertainty	What percentage of the product's features and function involved technology that was new to your firm?	2	0.85	Zirger and Hartley (1996); Griffin (1997); Tatikonda and Rosenthal (2000); Swink (1999, 2000); Swink and Calantone (2004)

Appendix B. (*Continued*)

Construct	Items	Scale*	Cronbach's alpha	Sources
	What percentage of the process technology used to manufacture the product was new to your firm?	2		
Project complexity	At the point in the development project when the number of staff was at its peak, approximately how many persons were dedicated full-time to the project?	3	0.86	Clark and Fujimoto (1991); Griffin (1993); Swink (1999); Swink and Calantone (2004)
	At the point in the development project when the number of staff was at its peak, approximately how many persons were dedicated part-time to the project?	3		
	How many different types of engineering or technical expertise were needed on the project (i.e., mechanical, electrical, or software engineers, chemists, materials specialists, industrial engineers, etc.)?	4		
Balanced management support	Top management was committed to making this project a success	1	0.68	Cooper (1988); Zirger and Maidique (1990); Pinto et al. (1993); Lee and Na (1994); Swink (1999, 2000)
	Resources were adequate to make the project a success	1		
	Top management relinquished authority to the project team for decisions	1		
Collocation	Degree of use on the project: collocated project personnel	5	0.64	Kessler (2000); Kessler et al. (2000); Swink (2002)
	Degree of use on the project: isolated project team from the rest of the company	5		
Collaborative environment	Teamwork and information sharing are highly valued in our division	1	0.64	Clark and Fujimoto (1991); Pinto et al. (1993); Swink (1999)
	Most people on the project are quite accessible	1		
	Data systems used by different groups in our division are compatible	1		
Design manufacturing integration	Manufacturing personnel participated early-on in product design phases	1	0.71	Swink and Calantone (2004); Swink (1999)
	Manufacturing function played a strong role in the design of the product	1		
	Manufacturing and product design personnel cooperated extensively	1		
	Degree of use on the project: design-for-manufacture methods	5		
NPD experience	On average over the last 5 years, how many separate product development projects have been started at your business division each year?	6	–	Graves (1989); Harter et al. (2000)
Time reduction experience	Over the past 5 years, roughly how many times has your division attempted to reduce product development time by 20% or more?	6	–	Graves (1989); Harter et al. (2000)
Explicit goals	Degree of use on the project: very explicit project objectives/goals	5	–	Kessler (2000); Zirger and Hartley (1996); LaBahn et al., 1996); Swink (2003)
Project activity overlap	Project activities were overlapped (performed concurrently) to a great degree	1	–	Calantone and Di Benedetto (2000); Kessler (2000); Swink (2003)

* Scale types: (1) 5-point scale (strongly disagree–strongly agree); (2) percentage scale; (3) 5-point scale anchored by ranges of staffing level; (4) 5-point scale anchored by ranges of number of types; (5) 5-point scale (not used–used extensively); (6) number of occurrences.

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