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# ENABLING FACTORS IN SUCCESSFUL PRODUCT DEVELOPMENT

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## Abstract

The research literature and industry best-practices report a vast number of enabling factors that contribute to successful *product development* (PD). Collectively this body of work also establishes the causal linkages between these enabling factors and overall success in PD. But what specific factors will produce what specific outcomes are vague and ambiguous. To address this apparent void, we find distinct sets of PD enabling factors that are statistically accurate predictors of the specific project outcomes of profit, market share, customer satisfaction, organizational effectiveness, and product quality. We are also motivated to help organizations improve their PD. To that end, we develop a diagnostic tool using the factors that predict our five PD outcomes. The tool is used to pinpoint weaknesses and focus improvements to achieve specific desired outcomes. Results of *in situ* testing of the tool are reported in this article. The guiding principles of this work are specificity and actionability: specific enabling factors that can produce specific results, and an actionable diagnostic-tool that practitioners can use to improve the practice and results of their PD projects.

*Key words: PD success factors, PD diagnostics, PD capability, PD performance*

## 1 Introduction

The effectiveness of product development (PD) is a very important issue. Enterprises large and small spend vast sums of money developing products. In the US alone, development expenditures have climbed from $94 billion in 1990 to $162 billion in the year 2000 [1]. By any measure this is a gigantic sum. There are only 26 countries in the world whose GDP is greater than $162 billion. Regrettably, studies also show that only about 10% of the products developed succeed, and "46% of the resources allocated to product development are either cancelled or fail to show an adequate return" [2]. Moreover, 31% of new products, even when introduced into pre-existing categories, fail [3]. We seek to make a modest contribution to the challenge of making PD more effective by providing metrics that define success, examining proposed factors that contribute to improving these metrics, and then testing them.

## 2 Methods

### 2.1 Overview

This work builds on previous academic research, industry practices, and company surveys we have undertaken. The overall process is described by the following steps:

- *Survey of previous work.* From journals and industry publications, we found 1106 enabling factors that contribute to successful PD and organizational performance. These factors were

reduced to 140 by content analysis and by eliminating redundancies using a KJ affinity-grouping approach.

- *Survey of companies.* To identify which of the 140 enabling factors can produce what outcomes, we surveyed 88 companies from a wide variety of industries. We obtained 83 valid responses from 92 PD managers whose average PD experience was 19.6 years.
- *Statistical Analyses.* Next we statistically determined which factors can predict the outcomes of profit, market share, customer satisfaction, product quality, and organizational effectiveness. Starting with 140 factors, we ran regressions on each of the five outcomes. We found 72 factors ($\alpha<.05$), which were then subjected to a principal component analysis (PCA). We found 23 axes contributing 80% of the variance within which 45 factors had a projection >.5. The 72 factors were also screened using Kruskal-Wallis statistics. This yielded 38 factors ($\alpha<.05$). This three-step screening process yielded 44 factors that are predictors of our 5 project outcomes.
- *Factor Grouping Analyses.* To organize the 44 enabling factors into a framework, we ran workshops with faculty, executives, and graduate students. A Deming Prize laureate moderated the workshops using his refinement of the KJ method. We found seven categories that grouped all the enabling factors. Then we framed our diagnostic tool using these seven categories.
- *Develop a Diagnostic Tool.* Next, the 44 statistically screened enabling factors were populated into our seven-category framework. Experts identified seven key external factors, not directly aligned with PD and, therefore, out of scope of our screening processes. These were added to the set of 44 enabling factors. In our diagnostic tool, each enabling factor was designed as a question to be scored on a scale of 1 to 7, anchored on descriptions of increasing levels of PD competency. Finally, to correlate scores to outcomes, we defined 23 PD output metrics to create an eighth category ("project results") for our diagnostic tool. This PD capability assessment tool can be used by organizations to identify project weakness, organizational deficiencies, and to pinpoint areas for improvement.
- *Test and Validation.* We are conducting field tests with companies on completed projects and additional trials are currently in progress.

## 2.2 Survey of previous work

There is a large body of work from researchers and industry practitioners to address the challenge of improving PD. Academic research concentrates on descriptive and representational frameworks of the PD process and how to organize PD activities. For our survey of this work, we selected representative work that covers the research and practice in this area. Brown and Eisenhardt [4] provide a review of the literature and identify three research streams. Krishnan and Ulrich [5] also review the research literature and position PD in a decision-making framework. Cooper [2] and Cooper and Kleinschmidt [6] in their benchmark studies, identify a phased development process and critical success factors for new product development. MIT's Lean Aerospace Initiative [7] presents a set of lean principles to be practiced in a multi-stakeholder value creation framework. Cambridge University [8] published a PD improvement process keyed-off with a diagnostic questionnaire. Carnegie Mellon's Capability Maturity Model presents four levels of maturity calibrated by the use of specific practices in software development [9]. Chiesa et al. [10] focus on innovation. The PDMA Handbook of New Product Development is an example of findings from industry practitioners about best practices in successful PD [11]. Product Genesis Inc.'s PERFORM adopts the Baldrige quality criteria and maps them to product development. NIST's (National Institute of Standards and Technology of the US) national Baldrige award defines criteria that can drive organizational performance [12]. Xerox and Arthur Andersen have their own set of criteria and checklists for PD project and

organizational evaluation [13]. PRTM measures the success of PD in terms of time-to-market and competitive advantage [14]. This body of work is summarized in Figure 1.

There are 1106 enabling factors in Figure 1. By eliminating redundant factors the list was reduced to 350. Although our focus on enabling PD factors may appear similar, our approach is distinctive. It is distinctive because we concentrate on very specific PD performance measures of profit, market share, customer satisfaction, organizational effectiveness, and product quality, rather than speaking generically of PD "success." Moreover, we identify the specific enabling factors that are strong predictors of these distinct performance outcomes. Finally, in order to make our findings actionable and practical in PD organizations, we construct a PD capability assessment instrument for evaluating PD organizational capability. Initial assessments are under test and evaluation *in situ.*

Figure 1. Summary of key PD research and best practices.

| **Authors** | **Key findings** | **Number of Factors** |
|---|---|---|
| Brown and Eisenhardt (1995) | PD as a rational plan, communications web, and disciplined problem solving. | 98 |
| Krishnan and Ulrich (2001) | PD as decision-making. Present an operations and an architecture model. | 65 |
| Cooper and Kleinschmidt (1995, 2001) | Overall new product performance measured program profitability and program impact. | 43 |
| Chiesa, Coughlan, and Voss (1996) | Framework to audit innovation processes: concept generation, PD, process, and technology acquisition. | 45 |
| MIT LAI Center (2002) | A lean enterprise creates value for its stakeholders by employing lean principles and practices. | 56 |
| Carnegie Mellon University SEI (1995) | Capability Maturity Model (CMM). Model of software development practices, used to assess a group's capability to perform software development. | 78 |
| University of Cambridge (2002) | A framework for new product development process improvement. | 135 |
| PDMA (1999) | A phase based product development | 49 |
| Baldrige National Quality Award (2004) | NIST's instrument to evaluate an enterprise from a business and total quality management perspective. | 86 |
| Xerox (2003) | Matrix model to assess PD process. | 120 |
| Product Genesis (2002) | A Baldrige based 7-category project assessment tool. Considers platform and product complexity issues. | 76 |
| McGrath (1995) | PD process model: includes decision-making, managing technology, pipeline, etc. | 54 |
| Arthur Andersen (2003) | A proprietary benchmarking tool that covers 10 major areas of product development. | 201 |
| **Total after reductions** | | **350** |

## 2.3 Survey of companies

Having identified 350 enabling factors for PD success, our next step was an evaluation by professional PD managers [15]. In preparation, we undertook another detailed review of the 350 enabling factors. We analyzed the text and context in which these enabling factors were reported in the literature. By eliminating those that were exceedingly similar, we were able to compress the 350 factors into 140. Using these 140 factors, we constructed our survey questionnaire. Two questions were asked for each factor: (i) how important is this factor to PD success? (ii) for this factor how capable is your company? In his article, we report only on capability. The questions of our survey questionnaire were designed for responses on an ordinal scale of 1 to 7 with anchored descriptions. Figure 2 shows a sample of three questions.

Figure 2. Sample questions from survey questionnaire.

| | How important is each to achieving success in product development? | | | | | | | How capable is your company at each? | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Not important | | Somewhat important | | Very important | | Extremely important | Not capable | | Somewhat capable | | Very capable | | Extremely capable |
| 1 Establishing product's core concept | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 Market positioning of the product | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3 Selecting the product architecture | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| etc. | | | | | | | | | | | | | | |

Each of the ordinals on the 1 -7 scale were anchored on descriptors as shown below.

Figure 3. Ordinal descriptors for PD capability.

| **Capability** | |
|---|---|
| Extremely capable | ▪ Produces unprecedented performance<br>▪ Redefined the process and practice<br>▪ Are disruptive to competitors |
| Very capable | ▪ Produces benchmark results<br>▪ Supported by engineering, cross-functional teams and processes<br>▪ Has visible strong senior management leadership |
| Somewhat capable | ▪ Produces acceptable and predictable results<br>▪ Have islands of local practice and optimization<br>▪ Follows conventional practices |
| Not capable | ▪ Produces acceptable results, but not consistent<br>▪ Practice is isolated and inconsistent<br>▪ Skill not widely available in the organization |

To collect data for our work, we gained agreement for our extensive interviews with each of the attendees of MIT's Industrial Liaison Program's Product Development Symposium. Participants at this symposium are primarily engineering managers and executives of companies who have responsibilities in PD. A total of 92 surveys were distributed, and we

obtained 83 valid questionnaires, a useable return rate of 90%+. A wide variety of industries were represented, e.g., 18% in automobile, 15% in electronics, 8% in IT. Among other industries represented were biomedical, defense, and financial services. Overall, 63% of the participants came from companies with greater than 2500 employees, 20% from companies with 500-2500 employees, with the remaining 18% from companies with less than 500 employees. The average of the respondents' professional experience was 19.6 years, ranging from 2 to 38 years with a standard deviation of 8.5 years.

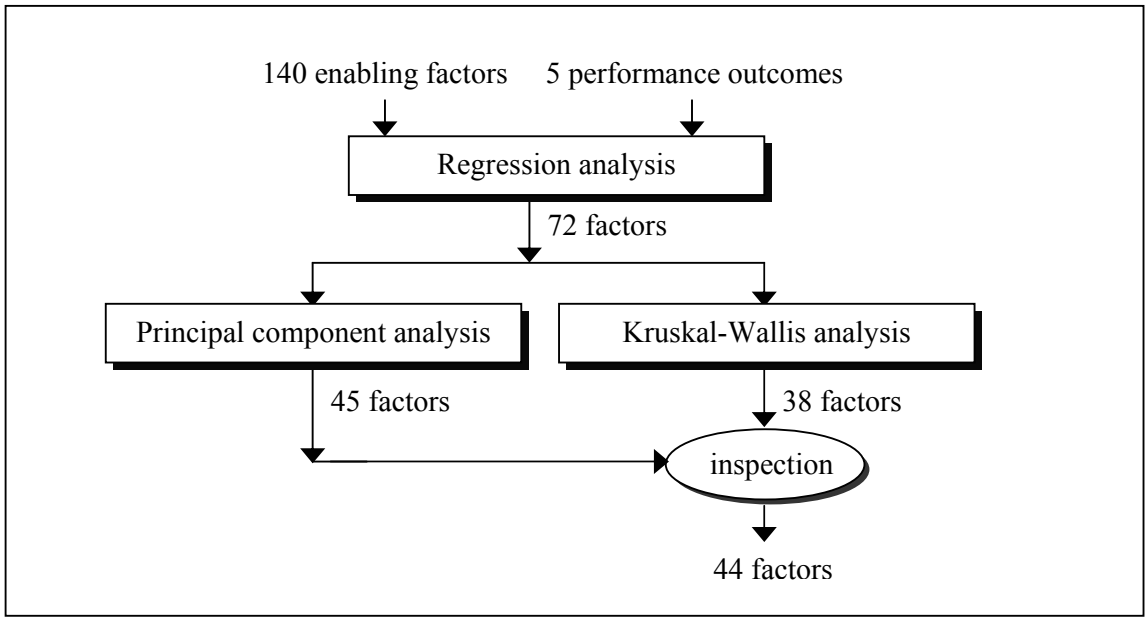
The top ten enabling factors that the respondents considered their organizations to be most capable are shown in Figure 4. In the following sections we will show a more detailed analysis of the survey data.

Figure 4. Top ten most capable enabling factors.

| | **Most Capable enabling factors in respondents' organizations** |
|---|---|
| **1** | Regulatory Compliance |
| **2** | Product Testing |
| **3** | Integration of health, safety, and environmental issues |
| **4** | Defining product's functional content |
| **5** | Establishing and maintaining customer relationships |
| **6** | Product validation |
| **7** | Focusing on continuous improvements |
| **8** | Technology selection for product |
| **9** | Mechanisms for project progress monitoring and control |
| **10** | Knowledge of competitive environment |

Beyond asking the respondents to evaluate their corporate capabilities in the 140 enabling areas, we also asked them to rate their organizations in five performance areas; profitability, market share, product quality, customer satisfaction, and organizational effectiveness. Then we used a screening process to identify correlations. The process, consisting of three steps is shown in Figure 5.

Figure 5. Screening process used for enabling factors.



We began with a regression of the 140 factors against our five output metrics. We found 72 factors that are significant at the 95% level. To further validate our selection, we screened the 72 factors using principal component analysis (PCA). We selected the axes that had the highest variance and collectively contribute 80% of the variance. This yielded 23 principal components. Within each principal component we selected those factors that had a projection >0.5. This process reduced the 72 factors to 45. We also screened the 72 factors using Kruskal-Wallis (KW) non-parametric statistics. The KW test decides whether the differences among the *k* samples signify genuine population differences among several random samples from the same population. The KW screen selected 38 factors at the<.05 significance level. Finally, we examined the 45 factors screened by the PCA analysis and the 38 factors from the KW analysis. From these we found that 44 factors would span the combined sets.

Figure 6 shows one example from the KW analysis that selects the factors that predict "market share" and their statistical significance. Note that some of these factors are also predictors of other outcomes. For example, the ability to manage "transition to sales" is also a predictor of "customer satisfaction," and "profit." A complete set of tables for our other PD outcomes are shown in the Appendix in Figures 13 through 16. An overall summary for our five PD performance outcomes is shown in Figure 7.

Figure 6. Factors that are predictors of the outcome of "market share."

| **Market share factors** | | **PD outcomes** | | | | |
|---|---|---|---|---|---|---|
| | *sig.* | profit | market share | product quality | cust. satisfac | org. effect. |
| Communicate strategic intent | 0.00 | | ☑ | ☑ | | ☑ |
| Manage culture change | 0.01 | | ☑ | ☑ | | ☑ |
| Transition to sales | 0.01 | ☑ | ☑ | | ☑ | |
| Partner satisfaction and loyalty | 0.02 | | ☑ | | | |
| Market positioning | 0.03 | | ☑ | | | ☑ |
| Define services processes | 0.04 | | ☑ | | ☑ | |
| Meeting financial goals | 0.04 | | ☑ | | | |
| Make-buy decisions | 0.00 | ☑ | ☑ | | | |
| Product pricing strategy | 0.01 | | ☑ | | | |
| Use customer satisfaction data | 0.02 | | ☑ | | ☑ | |
| Formal supplier ties | 0.03 | | ☑ | | | |
| Promote teamwork | 0.04 | | ☑ | | | |
| Knowledge of competitors | 0.04 | | ☑ | | | |
| Product's functional content | 0.04 | | ☑ | | ☑ | |

Figure 7. Number of factors that are predictors of the five outcomes.

| | Profit | Market share | Customer sat. | Product quality | Org. effect. |
|---|---|---|---|---|---|
| Profit | **5** | (2) | (2) | 0 | (1) |
| Market share | (2) | **14** | (4) | (2) | (3) |
| Customer satisfac. | (2) | (4) | **12** | (2) | (2) |
| Product quality | 0 | (2) | (3) | **4** | (2) |
| Org. effectiveness | (1) | (3) | (4) | (3) | **26** |
| All at α <.05. parentheses indicate number of factors included in the bold figure. | | | | | |

## 2.4 Factor Grouping Analysis

In this work, we are also motivated to help organizations improve their PD. This gave us the impetus to develop an assessment instrument to diagnose an organization's PD capabilities in order to help them identify areas of improvement.

Our first step in creating an assessment tool was to group all the factors, which emerged from the screening, into a coherent set of categories. We organized a series of KJ workshops with faculty, managers, executives, and graduate students. For these workshops, we were coached by MIT professor S. Shiba, a Deming Prize laureate, using the Language Processing Method [16], a refinement of the KJ method. The KJ workshops identified seven categories that grouped all the enabling criteria. They are: *leadership, organizational culture, human resources, information, product strategy, project execution,* and *product delivery*. The 44 down selected enabling factors were then populated into this seven category framework. A review by experts in PD research and practitioners determined that there were seven enabling factors, which were judged to be important additions to PD capability. These are: concept development, prototype plan, transition to manufacturing ramp-up, multidisciplinary staffing, work environment, risk analysis and management, and training and education. This brought the total enabling factors to 51.

## 2.5 Diagnostic tool development

Each enabling factor was designed as a question to be scored in the assessment tool so that it could be scored on a scale of 1 to 7. We anchored the scales with descriptors to minimize subjective interpretation and bias during survey taking. The following, Figure 8, is an example of an entry in the assessment tool, question 1.2, which asks about the experience of the project leader.

Figure 8. Example of question in PD capability assessment tool.

| **1.2 Project leader's experience** | | | |
|---|---|---|---|
| Experience limited to narrow product issues, weak in other areas. Needs help and rework very frequently. | Experienced in technical areas, but sometimes needs direction on business, financial and customer issues. | Has managed technical, business, financial and customer issues. Does not need help. | Has track record of complex technical projects, business, financial, customer issues. His advice is frequently sought. |
| → **1** → 1.5 → **2** → 2.5 → **3** → 3.5 → **4** → 4.5 → **5** → 5.5 → **6** → 6.5 → **7** | | | |

The following guidelines were given for scoring each question.

- "1" is not necessarily incompetence or worst performance. It gets the job done, albeit with weak results, or in a way that you do not want to repeat.
- "3" reflects a competent practice or characteristic.
- "5" reflects outstanding performance, result of substantial experience, diligence, or training.
- "7" reflects an exceptional level of breakthrough performance that is very hard to achieve and only a very small subset are capable of reaching.

In order to correlate the enabling factors with PD performance, we constructed 23 PD output metrics and created an eighth category for our instrument, "Results." 23 output metrics were organized into 5 subcategories: *project financial and market results, project customer satisfaction and loyalty results, organizational effectiveness results, product results, and project benchmarking*. (The complete outline of all the categories and questions are available on request.) A summary is shown in Figure 9.

Figure 9. The eight categories of the PD capability assessment tool.

| | Category | Number of factors |
|---|---|---|
| **1.0** | **Leadership**<br>Examines key characteristics of the project leader, power delegated, and whether there is clear strategic direction for the project. | 3 |
| **2.0** | **Organizational Culture**<br>Examines the extent to which management has taken advantage of the established values of the people to improve project outcomes. | 9 |
| **3.0** | **Human Resources**<br>Examines management's actions to improve the skills and the work environment. | 4 |
| **4.0** | **Information**<br>Examines the treatment of information as valuable assets, their quality, and whether it is systematically collected, shared, analyzed. | 7 |
| **5.0** | **Product Strategy**<br>Examines the product planning processes and extent to which they promote readiness for product development and product delivery. | 13 |
| **6.0** | **Project Execution**<br>Examines key issues of the product development process. | 11 |
| **7.0** | **Product Delivery**<br>Examines the extent manufacturing, sales, service and support are considered; or whether the product is "tossed over the wall." | 4 |
| **8.0** | **Results**<br>Examines the results of the project from multiple dimensions, financial and market, customer satisfaction and loyalty, organizational effectiveness, product results, and benchmarking. | 23 |

## 2.6 Test and validation

We tested and validated our PD assessment tool at an industrial field site [17]. We were assisted in this evaluation by a project manager, a marketing manager, and an engineering director who scored their PD projects using the assessment tool. The goal was to determine whether our assessment tool could correctly diagnose PD project problems. In these field tests, our tool was able to pinpoint project problems in three ways: (i) those factors with respondent scores with wide divergence from the mean, (ii) those factors with respondent scores with wide divergence from each other, and (iii) analysis of the correlations between the input factors' scores and the project's outcomes. We now discuss each of these in turn.

Figure 10, Factor Difference Histogram, is an example of the results from a "project A" evaluation of the factor's scores which exhibit a wide divergence from the mean – the factor has a positive or negative impact on the result. The x-axis shows the difference from the mean score. We focus our attention on the 30% of the factors that have the largest difference

from the mean. These are the factors with difference greater than 1.3. The histogram shows there are eight factors that meet this selection criterion. They are: cultural change management, customer satisfaction data, make-buy decisions, prototype plan, product volumes, product's market share in revenue, customer loyalty, and satisfaction with price for value.

Figure 10. Factor difference histogram for project A.

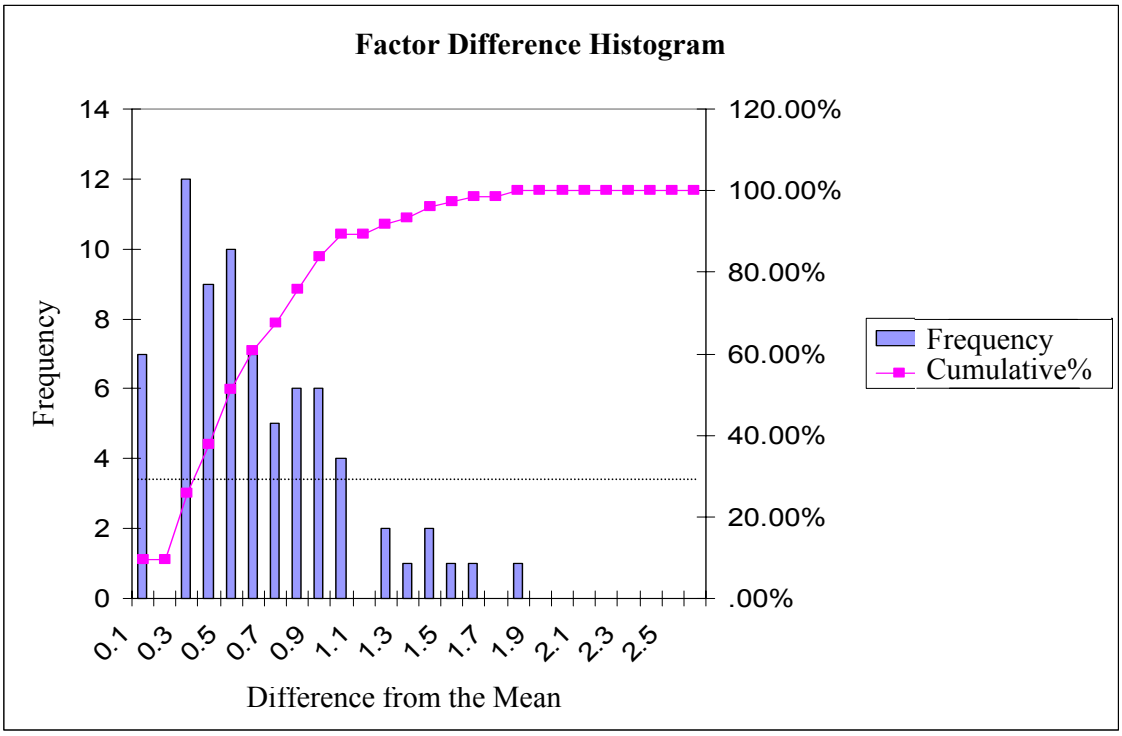
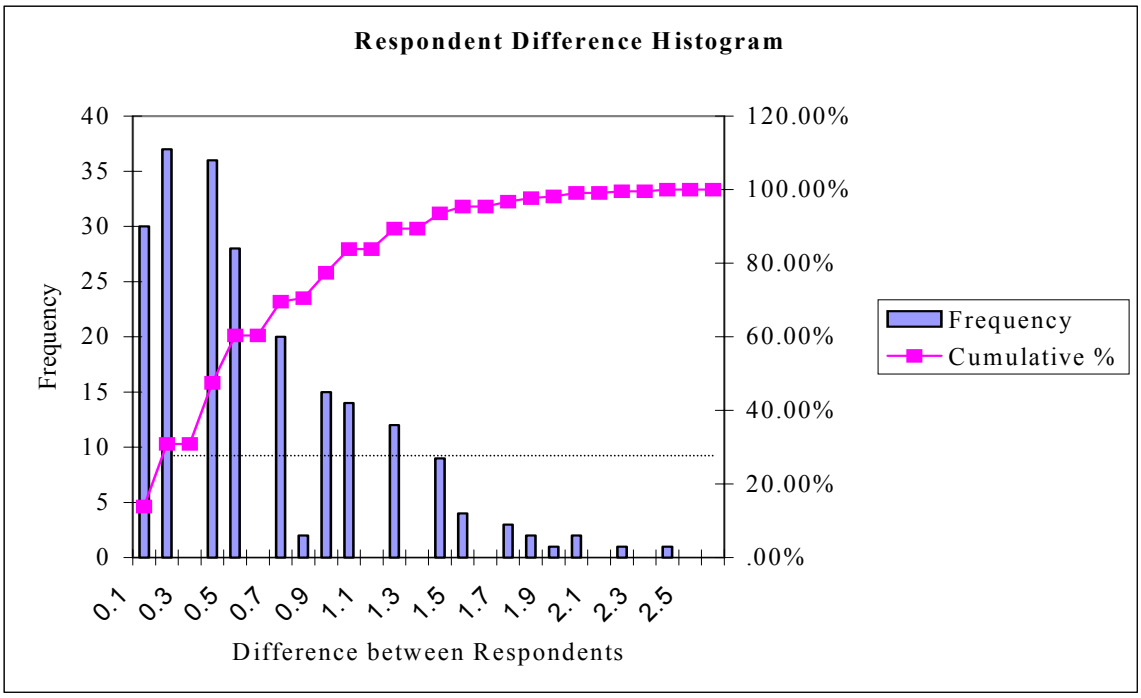



Figure 11, Respondent Difference Histogram, shows the results from a "project A" evaluation of the factors with respondent score which exhibit a wide divergence among respondents. The x-axis shows the difference between respondents. We focus our attention on the 30% of the factors that have the largest relative difference. These are the factors with a difference greater than 1.6. The histogram shows there are eight factors that meet this selection criterion. They are the following: cultural change management, customer satisfaction data, make-buy decisions, prototype plan, product volumes, product's market share in revenue, customer loyalty, and satisfaction with price for value. We note that these are the same eight factors that were selected from the Average Difference Histogram in Figure 10, an interesting result. That is, factors that most contribute to or retard success are also the ones which participants have largest variance in opinion on their contribution. This is intuitive, as persons closer to the factor will understand more how it contributes, and have stronger opinions, leading to a larger variance. This suggests variance among scores is another test to consider when screening questionnaires on PD performance for contributing factors on any project *post mortem*. For example, the eight factors from Figures 10 and 11 were able to identify problems that were very specific to project "A." They were problems in: (i) the decision making processes, (ii) inter-function communications within the PD organization, (iii) goal congruence among functions, and (iv) cultural change from new management.

Figure 11. Respondent difference histogram for project A.




Next, we look at the correlations between the enabling categories 1 through 7 against the project outcomes in category 8, Figure 12. Category 4, Information, shows a strong set of correlations with results. This is consistent with the view of PD as an information-intensive undertaking [18]. It is satisfying to note that Product Strategy, category 5, has a strong influence on key output metrics in Results, category 8. Product Delivery, category 7, shows the weakest correlations with results in general, suggesting that in this case Product Delivery was not important to the achievement of project's outcomes. Category 3, HR shows the most negative correlations with results. The reasons are project specific. During the course of the project, there were a plethora of HR programs, but they were perceived as "going through the motions" and a "waste of time" by the work force. They appeared uncoordinated and excessive in number. Figure 11 is a typical project post-mortem lessons learned result for a firm, and can provide focus on what to improve.

Figure 12. Correlations between input categories and project outcomes for project A.

| | | Input categories | | | | | | | Project outcomes | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| categories | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8.1 | 8.2 | 8.3 | 8.4 | 8.5 |
| 1 | Leadership | 1.00 | | | | | | | | | | | |
| 2 | Org. cult. | **0.56** | 1.00 | | | | | | | | | | |
| 3 | HR | -0.15 | **-0.57** | 1.00 | | | | | | | | | |
| 4 | Information | 0.45 | **0.96** | **-0.66** | 1.00 | | | | | | | | |
| 5 | Prod. strat. | 0.39 | **0.53** | 0.18 | **0.56** | 1.00 | | | | | | | |
| 6 | Proj. exec'tn | **0.86** | 0.49 | -0.15 | **0.50** | **0.65** | 1.00 | | | | | | |
| 7 | Prod. del. | 0.11 | 0.25 | **0.50** | 0.22 | **0.86** | 0.31 | 1.00 | | | | | |
| 8.1 | Fin. & mkt. | -0.33 | 0.29 | -0.19 | 0.49 | **0.60** | 0.10 | 0.47 | 1.00 | | | | |
| 8.2 | Cust. sat. | -0.14 | **0.60** | **-0.54** | **0.77** | **0.52** | 0.16 | 0.28 | **0.91** | 1.00 | | | |
| 8.3 | Org effect. | 0.42 | **0.65** | **-0.74** | **0.80** | 0.42 | **0.67** | -0.03 | **0.52** | **0.72** | 1.00 | | |
| 8.4 | Prod. result | 0.38 | 0.44 | -0.46 | **0.61** | **0.56** | **0.75** | 0.14 | **0.59** | **0.65** | **0.93** | 1.00 | |
| 8.5 | Benchmark | **0.92** | **0.62** | -0.38 | **0.59** | 0.34 | **0.83** | -0.10 | -0.16 | 0.08 | **0.63** | **0.57** | 1.00 |

# 3 Discussion

We have shown that there is support for the hypothesis that there exist distinct frugal sets of PD enabling factors that are predictors of specific PD project outcomes. This addresses an apparent void in the PD literature and fills a practical need to know what specific factors will produce what specific PD outcomes. Through a literature search, company surveys, and rigorous statistical screening processes, we found specific and distinct sets of PD enabling factors that are statistically strong predictors of the specific project outcomes of profit, market share, customer satisfaction, organizational effectiveness, and product quality. We selected these outcome metrics because in the company (a leading global IT research, hardware and software product development, manufacturing, and services firm) where one of the author's was employed, these were the metrics submitted by business units and product managers for corporate inspection. At the $\alpha<.05$ level, we found 5 factors that predict profit, 14 that predict market share, 12 that predict market share, 4 that predict product quality, and 26 that predict organizational effectiveness. From Figures 6, 13, 14, 15, and 16, we note that these sets are collectively exhaustive, but not mutually exclusive. It is not surprising that these sets have non-empty intersections. For example, that clarity in the product's functional content will have a positive impact on *market share* and *customer satisfaction* is not surprising. This property of overlapping effectiveness of the sets of enabling factors is a reason why PD is complex and challenging. We note that the factors that predict *product quality* and *profit* are mutually exclusive. This suggests that perhaps that quality is not "free" after all.

Using the enabling factors that predict PD project outcomes, we constructed a PD diagnostic tool to diagnose PD projects to permit improvements targeted at specific outcomes. This capability addresses a very practical and important need in PD practice. Unlike other PD diagnostic tools, which are proprietary to serve commercial interests, our tool is *open* to practitioners and researchers and available on demand by contacting the corresponding author. Our tool aligns consistently with the Baldrige criteria, a result of the data generated, not a result we forced. In field tests, we found that respondents could complete the survey in little over an hour. And unlike many other assessment tools, our tool does not require intensive or protracted training to use or administer. Feedback from respondents indicates that anchoring the descriptors is a very useful feature. It facilitates the respondents having a more uniform interpretation of the scoring scales. As in any data collection process, domain and project knowledge are required for the interpretation of the data. This was confirmed in our field trials. Our tool was able to pinpoint project problems in three ways: (i) those factors with respondent scores with wide divergence from the mean, (ii) those factors with respondent scores with wide divergence from each other, and (iii) analysis of the correlations between the input factors' scores and the project's outcomes.

The guiding principles of this work are specificity and actionability: specific enabling factors that can produce specific results, and an actionable diagnostic tool practitioners can use to improve the PD practice and PD results.

# 4 Acknowledgements

Support for this work was provided by MIT's Center for Innovation in Product Development, (CIPD), MIT's Lean Aerospace Initiative (LAI), and Product Genesis, Inc.

# 5 Appendix

Figures 13, 14, 15, and 16 show the factors that are predictors of profit, quality, customer satisfaction, and organizational effectiveness, respectively. The statistical significance of the factors from the K-W statistics are shown in the tables.

Figure 13. Factors that are predictors of the outcome "profit."

| **Profit factors** | | **PD outcomes** | | | | |
|---|---|---|---|---|---|---|
| | *sig.* | profit | market share | product quality | cust. satisfac | org. effect. |
| Power delegated to project leader | 0.08 | ☑ | | | | |
| Linkage to corporate goals | 0.01 | ☑ | | | | |
| Transition to sales | 0.02 | ☑ | ☑ | | ☑ | |
| Product's social responsibilities | 0.03 | ☑ | | | ☑ | |
| Correct make-buy decisions | 0.04 | ☑ | ☑ | | | ☑ |

Figure 14. Factors that are predictors of the outcome "quality."

| **Product quality factors** | | **PD outcomes** | | | | |
|---|---|---|---|---|---|---|
| | *sig.* | profit | market share | product quality | cust. satisfac | org. effect. |
| Technology readiness | 0.08 | | | ☑ | | |
| Investments in tools, training | 0.01 | | | ☑ | ☑ | |
| Communicate strategic intent | 0.02 | | ☑ | ☑ | ☑ | ☑ |
| Manage cultural change | 0.03 | | ☑ | ☑ | ☑ | ☑ |

Figure 15. Factors that are predictors of the outcome "customer satisfaction."

| **Customer satisfaction factors** | | **PD outcomes** | | | | |
|---|---|---|---|---|---|---|
| | *sig.* | profit | market share | product quality | cust. satisfac | org. effect. |
| Customer relationship | 0.00 | | | | ☑ | |
| Investments in tools, training | 0.01 | | | ☑ | ☑ | |
| Product architecture | 0.02 | | | | ☑ | |
| Reuse physical and design assets | 0.03 | | | | ☑ | ☑ |
| Knowledge of market potential | 0.04 | | | | ☑ | |
| Use of customer satisfaction data | 0.05 | | ☑ | | ☑ | |
| Product's social responsibilities | 0.01 | ☑ | | | ☑ | |
| Services processes | 0.01 | | ☑ | | ☑ | |
| Transition to sales | 0.03 | ☑ | ☑ | | ☑ | |
| Product's functional content | 0.04 | | ☑ | | ☑ | |
| Service & support complexity | 0.05 | | | | ☑ | |
| Knowledge management system | 0.05 | | | ☑ | ☑ | ☑ |

Figure 16. Factors that are predictors of the outcome "organizational effectiveness."

| **Organizational effectiveness** | | **PD outcomes** | | | | |
|---|---|---|---|---|---|---|
| | *sig.* | profit | market share | product quality | cust. satisfac | org. effect. |
| Establishing end-of-life strategy | 0.00 | | | | | ☑ |
| Communicating strategic intent | 0.00 | | ☑ | ☑ | ☑ | ☑ |
| Training and education | 0.00 | | | | | ☑ |
| Breakthrough ideas | 0.00 | | | | | ☑ |
| Market positioning the product | 0.01 | | | | | ☑ |
| Concurrent engineering process | 0.01 | | | | | ☑ |
| Organizational learning | 0.01 | | | | | ☑ |
| Leverage organizational culture | 0.01 | | | | | ☑ |
| Use project performance metrics | 0.01 | | | | | ☑ |
| Reuse physical and design assets | 0.01 | | | | ☑ | ☑ |
| Knowledge management system | 0.02 | | | ☑ | ☑ | ☑ |
| Team productivity | 0.02 | | | | | ☑ |
| Internal communications | 0.02 | | | | | ☑ |
| Internal task coordination | 0.02 | | | | | ☑ |
| Portfolio of new opportunities | 0.02 | | | | | ☑ |
| Appropriate risk taking | 0.02 | | | | | ☑ |
| PD process to fit the product | 0.03 | | | | | ☑ |
| Product pricing | 0.03 | | | | | ☑ |
| Formal ties with suppliers | 0.03 | | | | | ☑ |
| Correct make-buy decisions | 0.04 | ☑ | ☑ | | | ☑ |
| Manage project delays | 0.04 | | | | | ☑ |
| Product marketing | 0.04 | | | | | ☑ |
| Use of operational data | 0.05 | | | | | ☑ |
| Manage cultural change | 0.05 | | ☑ | ☑ | ☑ | ☑ |
| Methods, tools, techniques | 0.02 | | | | | ☑ |
| Data collection and management | 0.02 | | | | | ☑ |

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