Product Development Processes and Their Importance to Organizational Capabilities

by

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Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of

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at the

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ABSTRACT

Product development is a creative and interdisciplinary activity that transforms a market opportunity and technological innovation into successful products. It is a set of activity-based processes in a product-oriented enterprise, and is essential to the economic success of such organization. Determining important processes in the product development and determining their relationships with organizational capability are crucial to the sustainable success in product development. Studying their relationships would give us insights into the product development dynamics. The objectives of this research are to provide a framework to determine the importance of product development processes and their relationship with organizational capabilities, to provide an assessment vehicle that helps organizations assess their capabilities and make improvements, and to improve predictions of project outcomes as the ultimate goal.

To fulfill the objectives and to achieve the goal of this research, a step-based approach was adopted: first, Identify important processes in product development, second, identify an organization's capability using important product development processes identified through literature review and survey. Third, study various factors that influence the determination of importance of product development and the capability of product development were studied. Forth, test two hypotheses based on the statistics. The work in this thesis illustrates how various factors such as company size, industry sectors, and professional experience may influence the dynamics of product development process.

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1. Objectives and Discussion

1.1 Introduction & Problem Statements

Product development is a creative and interdisciplinary activity that transforms a market opportunity and technological innovation into successful products. Product development is not only a major activity in the life of a product-oriented enterprise, but also essential to the economic success of such organizations. Product development processes are organized in a way that requires participation by virtually all the major functions within the organization such as strategic planning, marketing, product design, manufacturing and financial planning and budgeting. It also involves interactions with stakeholders such as customers, suppliers that at outside of the organization.

Characteristics of Successful Product Development

A product development is successful if its products not only fulfills the needs and the requirements of customers, but also generates profits to its shareholders, and creates value to its stakeholder at large. In other words, the two main characteristics of a product development project are historically its quality and profitability, where "quality" represents how well the product satisfies the customer needs, and "profitability" represents how much profit it can generate with limitation of budget, and schedule. The instruments developed to measure the performance of a product development, therefore, were tailored to meet those two characteristics. The widely used measurements are drawn from three perspectives: consumer-based, financial and technical or process-based success.

- **Consumer-based**: Customer loyalty, and market share
- **Financial-based**: Cost & Expense. (Can this organization make money?)
- **Technical & Process-based**: TTM (Time-to-Market), quality

For example, PRTM [14] measures the success of product development in terms of the ability to cut time-to-market in half and competitive advantage; Cooper el ct [10] suggest 10 performance measures of a company's new product development: success rate, percentage of sales, profitability relative to spending, technical success rating, sale impact, profit impact, success in meeting sales objectives, success in meeting profit objectives, profitability relative to competitors, and overall success.

To effectively organize the product development activities within an organization and achieve their goals, many have adopted a phase-based approach in product development cycle. In this research, a generic product development cycle is divided into 6 phases: planning, concept development, product design & development, testing & validation, production ramp-up, product retirement:

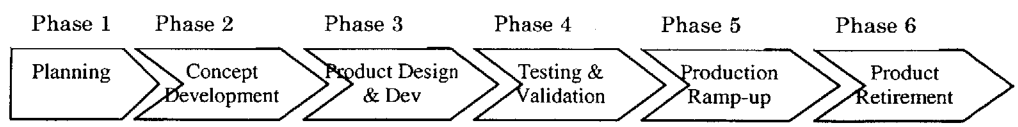


Figure 1.1 Product Development Cycle

Phase 1: Planning begins with assessment of technology development and market objectives. The output of this phase is the project mission statement, which specifies the target market for the product, business goals, and key assumptions and constrains. Some researches refer this phase as "phase zero", since in some product development settings, it precedes the project approval and the launch of the actual product development, despite its impact in the overall success of product development. In order to reflect it's crucial and formal role in the product development, we here refer to this phase as phase 1.

Phase 2: Concept development evaluates alternative approaches to product design, and selects appropriate form, function, and features for further development. Notice in this phase, not only the product's technical specifications are evaluated, but also the product's attributes in terms of customer needs and market requirement are evaluated. Questions that need to be answered in this phase include: what are the target values of the product attributes including pricing? What variants of the products will be offered, and what is the core product concept?

Phase 3: Product design and development define product detailed specifications, designs system architecture, and organizes and coordinates the development activities. The output of this phase is the product that is based on the approved concept and specification. The primary emphasis of this phase is on execution rather than analysis of the product opportunity or its feasibility, though efforts need to be made to reflect changes in market conditions and customer requirements.

Phase 4: Testing and validation complete acceptance testing and prepare for volume production and product. The output of this phase is the product that is valid for market requirement and is ready for production. Testing is an important step in the product development. Statistics shows that testing time in most software development is equivalent or exceeds the development time.

Phase 5: In product launch and production ramp-up phase, product is made using intended production systems. Products can be produced internally, or outsourced to third parties. Supply-chain system and management is often a critical issue in this phase. Other decisions need to be made include the timing of product launch to the market, the volume of production and the production capacity.

Phase 6: Product retirement prepares for the end of a product life and transition to new product. Many researches stop short of product development cycle at phase-5, citing that the completion of product development is when the product released to the market. This view didn't reflect the reality in a product development organization, as most product development efforts continue well beyond the launch date of the product. Incorporating product retirement into formal product development cycle helps capture the full spectrum of product development.

The Product Development Cycle helps companies to streamline their product development activities, and to deliver quality product in a timely manner. As stated earlier, this approach is design in response to meeting the goal of schedule, budget and quality. Product development activities in the development cycle were arranged as a set of processes, which involves multidisciplinary functions such as marketing, engineering, manufacturing. This adds a second dimension in the product development: processes that involve one or more functions in an organizations, and operates in a serial manner. Figure 1.2 shows the incorporation of both product development cycle and product development processes into one presentation, Product Development Landscape:

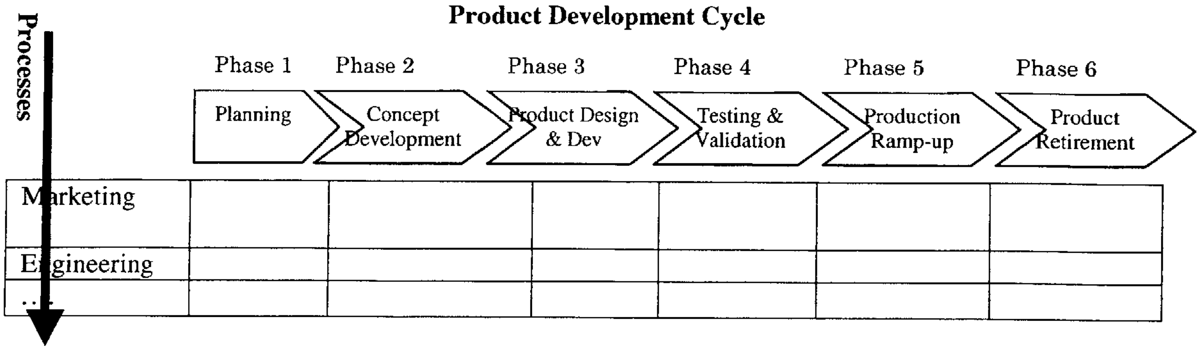


Figure 1.2 Product Development Landscape

Work that focused on some part of the product development landscape includes PRTM's 7 elements model of Product and Cycle-Time Excellence (PACE) [14], and Ulrich and Eppinger's [19] model of Product Design and Development.

Although the situation has improved considerably in the product development, many projects still fail to reach its completion within budget, delivery within schedule, fulfill quality expectation or financial goal. One particular situation has puzzled many companies is that even though it can be very successful in one project, it is difficult, if not possible to sustain and replicate such success to other projects within the same organization:

Developing a great product is hard; developing great products _consistently_ is even harder

Possible reasons for project failures include: improper estimation, weak project management, poorly engineered solutions, and many more. Among all those failures, many have fall into two categories: "process failure" and "process incompatibility" with organizational capability.

Process Failure: "Process failure" is that the processes followed in the project are not suitable. For example, the major reasons for runaways of the project are unclear objectives, bad planning, or, no project management methodology. For a project to succeed, a key parameter is the set of processes followed in the project. If suitable processes are chosen for the important tasks in the project, and the processes are executed properly, then the chances of a project succeeding become much higher. Failure of identifying critical processes in the product development, on the other hand will delay, if not fail the completion of product development. So,

Identifying important processes is crucial to the success of product development

In order to help identify important processes in the product development, four level of "importance" were defined in respects of customer/stakeholders' needs, management competency, and consequence of failure:

Extremely Important

- Non-negotiable to meet customers', stakeholders', and competitive requirements.
- Relentlessly inspected by my senior management.
- Failure implies vast infusion of unplanned resources.

Very Important

- High priority, but negotiable.
- Reviewed on exception by senior management.
- Failure recoverable with incremental resources.

Somewhat Important

- Nice to have.
- Delegated to trusted employee/manager.
- Failure recoverable with only extra effort.

Not Important

- Will not spend time or resources on this.
- Not cost-effective to address.

Process Incapability: Another source of project failure comes from "Process incapability", that is, the processes in product development are not compatible with organization's capability. Capability is defined as the ability to ***consistently*** succeed in developing new products through ***effective*** and ***sustainable*** processes. Two important attributes of organizational capability in product development are consistency and sustainability. Without consistency, an organization will not be able to replicate its success from one project to another, and sustain it competitive advantage in product development. So,

Improving organizational capabilities is crucial to sustain competitive advantage in product development

An organization's capability can be defined in four levels with different aspects:

Extremely Capable

- Produces unprecedented performance.
- Redefined the process and practice.
- Are disruptive to competitors.

Very Capable

- Produces benchmark results.
- Is supported by integrated engineering, cross-functional teams and processes.
- Has visible strong senior management leadership.

Capable

- Produces acceptable and predictable results.
- Have islands of local practice and optimization.
- Follows conventional practices.

Not Capable

- Produces acceptable results, but not consistent.
- Isolated and inconsistently practiced.
- Skill not widely available in the organization.

In the recently years, the research and assessment in product development started shift from improving phase-based product development cycle to improving organizational capabilities for product development. Software Engineering Institute's (SEI) at Carnegie-Mellon University has developed the Capability Maturity Model (CMM) for evaluating the capabilities of software development companies. Its model includes 5 levels of capability maturity. (More detailed description of CMM can be found in Chapter 2). The Malcolm Baldrige National Quality Award accounts for much of their support through its use as audit of the processes of quality rather than as the basis of awards.

In order to improve product development outcome of an organization, a framework to determine the importance of product development processes and their relationship to organizational capabilities needs to be developed.

This research is built upon the notion of identifying important processes and assessing organizational capabilities. Questions need to be addressed includes:

- What are the most important processes to product development and how capable of an organization at each of those processes
- Are they important in different ways? What are the factors in determine importance of processes and capability of an organization?
- How to help organizations to improve product development and their capabilities?

1.2 Objectives of the Research

The objectives of this research can be summarized as:

- Provide a framework to determine the importance of product development processes and their relationship with organizational capabilities
- Provide an assessment vehicle that helps organizations assess their capabilities and make improvement
- Improve predictions of project outcomes

As we have mentioned in the previous section, determining important processes in the product development and determining their relationships with organizational capability are crucial to the success of sustainable product development. Studying their relationships would guide us to the insights of product development dynamics.

In the end, the goal of capability research is to improve an organization's product development capabilities to produce competitive products & to achieve business performance by (1) analyzing end-to-end development process, (2) analyzing business processes that impact product development, (3) and formulating prescriptions to transform product development process, using a diagnostic & prescriptive method and making the analysis & data "open" to all practitioners in the public domain.

The focus of this research is on engineered product, which include both hardware and software in general, although much of the materials in this research can be useful to the development of any product or services. The research is also focused on project level of product development.

1.3 Research Framework

To fulfill the objectives and achieve the goal of this research, a stepped approach was adopted:

Step 1: Identify important processes in product development and identify an organization's capability in regard with important product development processes.
This step was done by tasks:

- ***Literature Review***: Academic papers and industry practices were reviewed, 14 papers were identified as important and studied in depth. A total of 352 processes relevant to product development were identified in this process.
- ***Survey Design:*** A questionnaire was designed to identify most important processes in product development, and to assess organizational capabilities to product development processes.
- ***Data Collection:*** A survey was conducted during CIPD Conference in October 2002 to collect data for further analysis.

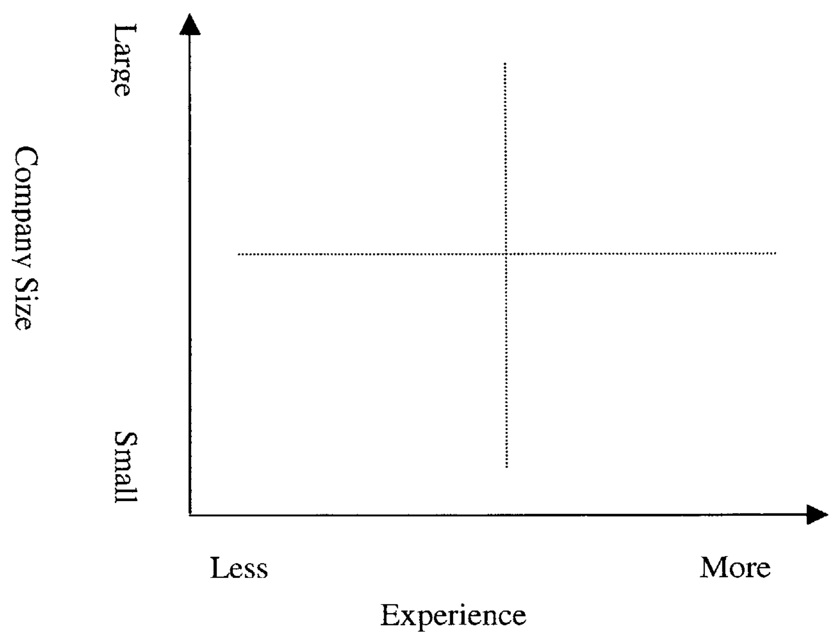
Step 2: Study various factors that influence the determination of importance of product development, and study various factors that contribute to the capability of product development.
The focuses of this part of study is on three factors:

- Company size, and
- Professional experience
- Company performance

Step 3: Determine the discrepancy of product development importance and organizational capability by two factors

Three hypothesis are to be studied here are:

1. Correlation exists between the importance of product development processes and the length of professional experience of those participated in product development
2. Process importance correlates to both company size and the length of professional experience



3. Correlation exists between an organization's product-development capabilities and its financial performance

2. Literature Review and Discussion

2.1 Literature Search

The objective of literature review is to capture the essence of past research work in product development and to build the foundation for developing effective tools to improve product development processes and organizational capabilities.

The papers reviewed in this research can be categorized into three streams: (1) academic research and general review of past work in product development, (2) tools and instruments that assess an organization's performance in product development and, (3) research and practices in assessing or improving, or both of product development processes and capabilities.

A total of 14 papers have been reviewed in depth (refer to table 3.1 for details) in this research. Among them, two papers fall into the category (1). They are S.L. Brown & K.M. Eisenhardt's (B&E, 1995) "Product Development: Past Research, Present Findings, and Directions" and V. Krishnan & K.T. Ulrich's (K&U, 2000) "Product Development Decisions: A Review of the Literature". Three papers – Arthur Andersen's "Global Best Practices", Cooper & Kleinschmidt's "Benchmarking the Firm's Critical Success Factors in New Product Development, and Chiesa & Voss's "Development of a Technical Innovation Audit" focus on performance assessment in category (2). The rest 9 papers focus on process and capability assessment in product development. The sections that follow will give brief descriptions of some of the reviewed articles.

2.2 Review Articles in Product Development

There have been several excellent review articles in the general area of product development (Shocker and Seinivasan 1979; Finger and Dixon 1989a, 1989b; Whitney 1990; Cusumano and Nobeoka 1992. etc.). In particularly, two articles, S.L. Brown & K.M. Eisenhardt's (B&E, 1995) "Product Development: Past Research, Present Findings, and Directions" and V. Krishnan & K.T. Ulrich's (K&U, 2000) "Product Development Decisions: A Review of the Literature", provide us comprehensive and up-to-date reviews of past research work done in the area of product development.

The first one categorized product development activities into three streams: rational plan, communication web, and disciplined problem solving. The second one, on the other hand, viewed product development in the perspective of decision-making and developed a causal based model to capture important issues in the course of product development.

2.2.1 "Product Development: Past Research, Present Findings, and Directions" (S.L. Brown & K.M. Eisenhardt)

S.L Brown and K.M Eisenhardt published this review paper of product development in 1995. It has since become one of the most comprehensive reviews in the area of product development. This paper categorizes the product development literature into three streams: product development as rational plan, communication web, and disciplined problem solving. It also developed a model that highlights the distinction between process performance and product effectiveness and the importance of agents, including team members, project leaders, senior management, customers, and suppliers, whose behavior affects these outcomes.

The success of a product development project, as B&E argued, can be measured by traditional means: product quality, time to the market, and productivity. The success of a product development project depends on the factors such as supply chain management, involvement of senior management, internal/external communication, and cross-functional teams.

B&E categorized the product development literature into three streams: rational plan, communication web, and problem solving discipline. In the perspective of rational plan, B&E emphasize that successful product development is the result of (a) careful planning and (b) well-organized cross-functional operations and (c) appropriate support of senior management. The research in this stream is primarily exploratory and athoretical. Data was typically collected through questionnaires or interviews. The performance, from this perspective, was measured by profit, revenues, and market share. There are two findings from part of research: (1) market pull is substantially more important than technology push, thus cross-functional view is a key component in product development; (2) three most important factors to the success of product development are product advantages, market attractiveness, and internal organization, where product advantage is the determinant factor.

The second stream narrowly focuses on communications among PD engineers Two theoretical basis for this steam are information-processing view and resource dependence view. It emphasizes that internal and external communications stimulate the performance of development team. The key factors of having effective communications are gatekeepers, power project manager, and cross-functional team. Performance measurement in this stream is usually subjective.

The disciplined problem solving, as the third stream in B&E's research, was attempting to find a balance act between relatively autonomous problem solving by the project team and the discipline of a heavyweight leader, strong product management, and an overarching product vision. Process performance is measured by speed and productivity, and product performance is measured by product integrity. Two problem-solving models are widely adopted: (1) for more stable products in mature settings focus on *planning* and *overlap*, (2) for less predictable products in uncertain settings focus on *experiential design.*

The detailed model of B&E can be found from reference [4]. The model is an integrative model that incorporates the findings from three research streams. The model is a causal path based model that identifies key factors affecting the success of product development. Although factors are presented, their interactions are not. It's unclear how interactions in fact influence results.

The disciplined problem solving was originated from Japanese management experience, which was the fashion in 1990's, especially the subtle control. It's questionable to be used in today's product development process

The factor models are presented in causal path, which suggest the possible use of System Dynamic to analyze the model. The key point of doing so is to introduce noise into the system and resolve the robustness of the model.

2.2.2 "Product Development Decisions: A Review of the Literature" (by V. Krishnan & K.T. Ulrich's)

V. Krishnan & K.T. Ulrich's published this review paper in January 2001 at Management Science. This is another review article in the general area of product development encompassing work in the academic fields of marketing, operations management, and engineering design. K&U reviewed over 200 articles in the area of product development. They focus their of literature search on three fronts:

- Product development projects in a single firm, as oppose to much of literature on technological innovation, which addresses innovation at the level of an entire industry or an entire firm.
- Focus on development of physical goods.
- Focus on the academic literature, reviewing the practitioner literature only to the extent it has been influential in the research community.

They adopted a view of product development as a series of decision-making, and identified about 60 major decisions that need to be made within product development organizations.

Decision perspective considers product development as a deliberate business process involving scores of generic decisions. While how products are developed differs not only across firms but also within the same firm over time, what is being decided seems to remain fairly consistent at a certain level of abstraction.

Product development decisions are organized into two categories: decisions within the context of a single project in actual developing the product, and the decisions a firm makes in establishing an organizational context and in planning development projects

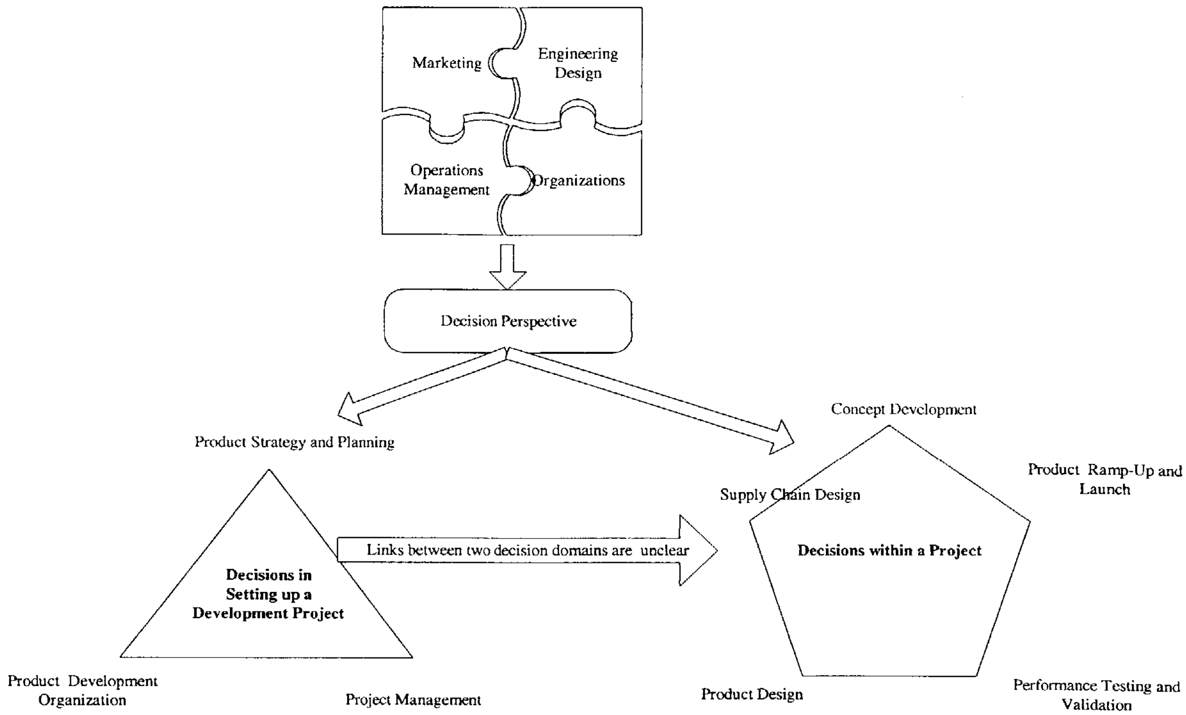


Figure 2.1 Research frameworks in K&U's product development review

2.3 Capability Maturity Model (CMM)

Capability Maturity Model (CMM) was originally developed by Software Engineering Institute's (SEI) at Carnegie-Mellon University for U.S. Department of Defense to evaluate the capabilities of software suppliers. It loosely has roots to Crosby's Quality Management maturity Grid (Crosby, 1979). The CMM is a reference model of mature practices in a specified discipline, used to assess a group's capability to perform that discipline. It describes an evolutionary improvement path for process maturity, and classifies the maturity of the software processes in five levels – namely initial, repeatable, defined, managed and optimized.

More than 5000 organizations have invested in CMM-based process improvement (Software Productivity Consortium, June 1998). It has become an effective tool for companies in developing large and complex software products to assess their current practices and improve their organizational capabilities in processes.

2.3.1 The Approach

SEI measures the performance of a software development project in three main aspects: cost, schedule and quality, where "quality" represents how well a product satisfies the customer needs, and cost and schedule reflects productivity. A project is successful if it meets or exceeds the expectations on all the three fronts – that is, the project reaches completion within budget, delivers within schedule, and fulfills quality expectations. Many projects fail in ways that can be categorized as "process failure", that is, the process followed in the project was not suitable. Examples of such failures include loose requirements management, bad planning and unclear objectives, weak project management and more. Process knowledge is, therefore, key to success in choosing a set of proper process that suit the project.

More importantly, an organization should be able to replicate the success of a project and diffuse the best practices from one project to others, and produce predictable outcomes. This is the meaning of capability of an organization in (software) product development. At the organizational level, the quality and productivity depends on three factors: process, people and technology (Software Engineering Institute. CMM based Appraisal for Internal Process Improvement (CBA IPI), Team Training Material, 1996). SEI believes that process has a major effect on the quality & productivity delivered by an organization. So the capability maturity model it developed is to improve the processes used by the organization.

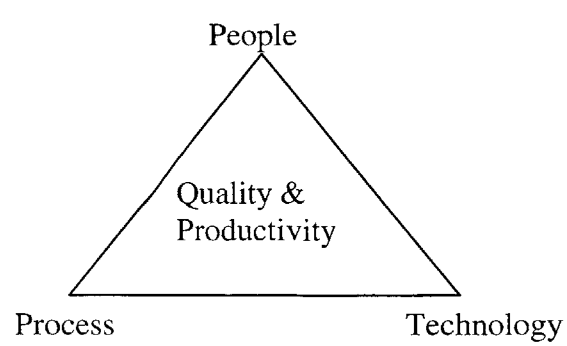


Figure 2.2. The process, people and technology triangle

2.3.2 The Capability Maturity Model

Once it is determined that improving processes are essential for an organization to deliver high-quality product while having high productivity, an important questions is: how to improve an organization's capability in product development? This is the question for which the Capability Maturity Model was developed. CMM is a framework that focuses on processes improvement. We briefly describe the CMM framework here. Details of the CMM framework can be found at [5].

Capability Maturity Model is descriptive and normative. It defines maturity as "the extent to which a specific process is explicitly defined, measured, controlled, and effective" (Paulk et al 1993). It assesses a software development organization to one of five levels of process maturity (initial, repeatable, defined, managed and optimizing). Each maturity level is a well-defined evolutionary plateau on the path to becoming a mature organization. A level provides a necessary foundation for effective implementation of processes at the next level.

The five CMM maturity levels are:

Initial Level: At the initial level, the process is characterized as ad hoc, and occasionally even chaotic. Few processes are defined, and the organization executes a project in a manner that the team and project manager sees fit. The development process is unpredictable and unstable because the process is constantly changed or modified as the work progresses or varies from one project to another. Performance depends on the capabilities of individuals or teams and varies with their innate skills, knowledge, and motivations.

Repeatable level: At this repeatable level, basic project management processes are established to track cost, schedule and functionality. The effective process discipline is in place to repeat earlier successes on similar projects, although the specific processes implemented by the projects may differ, and organization-wide process may not exist. An effective process can be characterized as practiced, documented, enforced, trained, measured and able to improve.

Defined Level: At defined level, the processes for the development at an organization have been precisely defined and regularly followed. An organization-wide process is implemented. Process for both management and engineering activities is integrated into a standardized process for the organization. All projects use an approved, tailored version of the organization's standard process. Activities are well integrated. A well-defined process can be characterized as including readiness criteria, inputs, standards and procedures for performing the work, verification mechanisms, outputs and completion criteria.

Managed level: At the managed level, detailed measures of the process and product quality are collected. Both process and product quality are quantitatively understood. And since the foundation of quantitative process management exists, the process capability can be improved in a controlled manner and the improvement can be evaluated quantitatively.

Optimized Level: At the optimized level, the entire organization is focused on continuous process improvement. Such continuous improvement is enabled by mechanisms at Level 4 to quantitatively evaluate feedback from the process and from piloting innovative ideas and technologies.

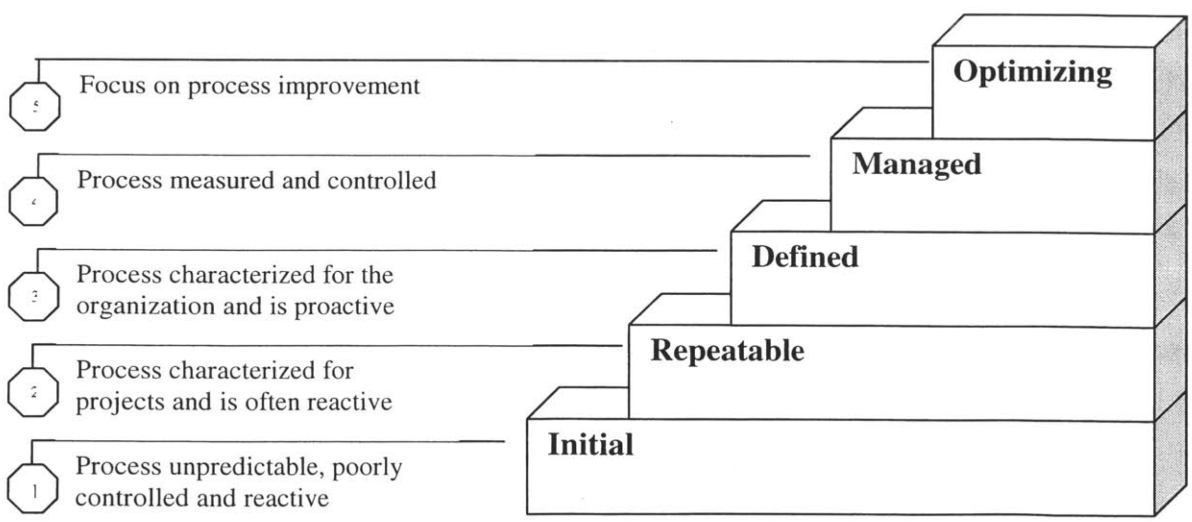


Figure 2.3 The CMM Maturity Levels

Levels are inclusive, so Level 2 practices must be essentially in place before Level 3 maturity can be achieved. Although higher maturity level processes maybe performed by organizations at lower maturity levels, with risk of not being consistently applied in a crisis.

The maturity level is indicative of process capability, and contains key process areas (KPAs). KPAs are the clusters of related practices performed collectively to achieve a set of goals. They are major building blocks in establishing the process capability of an organization. Each process area has been defined to reside at a given maturity level. The KPAs identify "what you do", where Maturity Levels identify "how well you do it".

The KPAs for the different levels can be found from reference [5]. It can be seen that most KPAs at Level 2 focus on project management, whereas the KPAs in Level 3 target instutionalization of processes and some additional processes for engineering. The KPAs at Level 4 revolve around quantitatively managing the process and projects, and KPAs in Level 5 focus on process improvement through defect prevention, technology introduction, and process enhancements.

2.3.3 Assessment of CMM & New Development at SEI

Seeking formal assessment and improvement under CMM can be time consuming and expensive. Many mangers at small and medium-sized organizations who genuinely want to improve their processes, despair at being able to draw any time or resources from their existing operation. Additionally, many small organizations rightly view the CMM as designed for large shops, thus they cannot see the direct value to them. To address this, SEI has developed "Personal Software Process (PSP)", that demonstrates the applicability and validity of the process discipline for individual efforts, and "Team Software Process (TSP)", that brings software-intensive system developers together as a team in an industry project setting. TSP and PSP are applications of CMM concepts to the micro-level of organizations.

Over the years, SEI has developed various models of CMM. Each model differs by discipline (software, systems, acquisition, etc.), structure (staged versus continuous), and ways of measuring maturity. These multiple modes have caused confusion in an organization, specifically when using more than one CMM. The CMMI is an integrated framework that uses common practices for software and system engineering. It provides integrated guidance for enterprise delivery of products and services. It also provides integrated appraisal methods for internal process assessments and external capability evaluations.

2.4 Malcolm Baldrige National Quality Awards Criteria

The Malcolm Baldrige Quality Award began in 1988 to promote quality management, or TQM, as an increasingly important approach for improving the competitiveness of American companies.

The dual goals of the Baldrige criteria are to improve value to customer, which results in marketplace success, and to improve overall financial and company performance to meet the needs of shareholders, owner, and other stakeholders. (The discussion of Baldrige Award in this research is based on Baldrige Award 1997 version).

According to the 1997 criteria booklet, the Award evaluates a company to the seven categories of criteria:

1. ***Leadership***

   The leadership category examines senior leaders' personal leadership and involvement in creating and sustaining values, company directions, performance expectations, customer focus, and a leadership system that promotes performance excellence. Also examined is how the company learns and improves continuously, and addresses its societal responsibilities and community involvement.

2. ***Strategic Planning***

   Strategic planning category examines how the company sets strategic directions, and how it determines key action plans. Also examined is how the plans are translated into an effective performance management system.

3. ***Customer and Market Focus***

   Customer and Market Focus is the focal point within the Criteria for examining how the company seeks to understand the voice of customers and of the marketplace. The Category stresses relationship enhancement as an important part of an overall listening and learning strategy. Vital information for understanding the voices of customers and of the marketplace must come from customer satisfaction results. In many cases, such results and trends provide the most meaningful information, not only on customers' views but also on their market behaviors – repeat business and positive referrals.

4. ***Information and Analysis***

   The Information and Analysis category examines the management and effectiveness of the use of data and information to support key company processes and the company's performance management system.

5. ***Human Resource Development and Management***

   The Human Resource Development and Management category examines how the workforce is enabled to develop and utilize its full potential aligned with the company's objectives. Also examined are the company's efforts to build and maintain an environment conducive to performance excellence, full participation, and personal and organizational growth.

6. ***Process Management***

   Process Management is the focal point within the Criteria for all key work processes. Built into the Category are the central requirements for efficient and effective process management – effective design, a prevention orientation, evaluation and continuous improvement, linkage to suppliers and partners, and overall high performance.

7. ***Business Results***

   The Business Results Category examines the company's performance and improvement in key business areas – customer satisfaction, financial and marketplace performance, human resource, supplier and partner performance, and operational performance. Also examined are performance levels relative to competitors.

Three factors (or evaluation dimensions) that the Baldrige Examiners look for in each section of an application are:

- Approach, the processes an organization uses to achieve quality product or services
- Deployment, refers to how broad and deep an organization's approach has been executed
- Results, only asked for in Category 7.0: Business Results.

In summary, the main objective of Baldrige Award is to improve total quality management, either in product or services. The National Institute of Standards and Technology, which administers the Baldrige, reports that of the publicly traded companies that won the award between 1988 and 1995 they returned a collective 248% in the stock market. The S&P index during the same time period showed about a 50% return. The biggest benefits of Baldrige criteria is that it provides a common framework that pulls out of all of the theories, tools, and approaches for running an effective organization. Malcolm Baldrige National Quality Award, accounts for much of their support through their use as audits of the processes of quality rather than as the basis of awards. However the Award didn't come without difficulties. Some companies that won the Awards have gone out of business or at least gotten into financial trouble even though they had exceptional levels of customer satisfaction and quality. The reason for this is that quality is only one aspect of a company's overall goal. In 1997, new standards were published to call for balance among customer satisfaction, employee satisfaction, and business results.
Furthermore, for TQM, or for a company at large to succeed, it needs to integrate its philosophies and practices into its day-to-day approach of running the business.

2.5 "Setting the PACE in Product Development" (M.E. McGrath et al., 1995)

Pittiglio Robin Todd & McGrath (PRTM) initially developed the *Product Cycle-time Excellence* (PACE) product development process in 1986. PACE was developed as an integrated approach to product development to address the deficiency of lacking concept, philosophies, and techniques for manufacturing. Over the years, PACE has become a popular process reference model for product development in many companies. It provides a common framework, standard terminology, industry-wide process benchmarks, a way of updating best practices, and a process for continuous improvement.

2.5.1 The Approach

PRTM draws a comparison of improvement in manufacturing in 1980s with improvement of product development in 1990s. They argue that there are many similarities between the change that took place in manufacturing in 80s and the changes taking place in product development in 90s. They think that the advantage of cutting time-to-market in half and consistently developing better products are so significant that the competitive balance in some industries is changing in favor of companies that can achieve these goals first. And these goals can only be achieved by redefining the underlying process using new management concepts, since a superior product development process is the only sustainable source of product advantage.

The benefits of improving product development process can be seen in financial (increased revenue), productivity (improved product development productivity, and operational (operational efficiency):

- An improved product development process can increase revenue by increasing product life-cycle revenue, improving market penetration, enabling success in time-sensitive market, and creating more successful product.
- An improved product development process can increase productivity by shortening development cycle times, reducing wasted development, improving resource utilization, and attracting technical talent.
- It can also improve other operational efficiencies by incorporating design for manufacturability, encouraging higher quality products, reducing the number of engineering change orders (ECOs), and improving the predictability of release.
- Achieved together, the benefits of an improved product development process can establish a significant competitive advantage.

2.5.2 The Seven Elements of Product Development Process

PACE views the process of product development as seven interrelated elements. They are decision-making, project team organization, development activity structure, development tools and techniques, product strategy, technology management, and pipeline management. Within each of these elements, there are issues to be addressed, and problems & deficiencies to be overcome to improve the overall product development process. The PACE architecture defines product development as an integrated process in which sub-processes, organizational structures, development activities, techniques, and tools work together with in a single overall framework.

Decision Making

Decision-making is the process that determines what product to develop and how development activities are organized. It helps the senior management lead the product development, and empowers project teams to develop the new product. Despite its importance, many companies don't have a formal decision-making process, or it is ineffective. To overcome such ineffectiveness, PACE defines a 5-phased process - Phase Review Process (PRP), and a formally designated product approval group - Product Approval Committee (PAC) that participates in the review process. The PAC makes decisions and allocates resources through the Phase Review Process for the new product development and investment. It typically consists senior management members.
PRP drives the other product development processes within PACE. It is the process wherein senior management makes various decisions. PRP consists 5 review phases: concept evaluation, planning & specification, development, test & evaluation and product release. At each review phase, actual performance is compared and critical decisions are made by the PAC.

Project Team Organization

Project team organization is one of the most essential elements to the success of a development project. It is where people work together and create the product. An effective project team organization should have the right communication and coordination mechanism, and a collective decision-making process. The problem with many project teams is that its structure, roles, and responsibilities were not clearly defined. PACE advocates Core Team concept where key members in this team coordinate their activities, communicate what they are doing, and collectively making decisions.

Development Activity Structure

Development activity is the actual work that takes place to develop a new product. Many companies don't get this right because, (1) companies are without any defined structure for product development, (2) those with detailed procedure manuals weren't followed, and (3) those with detailed procedure did not improve or speed the development. PACE' solution to these problems is to implement a well balanced and structured product development process with phases in response to that of Phase Review Process.

Development Tools and Techniques

Historically, improvement to the product development process have focused on the application of various design techniques and automated development tools. Unfortunately, many companies find that ROI in these development tools and techniques is minimal. The reasons for such poor return stem from to general sources: (1) companies were not applying the right techniques and tools, (2) they were applying them ineffectively because them do not have an overall product development process, or (3) had wrong measurements.

PACE doesn't provide another new tool for product development. It emphasizes on applying the right technique, or tool at right time, and within the context of an overall product development process.

Product Strategy Process

Product strategy is the starting point for the development of new products. PACE sees the problem as: (1) disconnection between product strategy and development projects) Product selected for development is not consistent with overall product strategy, (2) learn what fits and what doesn't by trail and error, not clear strategy.

Solution: PACE Strategy framework

Technology Management

The function of technology management is to identify opportunities for applying new technology, and initiate technology-development projects that further the company's core competencies and benefit multiple products. But many technology-based companies do not proactively manage their underlying technologies.

The technology management element within PACE defines the process for technology development and the transfer of technology to product development.

Pipeline Management

Definition: Better management across all product development projects over a defined time horizon.

Problems: (1) contention for scare resources across projects (2) misalignment between project skill requirements and departmental resources.

PACE developed a framework for project prioritization, cross-project resource management, and aligning functional capabilities and project requirement.

2.5.3 The PACE Architecture

The PACE architecture can be viewed as seven interrelated elements that are grouped along two dimensions: project management and cross-project management. Four elements: Phase Review Process, Core Teams, Structured development process, and development tools & techniques forms the basic foundation of PACE, and fall into the dimension of project management.

The next three elements: product strategy, technology management, and pipeline management provide the infrastructure necessary to manage the product development portfolio and integrate it within the enterprise as a whole.

3. Research Design and Survey Descriptive Statistics

3.1 Research Approach

Past research work has shown that more and more companies have come to realize the importance of processes in product development, and have implemented process improvement tools or instruments in one way or another. PRTM's "Product Cycle-Time Excellence" is one such tool that aims to improve an organization's product development process in seven areas. Processes (or elements, termed in PACE) such as effective decision-making and product strategic planning, as well as other five major processes, are essential to achieve best business results and sustain competitive advantage. In Software Engineering Institute at Carnegie Mellon University, a framework called Capability Maturity Model (CMM) was developed to improve product development capability in software initially. In the model, it helps to identify key process areas in software development and categorized them into five levels of maturity. Companies are then assessed based on their practices and performance in each key process area against defined maturity levels starting from 0.

Each model or assessment instrument reviewed in previous chapter emphasizes a set of product processes from different perspectives. If we were to improve organization's product development capability, we must first identify processes that are involved in product development, and furthermore we need to answer questions as:

- How important is each process to product development success,
- Are these processes important in different ways,
- And how capable is an organization at each of these processes.

What are the processes in product development?

A process is a series of actions or operations to achieve a given goal. A product development process typically involves formal/informal interactive steps/mechanisms implemented to achieve desire outcome (e.g. product). In other words, the two main characteristics of a process are goal achieving and execution. It is about to achieve a high level statement of outcome by effective implementation of a group of practices.

Examples of processes in product development include, such as product strategic planning process, technology transfer and management process, product quality assessment and control process, etc.

It is rarely in a product development setting that only one process or activity is involved. Typically a set of processes is implemented by an organization for its product development. For example, a product development project at a software outsourcing company involves a flow of processes depicted in Figure 3.1.

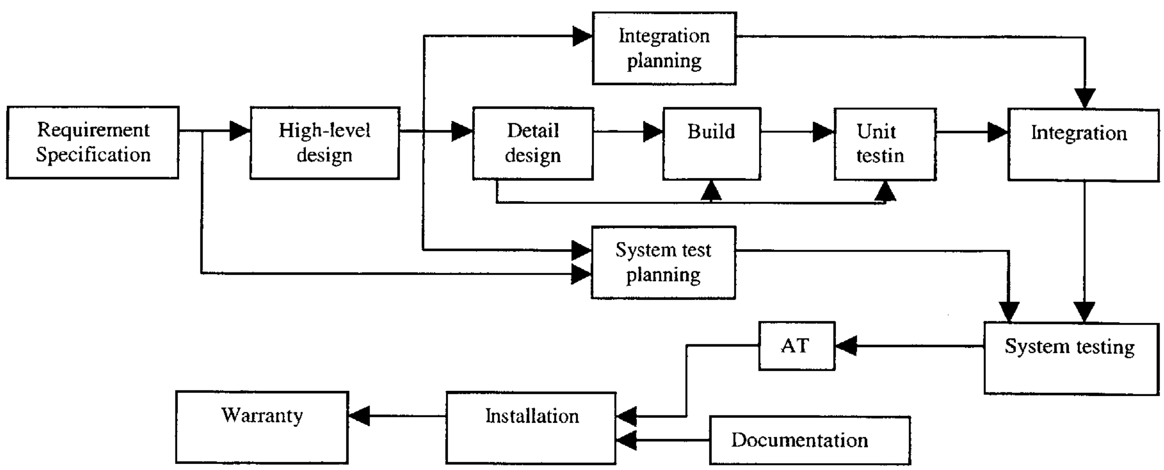


Figure 3.1 Development Process

Processes involved in product development may vary from one industry to another, from one company to another, or even from one project to another within a company. Variations may arise due to the nature of the product to be developed; it may also arise due to a company's incapability for implementing consistent processes. It is therefore a critical first step in determining processes in various settings. This would help us in the next steps to not only identify what are the specific and what are common processes in product development, but also provide us a good foundation in study the impacts of various factors to an organization's product development process capability.

In this research, 352 product development processes were initially identified from literature review. These processes are either from academic research that had been identified to be important in product development or best practices in industry.

Table 3.1 shows various sources of these processes.

Authors	Publication	Key findings	# processes
M.E. McGrath	Setting the PACE in Product Development	Proprietary 7 elements product development process model: includes decision-making, technology management, pipeline management, etc.	**54**
Malcolm Baldrige National Quality Awards(MBNQA)	Malcolm Baldrige National Quality Awards Criteria NIST	A "comprehensive" assessment tool to address business process effectiveness from a business and quality management perspective.	**86**
PDMA	The PDMA handbook of New Product development	A phase based product development process	**49**
MIT LAI Center	Lean Aerospace Initiative, MIT	"A lean enterprise is an integrated entity which efficiently creates value for its multiple stakeholders by employing lean principles	**56**
Arthur Andersen	Global Best Practices	A proprietary benchmarking tools that cover 10 majors areas of product development.	**201**
K.N. Otto	PERFORM Process Assessment Product Genesis Inc.	A Malcolm Baldrige based, seven-category project management assessment tool. Considers platform and product complexity issues.	**76**
Xerox	Xerox Engineering Excellence Process Strategy	A matrix based model to assess product development process	**120**
V. Krishnan, K.T. Ulrich	Product Development Decisions: A Review of the Literature	Product development in the perspective of decision-making. Comprehensive review of the literature.	**65**
S.L. Brown, K.M. Eisenhardt	Product Development: Past Research, Present Findings, and Directions	Product development as rational plan, communication web, and disciplined problem solving. Comprehensive literature review.	**98**
University of Cambridge	Speeding New Products to Market	A framework for new product development process improvement.	**135**
R.G. Cooper, E.J. Kleinschmidt	Benchmarking the Firm's Critical Success Factors in New Prod. Dev.	Overall new product performance measured program profitability and program impact.	**43**
CMU SEI	Capability Maturity Model Integration (CMM)	A reference model of mature practices in a specific discipline, used to assess a group's capability to perform that discipline.	**78**
V. Chiesa, P. Coughlan, C.A. Voss	Development of a Technical Innovation Audit	Framework to audit technical innovation. Four core processes: concept generation, product dev., process innovation, and technology acquisition.	**45**

Each source listed above covers one or more areas in product development. For example, in Brown & Eisenhardt's review article, it focuses in the areas of rational plan, communication, and disciplined problem solving. The processes abstracted in this source, therefore, lean towards those that deal with planning, internal & external communication, and organizational structure. In Malcolm Baldrige National Quality Awards, its assessment tool address process effectiveness from seven business and quality management categories. Altogether, these resources provide us a comprehensive list of processes implemented in product development.

To better serve further study and analysis of issues in product development, these 352 processes were combined and compressed down to140 to cover the full spectrum of product development processes. (A list of 140 processes can be found at appendix A).

How important is each process to product development success?

Not all the processes are equally important. Some processes play critical roles in the success of product development. Some processes, on the other hand, are implemented in support of other processes. Although they all contribute to the success of product development in one way or another, it is obvious their importance may vary in the course of product development as well as in the development of different products.

Determine important levels for different processes benefit an organization's product development effort in three fronts. First, it helps an organization to identify critical areas to tackle in product development, and prioritize tasks accordingly. It helps to cut development time, and therefore shorten new product's time-to market. Secondly, it helps an organization to efficiently allocate scarce resources, and lead to minimizing development cost and increasing productivity. As product development becomes more and more complex, and competition becomes more and more fierce, delivering product within schedule, cutting cost, and improving productivity are critical to the success of a project. Last, but not least, it helps an organization to identify best practices in its product development, and apply them other projects.

In this research, we defined importance of a process in the scale from 1 to 7, where 1 denotes not important, and 7 denotes extremely important. To ground the scale, each 7-point scale is also calibrated with 4 objective descriptors. Table 3.2 gives the description of each objective descriptor.

Extremely Important	**Scale 7**
1. Non-negotiable to meet customers', stakeholders', and competitive requirements. 2. Relentlessly inspected by my senior management. 3. Failure implies vast infusion of unplanned resources.	
Very Important	**Scale 5**
• High priority, but negotiable. • Reviewed on exception by senior management. • Failure recoverable with incremental resources.	
Somewhat Important	**Scale 3**
• Nice to have. • Delegated to trusted employee/manager. • Failure recoverable with only extra effort.	
Not Important	**Scale 1**
• Will not spend time or resources on this. • Not cost-effective to address.	

Table 3.2 Definition and description of process "Important" levels

Are these processes important in different way?

Process can be different in term of the levels of importance, it can also be affected by different factors. A company with more than 10,000 employees could weight the importance of a process quite different from a company with less than 100 people. An automobile company may have some specific processes that don't fit into the product development process in software industry. There are many factors, such as the company size, the industry sector that the company is in, and the experience of the people that participate the development project, which could impact the important level of a process in product development.

Determining what factors influence the rating of each process will enable us to design and develop effective models to fit different organizations' need and capability.

The research of this thesis has been primarily focused on three factors:

- The size of a company or an organization
- The industry sector that a company is in
- The professional experience of members in a product development project

The reasons that these three factors are chosen are because, first, past researches show that those three factors have impacts in the success of a project; second, these three factors are all quantifiable, which lead to reliable analysis; third, it is relative easy to obtain data on these factors.

How capable is an organization at each of these processes?

Capability is defined as "A talent or ability that has potential for development or use, or the capacity to be used, treated, or developed for a specific purpose (The American Heritage® Dictionary of the English Language). An organization's capability in product development is its ability to consistently succeed in developing new products through effective and sustainable processes.

Determine the difference between capability of an organization and importance of processes in product development reveals the gap between the current and desired performance, identifies where are the problems and needs, and provides information that can be used in developing action plans to improve performance.

Determine capabilities in product development will benefit an organization to achieve desired outcome of product development projects in a predictable way and to sustain competitive advantage in the long run.

To evaluate an organization's capability, a scale of 1 to 7 was defined. Whereas 1 denotes "not capable", and 7 denotes "extremely capable". Each 7 point scale is also calibrated with 4 objective descriptors to ground scale. Table 3.3 gives the definitions and descriptions of each objective descriptor.

Extremely Capable	**Scale 7**
• Produces unprecedented performance. • Redefined the process and practice. • Are disruptive to competitors.	
Very Capable	**Scale 5**
• Produces benchmark results. • Is supported by integrated engineering, cross-functional teams and processes • Has visible strong senior management leadership.	
Capable	**Scale 3**
• Produces acceptable and predictable results • Have islands of local practice and optimization. • Follows conventional practices	
Not Capable	**Scale 1**
• Produces acceptable results, but not consistent. • Isolated and inconsistently practiced. • Skill not widely available in the organization.	

Table 3.3 Definition and description of organizational capability

3.2 Questionnaire Construction

Having developed the research methodology, we next need to translate it into a detailed survey to collect data and serve as the basis of further analysis. The intent and survey goal can be summarized as follows:

- Acquire quantitative data about the "importance" of processes and "capability" of an organization in product development
- Collect data on factors that influence the level of importance of each process and the level of capability that each organization is at in each process
- Verify the processes drawn from literature review have covered the full spectrum of product development

As such, the survey can have two dimensions: an "importance" assessment and a "capability" assessment. And based on the research goal, a survey should meet the criteria of:

- Compressive list of processes relevant to product development
- Capable to measure process' "importance" and organizational "capability" quantitatively
- Well defined descriptions of "importance" and "capability" levels
- Including factors that influence the determination of process importance and organizational capability.

The mechanism of constructing a survey questionnaire involves several steps:

Step 1. Identify product development processes from literature reviews

As we mentioned in previous section, literature review exercise resulted in the initial 352 processes. This list is said to be comprehensive since it draws processes from two general fronts: the extensive research work in the product development and the best practices from industry leaders. The 352 processes were further combined and compressed into 140 to generate a manageable list of processes for surveying purpose. (Figure 3.2)

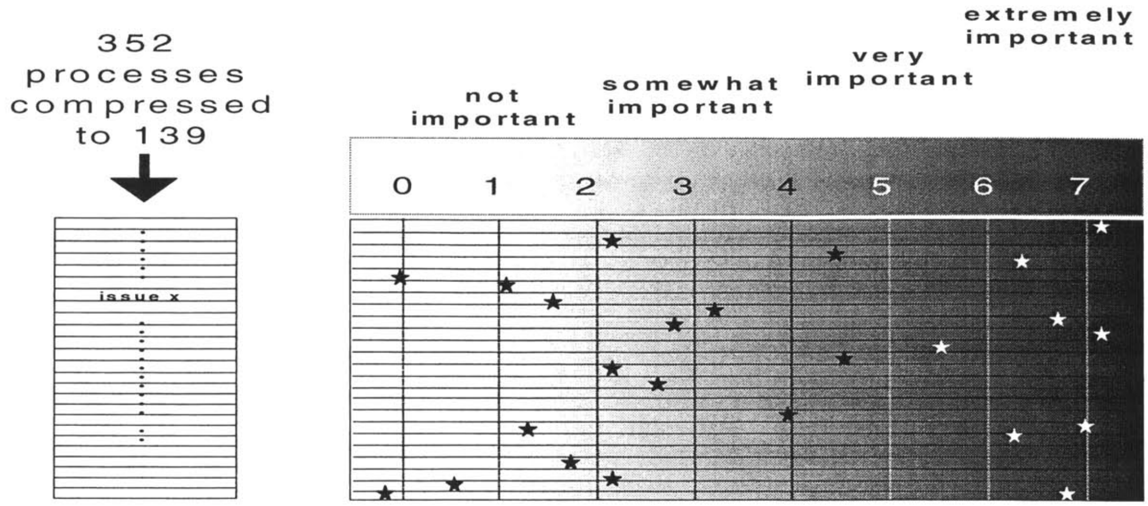


Figure 3.2 Processes compression process

Step 2. Design scales of importance and capability

Two assessment questions asked for rating each process in the survey are:

- How important is each to achieve success in product development, and
- How capable is your company at each.

Each process was assessed against these two questions by the scales of 7, where 1 is the lowest score and 7 is the highest score. The scales are also calibrated with 4 objective descriptors described in table 3.2 and 3.3.

Step 3. Randomize processes

The purpose of randomization is to make sure that all processes would be assessed equally. Two steps were taken:

1. The 140 issues were randomized before divided into four groups: A, B, C, and D, each of which contains 35 prcesses
2. The groups were paired up and combined into AB, AC, AD, DC, BD, and CD, to generate 6 sets of questionnaires.

A sample page of questionnaire is shown in Figure 3.3.

	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. Determining the organization's ability to market the product	1	2	3	4	5	6	7	1	2	3	4	5	6	7
2. Meeting projects financial goals	1	2	3	4	5	6	7	1	2	3	4	5	6	7
3. Benchmarking	1	2	3	4	5	6	7	1	2	3	4	5	6	7
4. Deployment of strategies to achieve product modularity	1	2	3	4	5	6	7	1	2	3	4	5	6	7
5. Performance optimization of the entire supply-chain	1	2	3	4	5	6	7	1	2	3	4	5	6	7
6. Specifications of supply-chain design parameters	1	2	3	4	5	6	7	1	2	3	4	5	6	7
7. Establishing market test and launch plans	1	2	3	4	5	6	7	1	2	3	4	5	6	7
8. Selection of technology for the product	1	2	3	4	5	6	7	1	2	3	4	5	6	7
9. Selecting the development process to fit the product	1	2	3	4	5	6	7	1	2	3	4	5	6	7
10. Maintaining a repertoire of methods, tools, and techniques for development	1	2	3	4	5	6	7	1	2	3	4	5	6	7
11. Developing mechanisms for internal task coordination	1	2	3	4	5	6	7	1	2	3	4	5	6	7

Page 1

Figure 3.3. A sample page of survey

Step 4. Determine factors that influence the importance of processes and capability of an organization

The last page of the questionnaire was designed to ask participants filling out background information about their company (size, performance, etc.), the industry sectors, the professional experience, and contact info. Most information from this page can be used as the basis of factor analysis.

- **Company size by employees:**

100 ---- 500 ---- 1000 ---- 1500 ---- 2000 ---- 2500+

- **Industry sector of your firm** ____________________

- **How successful would you say your company has been recent years in these areas?**

	poor		average		very good		exceptional
Market share results	1	2	3	4	5	6	7
Profitably	1	2	3	4	5	6	7
Customer satisfaction....................	1	2	3	4	5	6	7
Organizational effectiveness..........	1	2	3	4	5	6	7
Product Quality	1	2	3	4	5	6	7

- **Your years of professional experience** ______ **years**

- **% of your professional experience in ....**

planning	____ %	**design**	____ %
development	____ %	**integration and test**	____ %
sales/consulting	____ %	**maintenance and support** ...	____ %

- **Optional (privacy is guaranteed)**

I want to receive updates and to participate in the research ______yes______no

Name ____________________

e-mail ____________________ **phone** ________-________-__________

3.3 Data Collection & Descriptive Statistics

3.3.1 Data Collection

Given the scope of this research, a large amount of data needs to be collected and analyzed in order to derive valid conclusion.

The first round of survey was conducted during the MIT CIPD Conference in October 2002. The questionnaires were distributed to participants in MIT CIPD conference. A total of 92 people participated in the survey, and 83 valid responses were received.

3.3.2 Demographics Statistics

The respondents of the survey were participants in MIT CIPD Conference. Most of people participated in this conference are frontline engineering personnel who confronted with product development and project execution, and middle to senior managers who manage an organization's R&D division.

The respondents come from a wide range of industry sectors, 17.6% are from automobile industry, 15.3% from electronic industry, and 14.1% from manufacturing industry. The respondents from top three sectors represent roughly one half of all respondents. (See Figure 3.4)

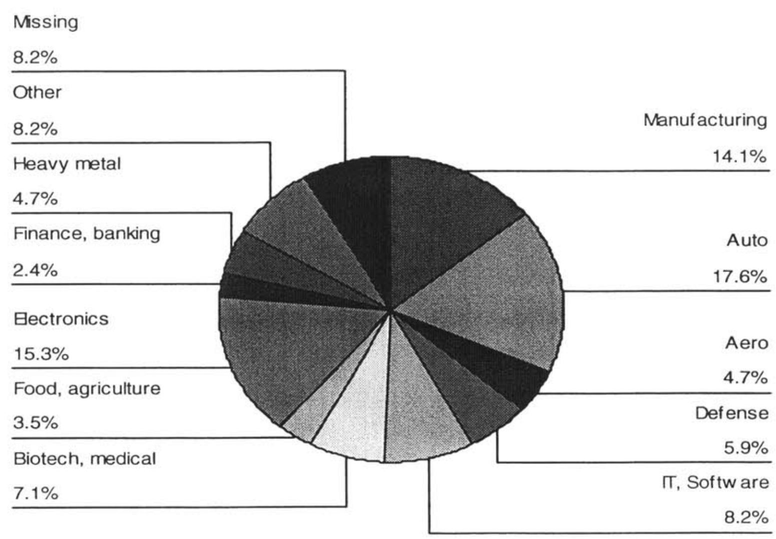


Figure 3.4 Distribution of respondents by Industry Sectors

Of the company's size, 62.7% of the respondents are from companies with more than 2500 employees, 19.3% of those are from middle size company with number of employee between 500 and 1500, 18% of those are from companies with less than 500 employees. (See Figure 3.5)

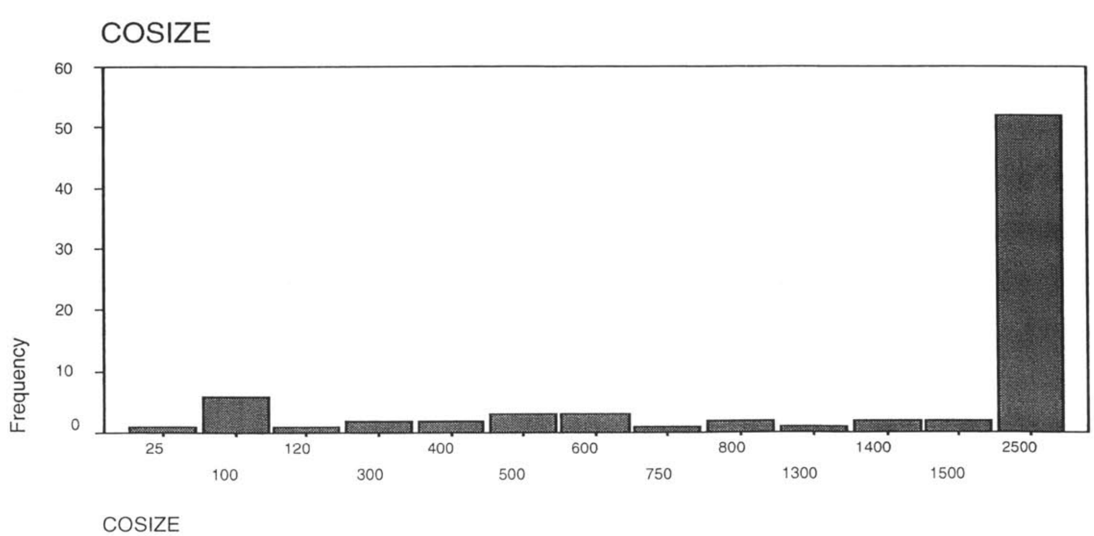


Figure 3.5 Distribution of respondents by company size

The respondents' professional experience spans from 2 years to over 37 years. The average experience of respondents is19.6 years. (See Figure 3.6)

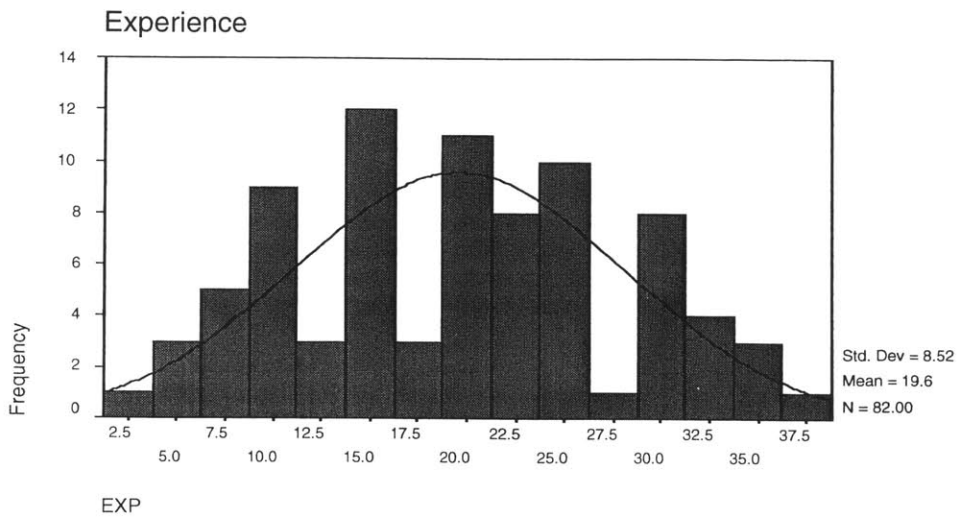


Figure 3.6 Distribution of respondents by professional experience

In summary, respondents for this survey have substantial experience in product development, work primarily for large companies and organizations.

3.4 Data Analysis

3.4.1 Descriptive Statistics in Regarding of Process Importance

After cleansing the survey data for missing variables and invalid cases, the following statistics analysis of the survey responses was conduct using the SPSS statistics analysis software.

Ten Most Important Processes (by all respondents)

Table 3.4 shows the ranking results of " Ten Most Important Processes" out of 140 by all the survey respondents. (Refer to Appendix B for the full list of ranking). The No.1 most important process is "Product Testing" with average score of 5.97, and standard deviation of 1.16.

	Descriptive Statistics	N	Min	Max	Mean	Std. Dev.
1	Product testing	36	1	7	5.97	1.16
2	Product validation	46	3	7	5.91	0.94
3	Regulatory compliance	41	2	7	5.88	1.25
4	Making appropriate levels of resource commitments, people and dollars	37	4	7	5.86	0.82
5	Decision making in development process	37	3	7	5.86	0.95
6	Maintaining knowledge of the competitive environment	42	3	7	5.86	1.14
7	Establishing, maintaining customer relationships	39	1	7	5.85	1.20
8	Development of program schedule	36	3	7	5.75	1.05
9	Determining the product's competitive advantages	46	2	7	5.72	1.11
10	Promotion of a culture that supports teamwork	43	3	7	5.70	0.91

Table 3.4. Ten most important processes (by all respondents)

The list indicates what processes were considered to be important in the product development in general. It can be derived that people view a process to be important if it falls in one of three categories:

- It is traditionally viewed as vital to the successful of product development. Example of such processes is "Development of program schedule".
- The process is universal practices no matter what industry the company in, or what product the company is developing. "Product testing", for example, is the process that almost all the companies have implemented.
- The processes that are required by regulation. Such as "Regulatory compliance".

Ten Least Important Processes (by all respondents)

Table 3.5 shows the ranking results of " Ten Least Important Processes" out of 140 by all the survey respondents. (Refer to Appendix B for the full list of ranking). The least important process is "Producing curriculum materials and content for engineering and product development training and education" with average score of 4.17, and standard deviation of 1.43.

Descriptive Statistics	N	Min	Max	Mean	Std. Dev.
140 Producing curriculum materials and content for engineering and product development training and education	47	1	7	4.17	1.43
139 Establishment of a product end-of-life strategy	46	1	7	4.24	1.69
138 Co-location of the PD team	34	1	7	4.26	1.80
137 Specifying product evolution roadmap specification	38	0	6	4.39	1.52
136 Improving work environment	37	2	6	4.41	1.04
135 Making the correct make-buy decisions	38	1	7	4.42	1.18
134 Measuring and managing manufacturing complexity	36	1	7	4.47	1.66
133 Demanding management unity	37	1	7	4.49	1.52
132 Having and using a knowledge management system	36	1	7	4.50	1.81
132 Making good use of project performance metrics	38	0	7	4.53	1.47

Table 3.5 Ten least important processes (by all respondents)

It shows that these processes fall roughly into three general categories:

- They are processes that play more of supporting role in the whole product development process. Example of such processes are "Producing curriculum materials and content for engineering and product development training and education", and "Improving work environment".
- They are processes that are traditionally not emphasized or not focused in the product development function. Example of such process is "Specifying product evolution roadmap specification", which traditionally view as a marketing function beyond product development.
- They are processes that are new to product development. Such as "Having and using a knowledge management system".

Future research will focus on distinguishing processes from different causes, and propose action plans accordingly.

Ten Most Agreed Important Processes in Product Development (by all respondents)

In regarding the agreement of important processes, respondents tend to agree most upon those processes listed in Table 3.6.

	Descriptive Statistics	N	Min	Max	Mean	Std. Dev.
1	Having and using a knowledge management system	36	1	7	4.50	1.81
2	Co-location of the PD team	34	1	7	4.26	1.80
3	Defining a multinational and international orientation for the product	36	1	7	4.67	1.77
4	Developing strong and formal ties between suppliers and R&D	37	1	7	4.59	1.77
5	Designing the product to meet social responsibilities	36	1	7	4.53	1.73
6	Setting the balance of projected revenues between old and new products	36	0	7	4.75	1.73
7	Establishment of a product end-of-life strategy	46	1	7	4.24	1.69
8	Measuring and managing manufacturing complexity	36	1	7	4.47	1.66
9	Proactive management of public concerns about the product or project	46	1	7	4.61	1.65
10	Fostering innovation and sharing knowledge throughout the supplier network	37	1	7	4.73	1.57

Table 3.6 Most agreed processes

Figure 3.7 below shows 'importance" vs. "agreement" of 140 processes. The average scores ranges from 4 to 6, and the standard deviations scales from 0.75 to 1.95.

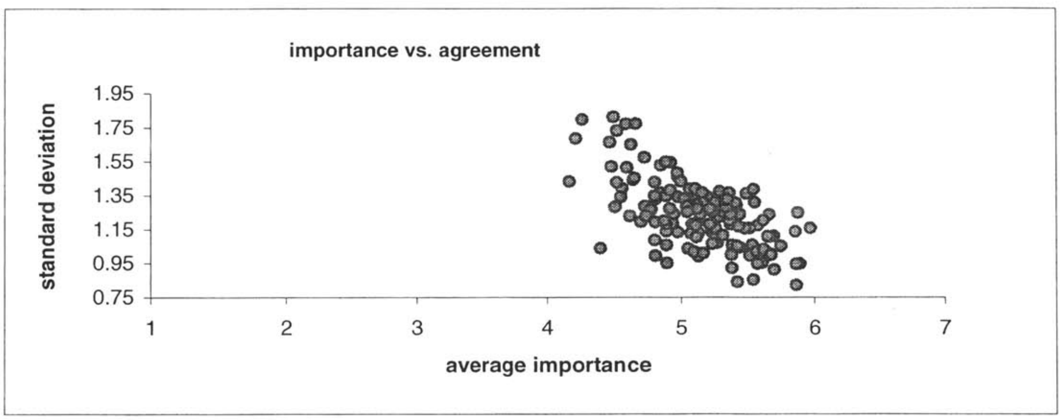


Figure 3.7

It is interesting to notice that none of the average scores fall below 4. This indicates that the processes were chosen are indeed relevant to the product development.

3.4.2 Factor Analysis of Important Processes

The purposes of factor analysis are:

- To find out what factors influence the determination of important level in product development processes, and
- To find out how they influence the product development processes

In the research that has been done so far, two factors, the company size and respondents' professional experiences, were studied extensively in the course of evaluating process important. Further discussion of correlations of these two factors in product development will continue in Chapter 4.

Important Processes by Company Size

The sample data from the survey was divided into three groups based on the size of the companies that respondents were coming from. Figure that right shows the breakdown of data into three size groups. The "large" company is defined as having 2500 and more employees. This is the largest group of three, 63% of respondents were from those companies. The "middle" is the company with number of employees from 500 to 2500. 13% of the respondents in survey were coming from this type of companies. The "small" is the company with less than 500 employees. About 18% of respondents are from small companies. 6% of respondents didn't provide the company size information.

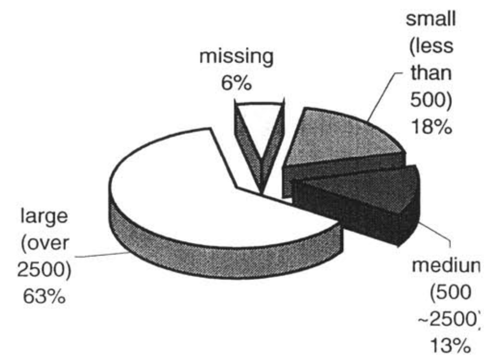


Table 3.8 shows the ranking results of top ten important processes by three "company-size" groups.

Small (less than 500)	Medium (500~2500)	Large (more than 2500)
Product testing	Regulatory compliance	Decision making in development process
Identifying new candidate technologies	**Product testing**	Product validation
Forecasting technology trends	Maintaining knowledge of the competitive environment	Establishing, maintaining customer relationships
Delegating power to the project leader	Coordinating market and product strategy to optimize financial results	Formulating a consistent business strategy for the product
Making appropriate levels of resource commitments, people and dollars	Setting financial metrics for the project includes for example, product cost, margin, revenue, life-cycle costs and expenses	Selecting capable project leaders
Decision making in development process	Setting the product's pricing strategy	Maintaining knowledge of the competitive environment
Obtaining and using customer feedback throughout product development	Defining the functional content of the product	Regulatory compliance
Product validation	Promotion of a culture that supports teamwork	Assigning clear responsibilities to each team member
Development of program schedule	Development of program schedule	Understanding the value chain of the product
Assigning clear responsibilities to each team member	Making appropriate levels of resource commitments, people and dollars	**Product testing**

Table 3.8 Importance rankings by different company size

It shows that the ranking of importance of product development processes varies based on the size of respondents' hosting companies. Some of the processes are on the list of all three or at least two "size" groups. One process in particular, product testing, is among the top ten list of all three. This is not a surprise as it was rated as No.1 by all respondents. It can be seen that different size groups weight importance of processes from different perspectives. For example, respondents from "small" companies are concerned about "delegating power to the project leader", where those from "large" companies are concerned more about "selecting capable projects leaders", Although these two processes are closely related, they are presented in the different way.

Figure 3.8 shows the distribution of top ten important processes by three size groups. It is interesting to observe the larger the company is, the higher the scores of each processes would be given in general, but the standard deviations tend to fluctuate less. One possible explanation maybe because large companies normally have well established rules and procedures for the product development. The 140 processes captured in this research reflect more of these processes in large sized companies than of small sized companies. Besides, processes in small sized companies may not be stipulated as formal as those in large sized companies. So opinion on what's important and what's not diverges more for people from small sized companies.

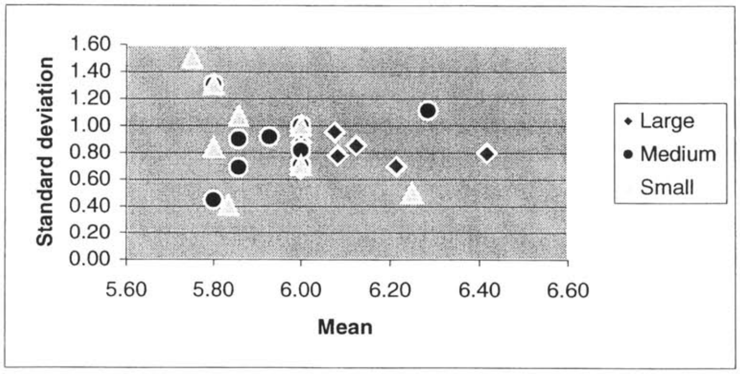
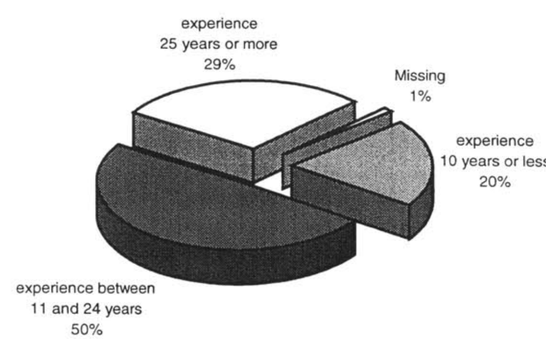


Figure 3.8 Distribution of most important processes by different company sizes

Important Processes by Professional Experience

The sample data can also be studied based on the respondents' professional experience. In our research, the sample was divided into three "experience" groups: "Less experienced" are those with less than 10 years experience, "experienced" are those with 11~24 years experience, and



"Most Experienced" are those with 25 years or more experience. "Less Experienced" represents 20% of all respondents; "Experienced" represents 50% of all respondents, and Most Experienced" respondents 29% of all respondents. There are 1% of respondents that didn't indicate their professional experience, and we exclude those samples from our analysis.

Table 3.9 shows the top ten of the processes rated by three different 'experience" groups.

10 years or less	Between 11 ~ 24 years	25 years or more
Transitioning products to production.	Product testing	Establishing, maintaining customer relationships
Regulatory compliance	Product validation	Maintaining knowledge of the competitive environment
Translating strategy into actionable initiatives	Making appropriate levels of resource commitments, people and dollars	Product testing
Maintaining knowledge of the competitive environment	Decision making in development process	Making appropriate levels of resource commitments, people and dollars
Formulating a consistent business strategy for the product	Assigning clear responsibilities to each team member	Gathering and using customer satisfaction data
Setting a clear role for senior management in product development	Regulatory compliance	Selection of technology for the product
Choosing cross functional representation PD team	Development of program schedule	Development of program schedule
Selecting capable project leaders	Promotion of a culture that supports teamwork	Decision making in development process
Employee retention	Defining the functional content of the product	Selecting experienced project leaders
Determining the organization's ability to deliver the technology	Building the technical proficiency of the development team	Selecting capable project leaders

Table 3.9 Comparison of top ten important processes by three "experience" groups

Figure 3.9 shows the mean vs. standard deviation of top ten processes in all three groups.

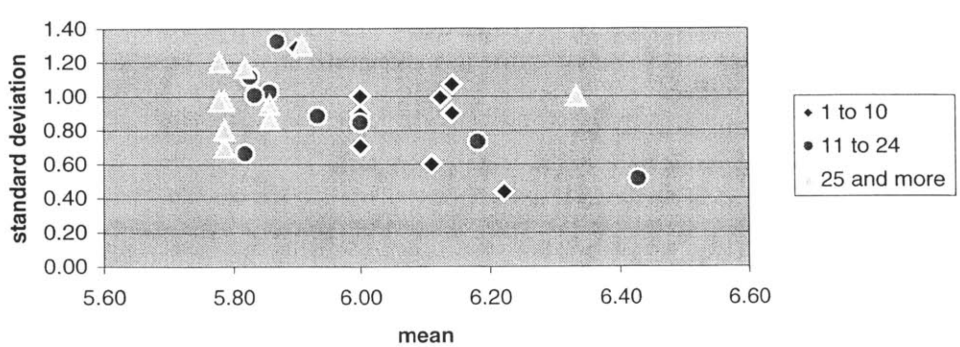


Figure 3.9 Distribution of most important processes by different experience groups

3.4.3 Descriptive Statistics in Regarding of Organizational Capability

The same statistic analysis has been applied to the evaluation of organization's capability as well:

Top Ten Processes that Organizations' Are Most Capable (by all respondents)

	Descriptive Statistics	N	Min	Max	Mean	Std. Dev.
1	Regulatory compliance	41	2	7	5.46	1.21
2	Product testing	34	3	7	5.21	1.09
3	Integration of health and safety and environmental issues and requirements in product development	39	1	7	4.92	1.40
4	Defining the functional content of the product	42	1	7	4.83	1.48
5	Establishing, maintaining customer relationships	39	1	7	4.77	1.39
6	Product validation	45	2	7	4.73	1.42
7	Focusing on continuous improvements	38	1	7	4.63	1.34
8	Selection of technology for the product	45	1	7	4.62	1.32
9	Establishing mechanisms for project progress monitoring and control	43	2	6	4.51	1.16
10	Maintaining knowledge of the competitive environment	42	2	7	4.50	1.33

Table 3.10 Most Capable Processes

Ten Processes That Organizations Are Least Capable (by all respondents)

	Descriptive Statistics	N	Min	Max	Mean	Std. Dev.
140	Establishment of a product end-of-life strategy	44	1	6	3.23	1.33
139	Having and using a knowledge management system	35	1	7	3.34	1.41
138	Promotion of risk taking with appropriate rewards	36	1	6	3.36	1.33
136	Developing strong and formal ties between suppliers and R&D	36	1	5	3.36	1.31
137	Fostering innovation and sharing knowledge throughout the supplier network	36	1	6	3.36	1.27
135	Specifying product evolution roadmap specification	37	1	6	3.38	1.19
134	Having senior management set cultural and behavioral norms for product development process	46	1	6	3.41	1.20
133	Motivating breakthrough ideas	36	1	7	3.42	1.36
132	Building the marketing proficiency of the development team	38	1	6	3.42	1.39
131	Making project operational data readily accessible	37	1	7	3.46	1.24

Table 3.11 Ten processes that organizations are least capable

The ten least processes that organizations are capable at can be observed in two ways:

- The organization don't recognize it's important (or lower down the list), or relevant to product development, so don't make much efforts in these.
- Simply not capable, such as "Motivating breakthrough ideas"

4. Hypothesis Testing

4.1 Kruskal-Wallis Analysis

Kruskal-Wallis one-way analysis of variance by ranks is a statistical method for detecting differences among several groups (k) of samples. Its application is the most commonly used test in various areas, including biology, psychology, sociology, economy and many others. Kruskal-Wallis test decides whether the differences among the k samples signify genuine population differences or whether they represent merely chance variations such as are to be expected among several random samples from the same population. The non-parametric Kruskal-Wallis technique we use in this paper has the null hypothesis that the k samples come from the same population.
The rationale of the Kruskal-Wallis test is that when all the data points were drawn from the same population, the values in each of the k sample groups follow the same distribution. Thus the differences of the sum of the ranks of values among sample groups are merely the result of randomness in measurement or collection, following a chi square distribution.

In the computation of the Kruskal-Wallis test, each of the data points (N) are replaced by ranks. All of the scores from all of the k samples combined are ranked in a single series, with the smallest score ranking first. The Kruskal-Wallis test determines whether the sum of the ranks in each sample group are so disparate that they are not likely to have come from samples drawn from the same population. It can be shown that if this is true, then H defined as below is distributed approximately as chi square with degree of freedom $df = k - 1$.

$$H = \frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_j^2}{n_j} - 3(N+1)$$

where k is the number of samples

n_j is the number of cases in the j th sample group

N is the number of cases in all sample groups combined

R_j is the sum of ranks in j th sample group

If the observed value of H is equal to or less than the value given by chi square distribution for the previously set level of significance and degree of freedom, then the null hypothesis may be accepted at that level of statistical significance.

4.2 Hypothesis 1

Correlation exists between the importance of product development processes and the length of experience of those participated in product development

As we observed from the findings and the preliminary analysis in Chapter 3, the importance of processes varies from one experience group to another. In order to test hypothesis 1, Kruskal-Wallis analysis is applied. In this case, the three experience groups are denoted as 1, 2, 3, with 1 represents less experienced, and 3 represents most experienced.

Kruskal-Wallis analysis not only validates our hypothesis 1 to be true, but also revealed that there are four types of relationships exist between experience and importance of processes. They can be depicted into different shapes of relations: upward, downward, V curve, and ^ curve.

1. Upward Slope

Upward slopes denote that the ***more*** experience a person has, the ***more*** important he/she thinks the process to be. There are three processes out of total 140 processes that fall into this category. Those three are:

- Gathering and using customer satisfaction data
- Specifying product evolution roadmap specification
- Managing rework

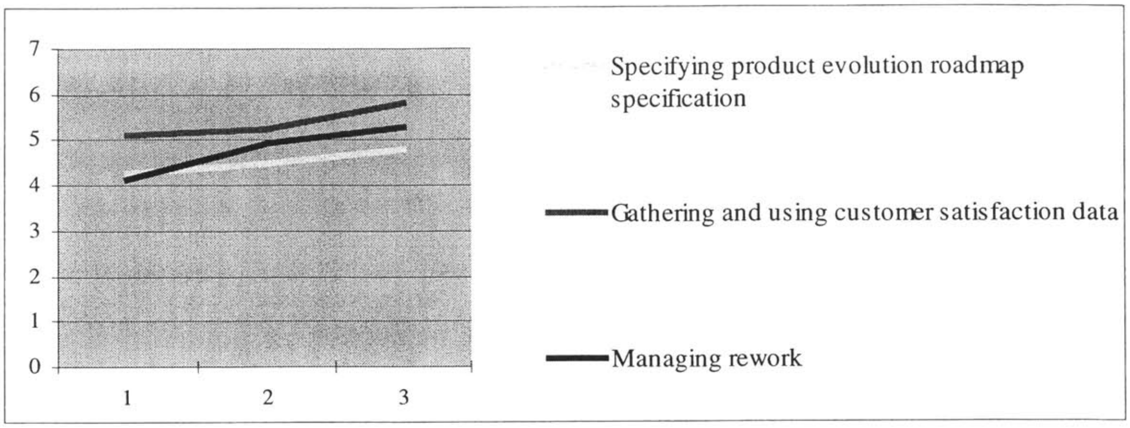


Figure 4.1 Upward Slope: The importance of processes has positive correlation with the professional experience

2. Downward Slope

Downward slope denotes that the ***more*** experience a person has, the ***less*** important he/she thinks the process to be. There are five processes out of total 140 processes that fall into this relationship. (Figure [4.2])

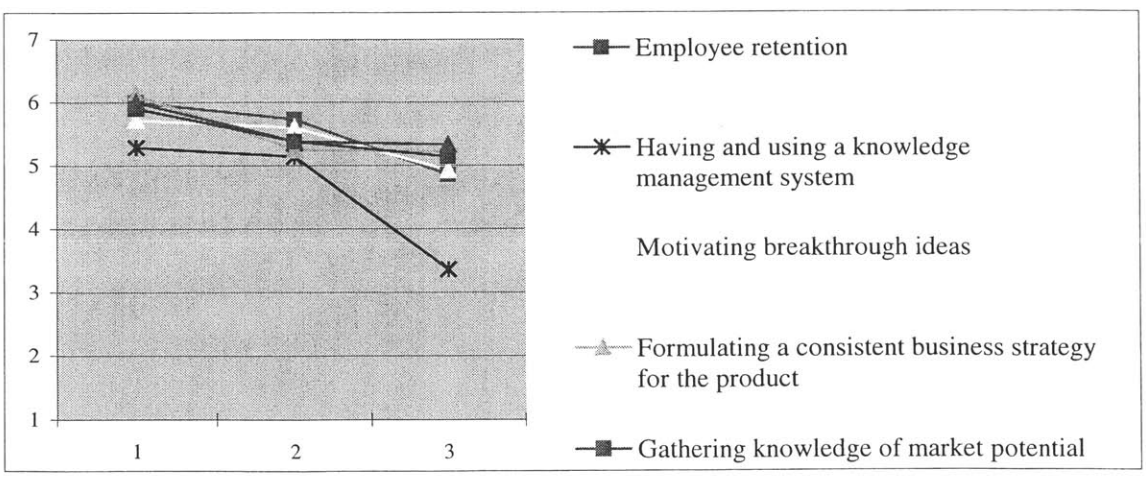


Figure 4.2 The importance of processes has negative correlation with the professional experience

3. V Curve

Downward slope denotes that the ***less*** experienced ***and*** the ***most*** experienced would give a ***higher*** score to a specific process, while those with experience ***in between*** would give a ***lower*** score to that process. There are four processes out of total 140 processes that fall into this relationship. (Figure [xx])

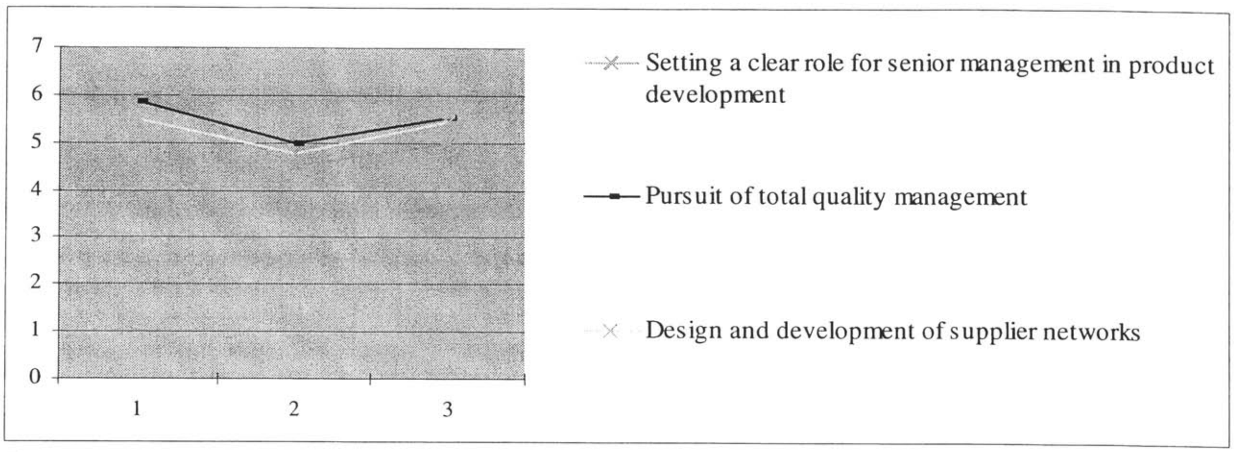


Figure 4.3 Importance of processes were rated low in the middle

4. ^ Curve

^ curve happens when both less experienced and most experienced groups give a lower score on the importance of a process, while experienced (experience between less and most) give it a higher score. This category has by far included most number of processes among four types of relationships. 15 processes fall into this category.

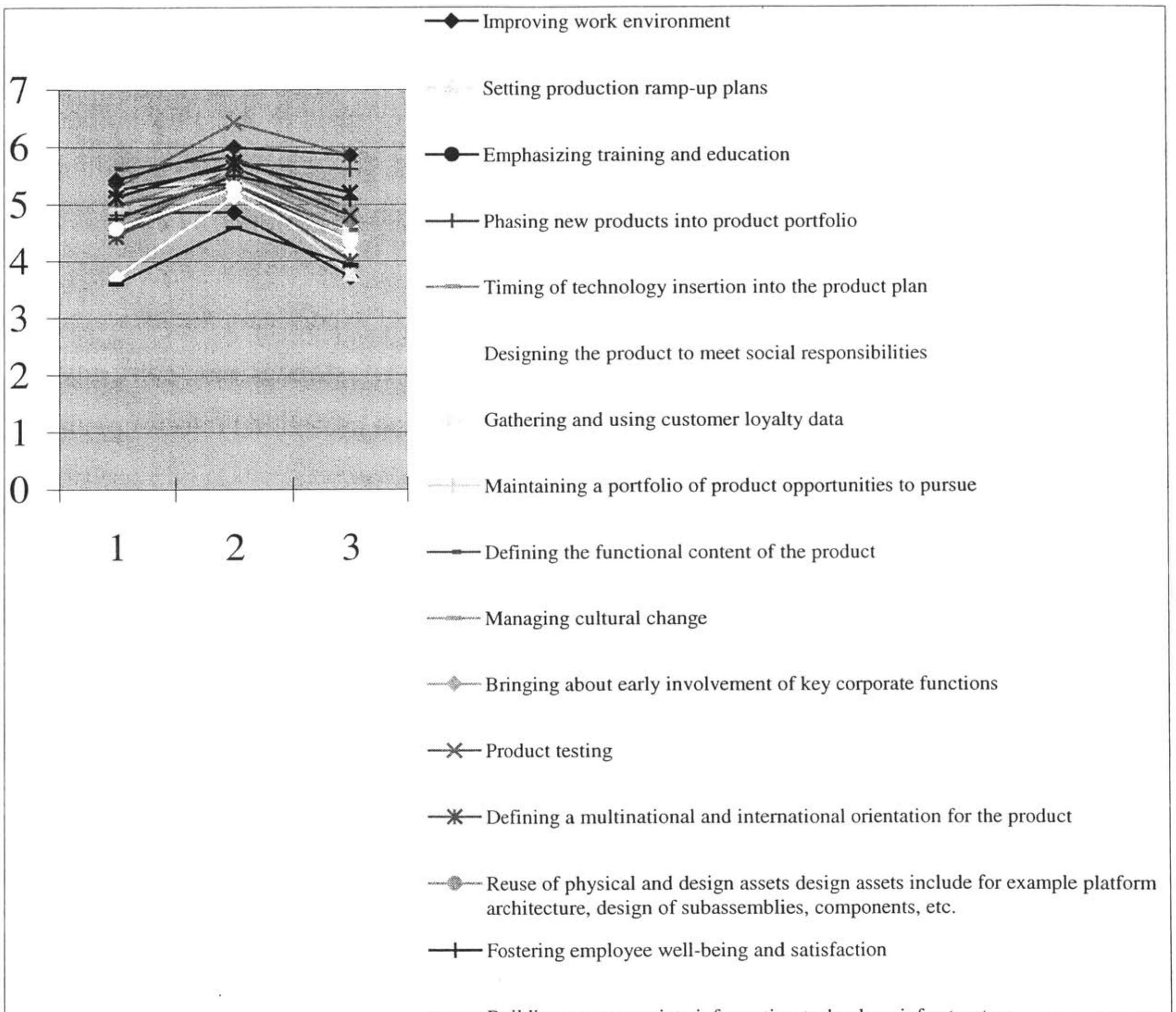


Figure 4.4 The importance of processes were rated higher in the middle

4.3 Hypothesis 2

Process Importance and organization's capability correlate to both company size and professional experience

Initial findings in Chapter 3 and statistic analysis discussed in Section 4.2 suggest that either one of the factors, the company size and the professional experience of a person in a development team, influence the determination of important levels of development processes as well as capability levels an organization has in product development. In hypothesis 2, we assume that those two factors have combined impacts in process importance and organizational capability.

To study the effect of both company size and professional experience, the importance domain (so as to capability domain) can be viewed with two dimensions: company size and professional experience. The sample data are then can be divided into four sub-groups: (1) less experienced and from small company, (2) experienced and from small company, (3) experienced from large company, and (4) less experienced from large company, as shown in Figure 4.5.

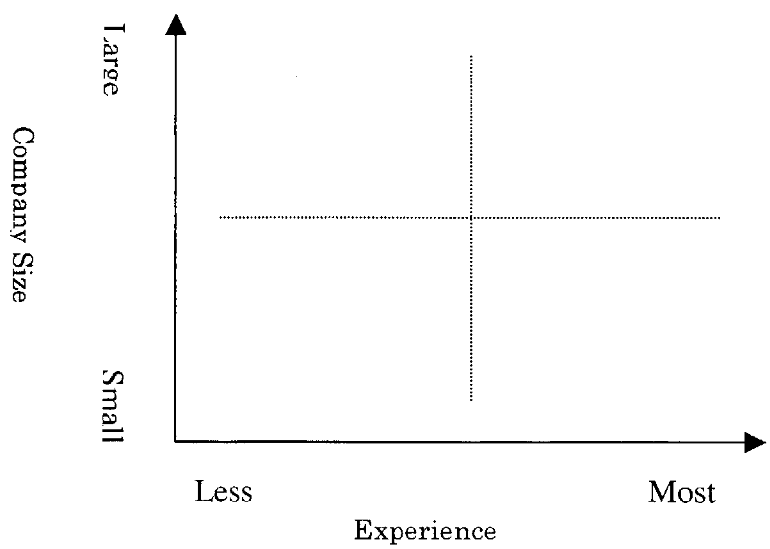


Figure 4.5

The analysis below shows that hypothesis 2 partially holds true.

Process Importance correlate to both company size and professional experience

Figure 4.6 depicts the distribution of important processes from four sub-groups defined above. Respondents with less experience and from small size companies give relatively low rates (low means) to process importance in general and with quite diverged view in what's important (large standard deviations). Respondents with more experience and from large companies tend to give higher points in general and their views of what's important in product development tend to be close.

This indicates that first part of the hypothesis is true: process importance correlates to company size and professional experience. The larger the company and the more experience a person has, the more important of product development processes are perceived. The smaller the company is and the less experience a person has, the less important of product development processes are perceived.

This view may not be surprise, as on hand, large companies tends to have more formalized product development processes and people work there have more opportunities to learn the importance of processes. On the other hand, people with more experience may have learned from their past work that processes are critical to the success of a project.

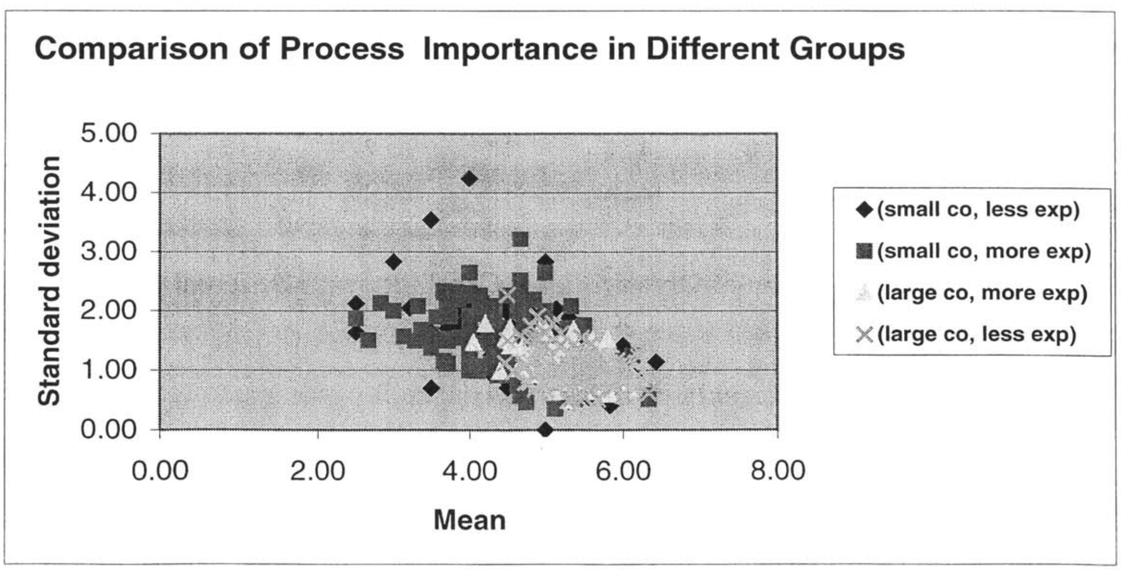


Figure 4.6 Comparison of Process Importance in Different Groups

It is also interesting to notice that the factor of the company size has larger influence on determination of process importance than that of professional experience. More analysis needs to be done on this. One explanation may be that the company size factor is at organizational level, it has larger impact in product development as a whole, while professional experience is at personal level, and it has relatively less impact on product development processes.

Organizational capability correlate to both company size and professional experience

The second half of hypothesis is about the correlation between organizational capability and two factors, company size and professional experience. The same analysis can be applied to this part of research.

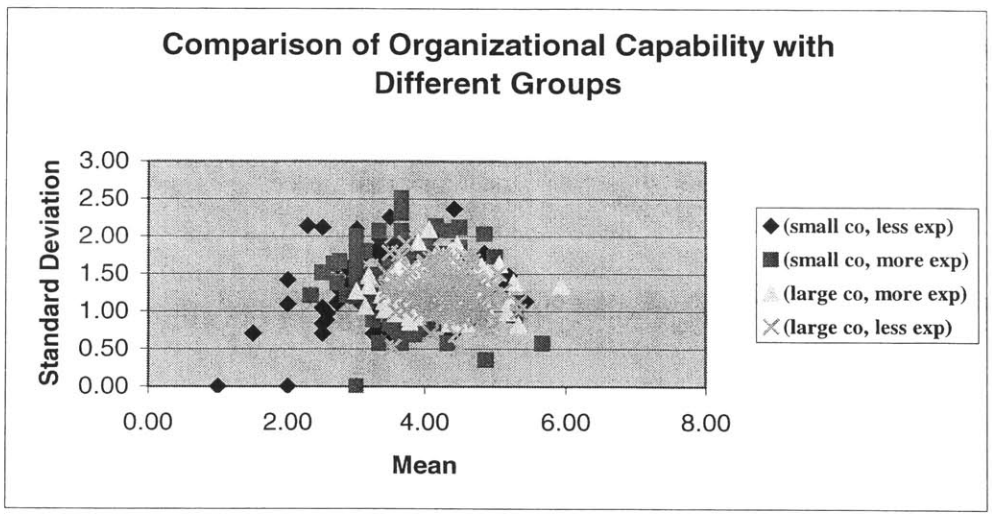


Figure 4.7 Comparison of Organizational Capability with Different Groups

Figure 4.7 shows the comparison of organizational capability rating among with groups. It doesn't indicate much difference when comes to rate an organization's product development capabilities. People give ratings of an organization's capabilities regardless with their own experience and with the consideration of the size of the organization they are in. So this part of the hypothesis doesn't hold true.

Table 4.1(a~d) lists the top ten important processes rated by each of four sub-groups. It shows that each sub-group weighted the importance of processes differently.

Descriptive Statistics (less exp, small co)	N	Min	Max	Mean	Std. Dev.
Regulatory compliance	7	4	7	6.43	1.13
Maintaining knowledge of the competitive environment	7	5	7	6.14	0.90
Employee retention	2	5	7	6.00	1.41
Product testing	2	5	7	6.00	1.41
Translating strategy into actionable initiatives	2	5	7	6.00	1.41
Coordinating market and product strategy to optimize financial results	7	5	7	6.00	1.00
Defining the functional content of the product	7	5	7	5.86	0.69
Setting financial metrics for the project includes for example, product cost, margin, revenue, life-cycle costs and expenses.	7	5	7	5.86	0.69
Setting the product's pricing strategy	7	5	7	5.86	0.90
Product validation	6	5	6	5.83	0.41

Table 4.1a. Top Ten Important Processes by respondents with less experience and from small companies

Descriptive Statistics (more exp, small co)	N	Min	Max	Mean	Std. Dev.
Product testing	6	6	7	6.33	0.52
Selection of technology for the product	3	6	7	6.33	0.58
Establishing, maintaining customer relationships	8	4	7	6.13	1.25
Development of program schedule	7	4	7	6.00	1.15
Making appropriate levels of resource commitments, people and dollars	7	5	7	6.00	0.82
Transitioning the product to the sales function	3	5	7	6.00	1.00
Decision making in development process	7	4	7	5.71	0.95
Transitioning products to production	8	5	7	5.63	0.74
Assigning clear responsibilities to each team member	7	5	7	5.57	0.79
Phasing new products into product portfolio	6	3	7	5.50	1.76

Table 4.1b. Top Ten Important Processes by respondents with more experience and from small companies

Descriptive Statistics (more exp, large co)	N	Min	Max	Mean	Std. Dev
Identifying customer needs by market segment	13	5	7	6.15	0.80
Meeting projects financial goals	11	5	7	6.09	0.70
Establishing, maintaining customer relationships	11	5	7	6.09	0.94
Formulating a consistent business strategy for the product	10	5	7	6.00	0.94
Decision making in development process	15	5	7	5.93	0.80
Maintaining knowledge of the competitive environment	15	4	7	5.93	0.96
Making appropriate levels of resource commitments, people and dollars	15	4	7	5.93	0.80
Gathering data and analyses to support decision making	11	5	7	5.91	0.94
Integration of health and safety and environmental issues and requirements in product development	11	4	7	5.91	0.94
Selecting capable project leaders	11	4	7	5.91	1.04

Table 4.1c. Top Ten Important Processes by respondents with more experience and from large companies

Descriptive Statistics (less exp, large co)	N	Min	Max	Mean	Std. Dev
Decision making in development process	10	5	7	6.40	0.70
Product validation	15	5	7	6.33	0.62
Translating strategy into actionable initiatives	10	5	7	6.20	0.92
Understanding the value chain of the product	10	3	7	6.20	1.32
Regulatory compliance	10	4	7	6.20	1.23
Risk analysis and risk management processes	15	5	7	6.20	0.77
Setting the priority among product requirements	6	5	7	6.17	0.75
Transitioning products to production	7	5	7	6.14	0.69
Selecting capable project leaders	7	5	7	6.14	0.69
Choosing cross functional representation PD team	7	5	7	6.14	0.69

Table 4.1d. Top Ten Important Processes by respondents with less experience and from large companies

4.4 Hypothesis 3

Correlation exists between an organization's product-development capabilities and its financial performance

In the survey, the participants were asked to rate their companies' performance in terms of five categories: market share results, profitability, customer satisfaction, organizational effectiveness, and product quality. The calibration of each is scaled from 1 to 7, in which 1 is denoted to poor performance and 7 is denoted to exceptional performance. Two factors – market share and profitability, are studied in this section in regard to their relationship to organizational capabilities in product development.

1. Correlation Between PD capability and market share

In order to perform a Kruskal-Wallis test, the market share results data were grouped into three sets according to the level of ratings:

- Set 1 - low market share: rating 1~3
- Set 2 - medium market share: rating 4,5
- Set 3 - high market share: rating 6,7

Table 4.2 shows the distribution of ratings in term of market share results. About half of the respondents rated their companies to be with average market share results. Twentysix percent fell into low market share rank, and another eighteen percent were in high market share brackets.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	21	25.3	26.3	26.3
	2	44	53.0	55.0	81.3
	3	15	18.1	18.8	100.0
	Total	80	96.4	100.0	
Missing	System	3	3.6		
Total		83	100.0		

Table 4.2 Distribution of ratings in market share results

A Kruskal-Wallis test of all 140 processes on the grouping variable of market share results reveals positive correlations exist between market share and organization's PD capabilities in seven areas. (Figure 4.8). They are:

- Promotion a culture that supports team work
- Forecasting manufacturing volumes
- Transitioning the product to the sales functions
- Making correct make-buy decisions
- Meeting project financial goals
- Development of program schedule
- Setting production ramp-up plans

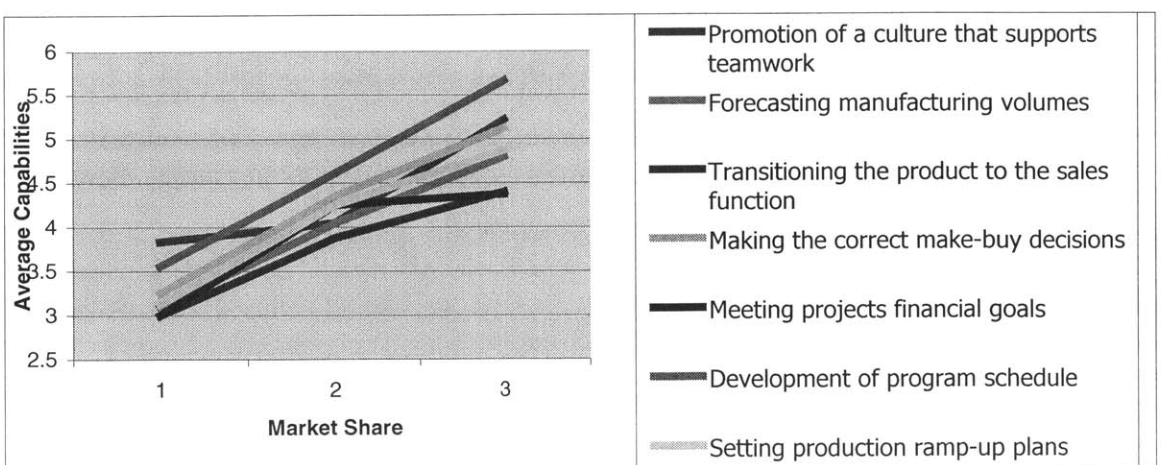


Figure 4.8 Correlation between Market share and Average capabilities

A common theme behind these seven processes can be observed as that all of them are addressing issues across more than one fuctions within an organization. For example, "promotion of a culture that supports teamwork" is an effort taken by an organization as a whole. "Making the correct make-buy decisions" needs thorough considerations of market condition, competition and technology selection. These processes show a strong characteristics as being cross-funtioning and facilitating transioning from one function to another.

Figure 4.9 shows that on average, the higher the market share, the higher the avarege score of organizational capabilities of each of 140 processes, and vice vesa. But the variations of average scores are larger for higher market share companies than that for lower market share companies. This seems to suggest that for companies to persue large market share, they tend to be more focued on some processes, rather than spend their resources equally on every process involved in product development.

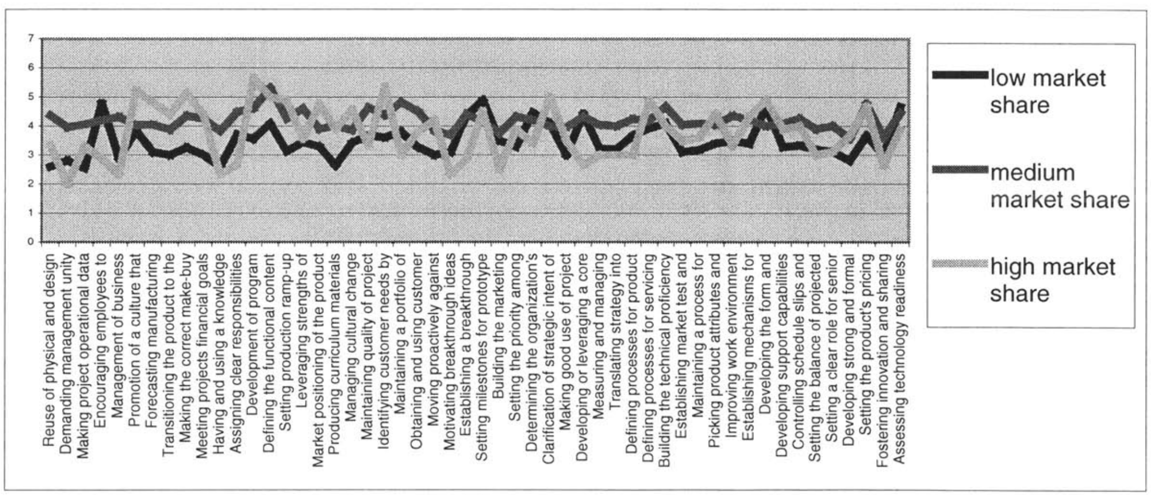


Figure 4.9 Average scores of organizational capabilities at three market share levels (Only a subset of 140 processes is shown here)

2. Correlation between PD capability and profitability

A similar Kruskal-Wallis test was also performed on profitability. Three sets of profitability groups were formed as such:

- Set 1 – low profitability: rating 1~3
- Set 2 – medium profitability: rating 4,5

- Set 3 – high profitability: rating 6,7

About 40% respondents rated their companies to be low in profitability, and 43% rated their companies to be on average of profitability. Only 16.5% respondents rated their companies high in profitability.

PROFIT

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	32	38.6	40.5	40.5
	Medium	34	41.0	43.0	83.5
	High	13	15.7	16.5	100.0
	Total	79	95.2	100.0	
Missing	System	4	4.8		
Total		83	100.0		

Table 4.3 Distribution of respondents in term of profitability

Figure 4.10 indicates that there are 6 processes showed positive correlations between profitability and average PD capabilities of an organization.

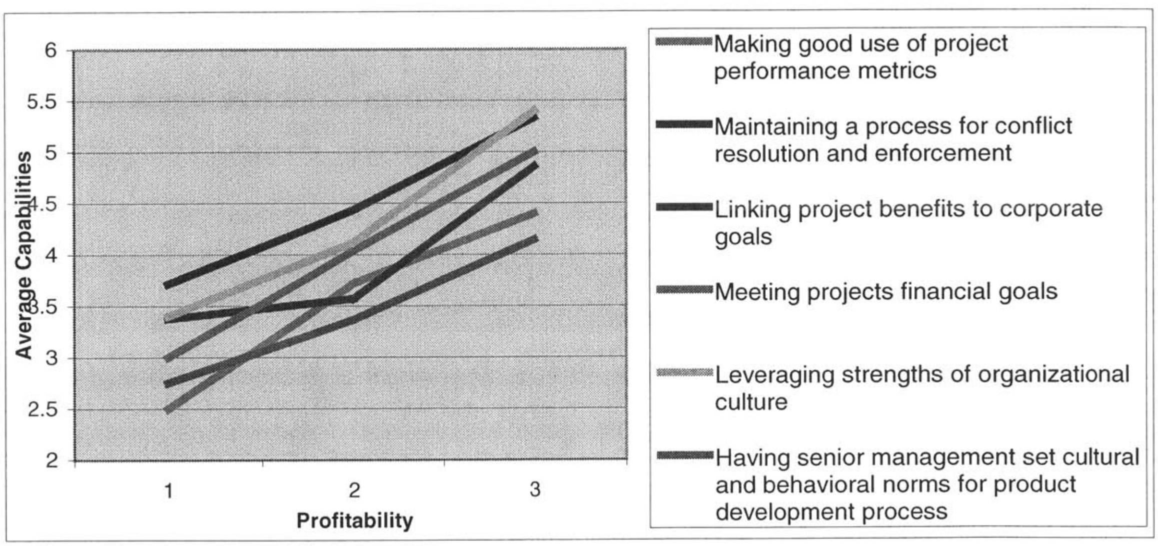


Figure 4.10 Correlation between PD capability and profitability

These six processes are:

- Making good use of project performance metrics
- Maintaining a process for conflict resolution and enforcement
- Linking project benefits to corporate goals
- Meeting projects financial goals

- Leveraging strengths of organizational culture
- Having senior management set cultural and behavioral norms for product development process

These processes tend to be tightly related to the measurements of a company's performance. For example, "meeting projects financial goals" directly tackles issue of financial performance of a project. It is no surprise that a company that has higher capabilities in these areas should achieve better financial outcome in term of profitability.

Figure 4.10 shows average scores of organizational capabilities at three market share levels. Although the higher the profitability, the higher the avarege score of organizational capabilities of each of 140 processes, and vice vesa, the gaps among these three groups are not as clear as that of market share results.

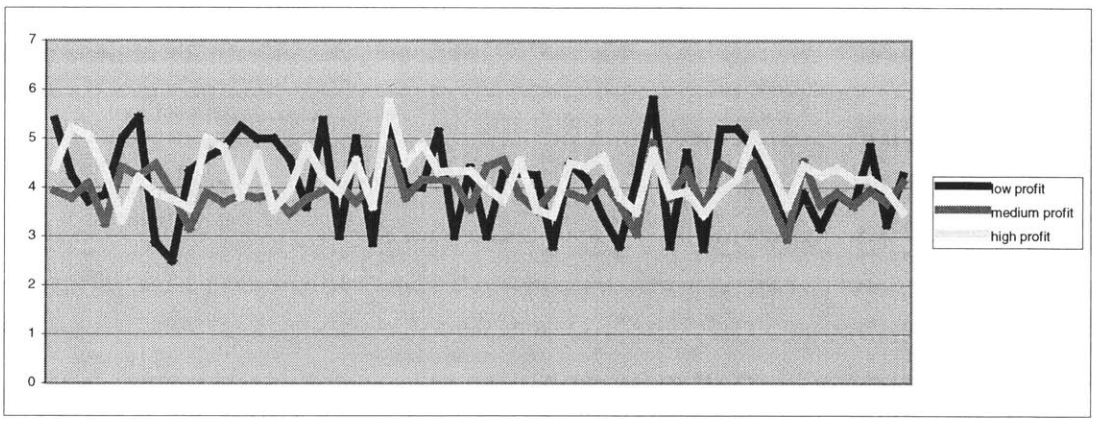


Figure 4.10 Average scores of organizational capabilities at three profitability levels (Only a subset of 140 processes is shown here)

5. Conclusions and Next Steps

5.1 Findings and Conclusions

In this research, we have constructed and tested a framework for understanding important processes in product development and relationships with organizational capabilities. The work also illustrates how various factors such as company size, industry sectors, and professional experience may influence the dynamics of product development process.

5.2 Next Steps

The work done in this research has opened up a wide range of research in improving product development processes and organizational capabilities.
In short run, the research work will continue on the study of factors analysis, correlation analysis between company's performance and product development capability, assessment of "Importance" vs. "Capability", retrofit of the findings to references, and design of appropriate clustering in processes' grouping

Factor analysis
As we mentioned earlier, many factors influence the important level of a process in product development as well as the capabilities of an organization's product development. Two factors that have been studied extensively in this research so far are company size and professional experience. The findings are encouraging, as they have shown the correlations between factors and importance/capability. In the next step, two more factor analysis can be done; they are industry sectors that a company in and the "functional roles" of a product development participant.
Initial analysis has shown that companies in different sectors have common issues when dealing with product development, but they also have different focus on other issues. Finding out what's important for different industry sectors, and what's the specific issues impacting their capabilities would not only help to develop tailored improvement instruments for companies in different sectors, but also develop cross-sector strategies.

A person in a product development team can have different roles such as design, development, technical marketing, testing, service and support, or any combinations of those roles. Each role has its own focus, and the person that assumes such a role would weight different processes in product development differently. Finding such difference would lead us to design effective cross-functional teams in product development.

Correlation analysis between company's performance and important ratings

In this part of research, we want to check self-assessment of output metrics with market's assessment of a company's performance. That is to find out:

- How "important" ratings correlate with a company's performance perceived by the market, and
- How "capability" ratings correlate with a company's performance perceived by the market

In the survey, we have asked the participants to rate their companies' performance in terms of market share results, profitability, customer satisfaction, organizational effectiveness and product quality. The data collected on these five metrics can be used to compare with the companies' "real" performance from market place.

"Importance" vs. "Capability" assessment

The insight of this analysis would lead us find the gap between what a company has done, and what it needs to be done, and to develop effective tools to improve a company's capabilities in product development.

Compare survey findings with references, and assess how well each reference predicted importance

All the processes in this research were drawn from one or more resources in the literature session. This gives us a great opportunity to retrofit our findings to those resources, and analyze the similarity and discrepancy between our findings and past research.

Grouping exercise onto different populations

To effectively design an assessment instrument, we need to group the 140 processes into a meaningful way. One such exercise has been done during our survey in CIPD conference, and results a clustering chart shown in the figure 5.1

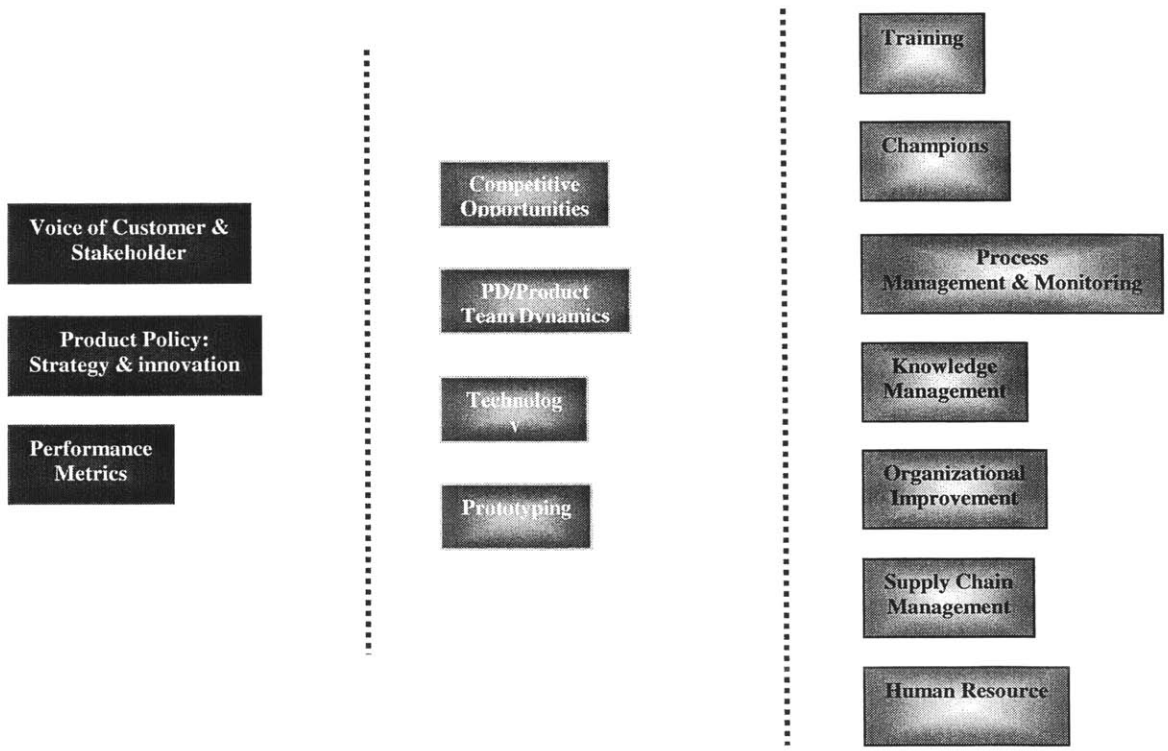


Figure 5.1 Processes Grouping

Further grouping exercises need to be done to find appropriate clusters.

In the long run, our aim is to provide an assessment vehicle that helps organizations assess their capabilities and make improvement and improve predictions of project outcomes for an organization.

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Appendix A Important Processes Ranking

Descriptive Statistics	N	Min	Max	Mean	Std. Dev.
Product testing	36	1	7	5.97	1.16
Product validation	46	3	7	5.91	0.94
Regulatory compliance	41	2	7	5.88	1.25
Making appropriate levels of resource commitments, people and dollars	37	4	7	5.86	0.82
Decision making in development process	37	3	7	5.86	0.95
Maintaining knowledge of the competitive environment	42	3	7	5.86	1.14
Establishing, maintaining customer relationships	39	1	7	5.85	1.20
Development of program schedule	36	3	7	5.75	1.05
Determining the product's competitive advantages	46	2	7	5.72	1.11
Promotion of a culture that supports teamwork	43	3	7	5.70	0.91
Transitioning products to production	39	1	7	5.69	1.22
Selecting capable project leaders	39	4	7	5.69	0.89
Assigning clear responsibilities to each team member	37	3	7	5.68	1.00
Obtaining and using customer feedback throughout product development	47	1	7	5.66	1.24
Translating strategy into actionable initiatives	37	3	7	5.65	1.11
Picking product attributes and their target values	44	3	7	5.64	0.97
Setting financial metrics for the project includes for example, product cost, margin, revenue, life-cycle costs and expenses.	42	3	7	5.62	1.03
Establishing mechanisms for project progress monitoring and control	43	3	7	5.60	0.95
Moving proactively against project delays	47	3	7	5.60	0.95
Having a pre-project exploration/planning phase	47	2	7	5.57	1.17
Identifying customer needs by market segment	35	3	7	5.57	0.95
Defining the functional content of the product	42	1	7	5.55	1.31
Selection of technology for the product	46	3	7	5.54	1.05
Understanding the value chain of the product	37	2	7	5.54	1.39
Risk analysis and risk management processes	47	3	7	5.53	1.16
Choosing cross functional representation PD team	39	4	7	5.51	0.97
Selecting experienced project leaders	39	3	7	5.51	1.05
Determining the organization's ability to deliver the technology	47	3	7	5.51	1.00
Delegating power to the project leader	47	2	7	5.49	1.04
Clarification of strategic intent of the product includes for example, clear vision of the product's intended image, performance, and fit with corporate competencies, culture, and customers, etc.	41	1	7	5.49	1.36
Integration of health and safety and environmental issues and requirements in product development	39	1	7	5.46	1.19
Gathering knowledge of market potential	46	1	7	5.46	1.24
Formulating a consistent business strategy for the product	38	1	7	5.45	1.29
Meeting projects financial goals	39	2	7	5.44	1.17
Controlling schedule slips and slip-rate	39	4	7	5.44	0.88
Phasing new products into product portfolio	35	2	7	5.43	1.17
Building the technical proficiency of the development team	47	1	7	5.43	1.25
Employee retention	36	4	7	5.42	0.84
Developing or leveraging a core competency for the project	36	2	7	5.42	1.05

Establishing a breakthrough product concepts	39	3	7	5.41	1.29
Setting the product's pricing strategy	42	2	7	5.40	1.31
Assessing technology readiness for inclusion in the product	42	3	7	5.38	1.06
Motivating breakthrough ideas	37	3	7	5.38	0.92
Gathering and using customer satisfaction data	43	3	7	5.37	1.00
Identifying stakeholders and their requirements	46	3	7	5.37	1.18
Linking project benefits to corporate goals	41	2	7	5.37	1.24
Establishing core concept of the product	36	1	7	5.36	1.33
Market positioning of the product	37	1	7	5.35	1.27
Involving customers throughout product development process	35	1	7	5.34	1.33
Emphasizing factors that speed products to market	42	2	7	5.33	1.28
Gathering data and analyses to support decision making	39	3	7	5.33	1.13
Identifying new candidate technologies	46	1	7	5.33	1.21
Rewarding innovation	43	2	7	5.33	1.32
Coordinating market and product strategy to optimize financial results	40	2	7	5.33	1.25
Pursuit of total quality management	42	3	7	5.31	1.12
Developing teamwork skills	39	3	7	5.31	0.98
Encouraging employees to develop new ideas	39	1	7	5.28	1.26
Focusing on continuous improvements	38	2	7	5.26	1.22
Putting in place mechanisms for internal communications among team members	43	2	7	5.26	1.09
Fostering employee well-being and satisfaction	43	2	7	5.26	1.16
Maintaining awareness of the product's financial position	47	1	7	5.26	1.31
Forecasting technology trends	47	1	7	5.26	1.26
Evaluating technology readiness for product development	38	3	7	5.24	1.08
Managing cultural change	43	3	7	5.23	1.15
Reuse of intangible assets, for example, intellectual capital, relationships, etc.	43	3	7	5.23	1.07
Setting the priority among product requirements	35	3	7	5.23	0.97
Promotion of risk taking with appropriate rewards	37	2	7	5.22	1.18
Maintaining a portfolio of product opportunities to pursue	37	1	7	5.22	1.27
Collecting knowledge about competitive intensity of the market	38	3	7	5.21	0.93
Determining the organization's ability to market the product	38	2	7	5.21	1.26
Implementing processes for concurrent engineering and development	42	3	7	5.17	1.01
Project leader setting a vision for the project	43	1	7	5.16	1.31
Bringing about early involvement of key corporate functions	47	1	7	5.15	1.30
Maintaining a system for data collection and management	42	1	7	5.14	1.24
Identification of productivity metrics	42	3	7	5.12	1.27
Defining processes for servicing the product	42	1	7	5.12	1.29
Maintaining quality of project operational data	35	2	7	5.11	1.11
Measuring project team productivity	37	2	7	5.11	1.17
Having senior management set cultural and behavioral norms for product development process	47	3	7	5.11	1.32
Design and development of supplier networks	41	2	7	5.10	1.02
Transitioning the product to the sales function	46	1	7	5.09	1.40
Establishing market test and launch plans	47	0	7	5.09	1.53
Gathering and using customer loyalty data	36	2	7	5.08	1.18
Building an appropriate information technology infrastructure	41	3	7	5.07	1.13

Competing for resources from other projects	47	2	7	5.06	1.29
Maintaining access to senior management	42	1	7	5.05	1.29
Generating and evaluating many alternative product concepts	43	1	7	5.05	1.25
Forecasting manufacturing volumes	46	1	7	5.04	1.33
Setting milestones for prototype	39	3	7	5.03	1.06
Acquiring technologies to be used for prototyping	41	1	7	5.02	1.33
Selecting the development process to fit the product	47	1	7	5.00	1.35
Timing of technology insertion into the product plan	37	1	7	5.00	1.43
Setting a clear role for senior management in product development	39	1	7	5.00	1.50
Coordination among and transition between development process phases	39	2	7	5.00	1.08
Reuse of physical and design assets design assets include for example platform architecture, design of subassemblies, components, etc.	36	1	7	4.97	1.48
Setting production ramp-up plans	38	1	7	4.95	1.47
Selecting the product architecture	34	1	7	4.94	1.25
Developing mechanisms for internal task coordination	47	2	7	4.94	1.19
Making investments in infrastructure, tools and training	39	2	7	4.92	1.09
Establishing a prototyping plan	38	1	7	4.92	1.28
Establishing mechanisms for external communication (e.g. among customers and suppliers)	37	1	7	4.92	1.38
Emphasizing training and education	36	1	7	4.92	1.27
Benchmarking	38	2	7	4.89	1.33
Specifications of supply-chain design parameters	46	3	7	4.89	1.06
Developing the form and industrial design of the product	40	1	7	4.85	1.53
Measuring partner satisfaction and loyalty	42	2	7	4.81	1.19
Emphasizing financial/business analysis processes and tools	36	1	7	4.81	1.35
Management of business alliances	36	1	7	4.81	1.43
Performance optimization of the entire supply-chain	46	2	7	4.80	1.09
Maintaining a repertoire of methods, tools, and techniques for development	47	0	7	4.79	1.33
Measuring and managing product service and support complexity	45	1	7	4.78	1.29
Managing rework	41	0	7	4.76	1.41
Setting the balance of projected revenues between old and new products	36	0	7	4.75	1.73
Definition of the supply-chain	39	1	6	4.74	1.23
Fostering innovation and sharing knowledge throughout the supplier network	37	1	7	4.73	1.57
Making project operational data readily accessible	37	2	7	4.70	1.33
Pursuing organizational learning	47	1	6	4.70	1.20
Leveraging strengths of organizational culture	38	3	7	4.68	1.07
Defining a multinational and international orientation for the product	36	1	7	4.67	1.77
Defining processes for product support	35	1	6	4.66	1.45
Defining the structure of value chain from suppliers to sales, distribution, support and services	40	1	7	4.65	1.44
Developing support capabilities for employees	45	1	6	4.64	1.23
Proactive management of public concerns about the product or project	46	1	7	4.61	1.65
Having a PD gatekeeper (A gatekeeper is an individual who frequently obtain information external to the group and then share it within the project team)	40	1	7	4.60	1.52
Developing strong and formal ties between suppliers and R&D	37	1	7	4.59	1.77
Deployment of strategies to achieve product modularity	46	1	7	4.59	1.39
Building the marketing proficiency of the development team	38	1	7	4.58	1.29

Maintaining a process for conflict resolution and enforcement	45	1	7	4.56	1.34
Definition and development for the sales and distribution processes	38	1	7	4.55	1.50
Designing the product to meet social responsibilities	36	1	7	4.53	1.73
Making good use of project performance metrics	38	0	7	4.53	1.47
Having and using a knowledge management system	36	1	7	4.50	1.81
Demanding management unity	37	1	7	4.49	1.52
Measuring and managing manufacturing complexity	36	1	7	4.47	1.66
Making the correct make-buy decisions	38	1	7	4.42	1.18
Improving work environment	37	2	6	4.41	1.04
Specifying product evolution roadmap specification	38	0	6	4.39	1.52
Co-location of the PD team	34	1	7	4.26	1.80
Establishment of a product end-of-life strategy	46	1	7	4.24	1.69
Producing curriculum materials and content for engineering and product development training and education	47	1	7	4.17	1.43

Appendix B Capability Ranking

	Descriptive Statistics	N	Min	Max	Mean	Std. Dev.
1	Regulatory compliance	41	2	7	5.46	1.21
2	Product testing	34	3	7	5.21	1.09
3	Integration of health and safety and environmental issues and requirements in product development	39	1	7	4.92	1.40
4	Defining the functional content of the product	42	1	7	4.83	1.48
5	Establishing, maintaining customer relationships	39	1	7	4.77	1.39
6	Product validation	45	2	7	4.73	1.42
7	Focusing on continuous improvements	38	1	7	4.63	1.34
8	Selection of technology for the product	45	1	7	4.62	1.32
9	Establishing mechanisms for project progress monitoring and control	43	2	6	4.51	1.16
10	Maintaining knowledge of the competitive environment	42	2	7	4.50	1.33
11	Delegating power to the project leader	46	1	7	4.50	1.67
12	Acquiring technologies to be used for prototyping	40	2	6	4.45	1.15
13	Development of program schedule	35	2	7	4.43	1.29
14	Establishing a prototyping plan	38	1	7	4.42	1.39
15	Establishing core concept of the product	36	1	7	4.42	1.38
16	Linking project benefits to corporate goals	41	1	7	4.41	1.40
17	Setting milestones for prototype	39	2	7	4.41	1.07
18	Building the technical proficiency of the development team	46	1	7	4.39	1.26
19	Design and development of supplier networks	41	2	7	4.39	1.16
20	Choosing cross functional representation PD team	39	2	7	4.38	1.04
21	Maintaining access to senior management	42	2	7	4.38	1.45
22	Assessing technology readiness for inclusion in the product	42	2	7	4.38	1.13
23	Setting financial metrics for the project includes for example, product cost, margin, revenue, life-cycle costs and expenses.	42	2	7	4.38	1.45
24	Determining the product's competitive advantages	45	2	6	4.38	1.19
25	Developing the form and industrial design of the product	40	1	7	4.38	1.55
26	Employee retention	35	2	7	4.37	1.40
27	Maintaining a portfolio of product opportunities to pursue	35	1	7	4.37	1.55
28	Setting the product's pricing strategy	42	1	7	4.36	1.59
29	Implementing processes for concurrent engineering and development	42	2	6	4.33	1.16
30	Decision making in development process	36	2	6	4.31	1.17
31	Identification of productivity metrics	42	1	7	4.29	1.55
32	Project leader setting a vision for the project	43	1	6	4.28	1.10
33	Understanding the value chain of the product	36	1	6	4.28	1.06
34	Maintaining a repertoire of methods, tools, and techniques for development	45	1	7	4.27	1.57
35	Maintaining quality of project operational data	34	2	7	4.26	1.33
36	Transitioning products to production	39	1	7	4.26	1.45
37	Promotion of a culture that supports teamwork	43	2	7	4.26	1.11
38	Defining processes for servicing the product	42	1	7	4.24	1.32
39	Making the correct make-buy decisions	38	1	7	4.24	1.32

40	Identifying customer needs by market segment	34	2	6	4.24	1.23
41	Putting in place mechanisms for internal communications among team members	43	1	6	4.21	1.21
42	Definition of the supply-chain	39	1	6	4.21	1.32
43	Developing teamwork skills	39	2	6	4.21	1.15
44	Developing or leveraging a core competency for the project	35	1	6	4.20	1.16
45	Clarification of strategic intent of the product includes for example, clear vision of the product's intended image, performance, and fit with corporate competencies, culture, and customers, etc.	41	1	7	4.20	1.42
46	Identifying stakeholders and their requirements	45	2	6	4.18	1.09
47	Phasing new products into product portfolio	34	1	7	4.18	1.31
48	Building an appropriate information technology infrastructure	41	1	7	4.17	1.24
49	Gathering data and analyses to support decision making	39	2	7	4.15	1.31
50	Defining a multinational and international orientation for the product	34	1	7	4.15	1.40
51	Gathering and using customer loyalty data	35	1	7	4.14	1.42
52	Benchmarking	38	1	7	4.13	1.42
53	Encouraging employees to develop new ideas	39	2	7	4.13	1.45
54	Pursuit of total quality management	42	1	7	4.12	1.47
55	Designing the product to meet social responsibilities	34	1	7	4.12	1.49
56	Fostering employee well-being and satisfaction	43	1	6	4.12	1.33
57	Assigning clear responsibilities to each team member	36	2	7	4.11	1.26
58	Leveraging strengths of organizational culture	38	1	7	4.11	1.37
59	Managing rework	39	2	6	4.10	1.14
60	Selecting experienced project leaders	39	1	6	4.10	1.17
61	Maintaining awareness of the product's financial position	46	1	7	4.09	1.43
62	Establishing a breakthrough product concepts	39	1	7	4.08	1.44
63	Selecting capable project leaders	39	1	6	4.08	1.13
64	Maintaining a system for data collection and management	42	1	7	4.07	1.28
65	Determining the organization's ability to deliver the technology	46	1	6	4.07	1.25
66	Selecting the product architecture	34	1	7	4.06	1.28
67	Setting production ramp-up plans	38	1	7	4.05	1.45
68	Meeting projects financial goals	39	1	7	4.05	1.23
69	Making investments in infrastructure, tools and training	39	1	6	4.05	1.21
70	Gathering and using customer satisfaction data	43	1	7	4.05	1.63
71	Specifications of supply-chain design parameters	45	2	7	4.04	1.13
72	Emphasizing training and education	35	1	7	4.03	1.42
73	Improving work environment	36	1	7	4.03	1.23
74	Evaluating technology readiness for product development	38	2	7	4.03	1.35
75	Obtaining and using customer feedback throughout product development	46	1	7	4.02	1.45
76	Performance optimization of the entire supply-chain	45	2	6	4.00	1.04
77	Establishing mechanisms for external communication (e.g. among customers and suppliers)	36	1	7	4.00	1.33
78	Setting the priority among product requirements	36	1	6	4.00	1.17
79	Involving customers throughout product development process	35	1	6	4.00	1.19
80	Having a pre-project exploration/planning phase	46	1	6	4.00	1.43
81	Identifying new candidate technologies	45	1	7	3.98	1.42
82	Defining processes for product support	33	2	6	3.97	1.26
83	Picking product attributes and their target values	43	2	7	3.95	1.17

84 Coordination among and transition between development process phases	39	2	6	3.95	1.07
85 Controlling schedule slips and slip-rate	39	2	7	3.95	1.30
86 Market positioning of the product	37	1	6	3.95	1.31
87 Forecasting manufacturing volumes	45	1	6	3.93	1.45
88 Collecting knowledge about competitive intensity of the market	38	1	6	3.92	1.38
89 Risk analysis and risk management processes	46	1	6	3.91	1.33
90 Rewarding innovation	43	1	7	3.91	1.57
91 Coordinating market and product strategy to optimize financial results	40	1	7	3.90	1.34
92 Forecasting technology trends	46	1	6	3.89	1.48
93 Developing support capabilities for employees	44	1	6	3.89	1.33
94 Managing cultural change	43	1	6	3.88	1.10
95 Competing for resources from other projects	46	1	6	3.85	1.17
96 Pursuing organizational learning	46	1	7	3.85	1.46
97 Proactive management of public concerns about the product or project	45	1	7	3.84	1.57
98 Determining the organization's ability to market the product	38	2	6	3.84	1.20
99 Emphasizing factors that speed products to market	42	1	7	3.83	1.29
100 Selecting the development process to fit the product	46	1	7	3.83	1.39
101 Reuse of intangible assets, for example, intellectual capital, relationships, etc.	43	2	6	3.81	1.24
102 Bringing about early involvement of key corporate functions	46	1	6	3.80	1.24
103 Deployment of strategies to achieve product modularity	45	1	6	3.78	1.22
104 Timing of technology insertion into the product plan	36	1	6	3.78	1.22
105 Maintaining a process for conflict resolution and enforcement	44	1	7	3.77	1.27
106 Management of business alliances	35	1	6	3.77	1.46
107 Reuse of physical and design assets design assets include for example platform architecture, design of subassemblies, components, etc.	35	2	7	3.77	1.40
108 Emphasizing financial/business analysis processes and tools	35	1	7	3.74	1.56
109 Moving proactively against project delays	46	1	6	3.74	1.41
110 Measuring and managing manufacturing complexity	34	1	6	3.74	1.48
111 Transitioning the product to the sales function	45	1	7	3.73	1.32
112 Having a PD gatekeeper (A gatekeeper is an individual who frequently obtain information external to the group and then share it within the project team)	39	1	7	3.72	1.49
113 Defining the structure of value chain from suppliers to sales, distribution, support and services	39	1	7	3.72	1.21
114 Producing curriculum materials and content for engineering and product development training and education	46	1	7	3.72	1.67
115 Developing mechanisms for internal task coordination	46	2	7	3.72	1.03
116 Co-location of the PD team	35	1	7	3.71	1.45
117 Translating strategy into actionable initiatives	36	2	7	3.69	1.26
118 Establishing market test and launch plans	45	1	7	3.69	1.41
119 Making appropriate levels of resource commitments, people and dollars	36	1	6	3.67	1.31
120 Making good use of project performance metrics	37	1	7	3.65	1.25
121 Gathering knowledge of market potential	45	2	7	3.64	1.17
122 Setting the balance of projected revenues between old and new products	34	1	6	3.62	1.30
123 Generating and evaluating many alternative product concepts	43	1	7	3.60	1.31
124 Definition and development for the sales and distribution processes	37	1	6	3.59	1.38

125 Measuring and managing product service and support complexity	44	1	6	3.59	1.17
126 Setting a clear role for senior management in product development	39	1	7	3.59	1.43
127 Measuring project team productivity	36	1	7	3.56	1.61
128 Measuring partner satisfaction and loyalty	39	1	6	3.54	1.14
129 Formulating a consistent business strategy for the product	39	1	7	3.54	1.43
130 Demanding management unity	36	1	6	3.47	1.25
131 Making project operational data readily accessible	37	1	7	3.46	1.24
132 Building the marketing proficiency of the development team	38	1	6	3.42	1.39
133 Motivating breakthrough ideas	36	1	7	3.42	1.36
134 Having senior management set cultural and behavioral norms for product development process	46	1	6	3.41	1.20
135 Specifying product evolution roadmap specification	37	1	6	3.38	1.19
136 Developing strong and formal ties between suppliers and R&D	36	1	5	3.36	1.31
137 Fostering innovation and sharing knowledge throughout the supplier network	36	1	6	3.36	1.27
138 Promotion of risk taking with appropriate rewards	36	1	6	3.36	1.33
139 Having and using a knowledge management system	35	1	7	3.34	1.41
140 Establishment of a product end-of-life strategy	44	1	6	3.23	1.33