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**CONCURRENT ENGINEERING ACROSS DISTANCE AND TIME:
MANAGING THE INTERFACE BETWEEN
ENGINEERING/R&D AND MANUFACTURING**

A Thesis in
Management Studies

by

Karim K. Hirji, B.Sc.'92 (Co-op) - Simon Fraser University

**Submitted in Partial Fulfilment
of the Requirements
for the Degree of**

Master of Management Studies

April 1994

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Dennis Glen Robinson Hargettman

Thesis Supervisor

K. Hirji

Director, School of Business

**Carleton University
April 1994**

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

*In the Name of Allāh,
the Merciful and the Compassionate*

"To seek knowledge is a duty of every Muslim man and woman."

Prophet Muhammed (S.A.S.)

ABSTRACT

Concurrent Engineering Across Distance and Time: Managing The Interface Between Engineering/R&D And Manufacturing

Karim K. Hirji

This study examines how single and multi-location manufacturing firms deliver new products to market using concurrent engineering (CE) principles. Three major issues examined include: (1) what are the managerial and technological responses that support CE in general; (2) how is CE practiced, what are the special problems encountered, and how are they resolved when team members are geographically dispersed; and (3) what are the cognitive and cultural differences between the upstream engineering/R&D and the downstream manufacturing functions that are relevant to CE implementation.

A total of 47 CE projects from 13 leading American, Australian, Canadian, and European companies in the automobile, chemical, computer, electronics, shipbuilding, and telecommunications industries were examined. Data was collected by administering a mail survey and analyzed by using discriminant function analysis, factor structure analysis, and regression analysis.

Results indicate that CE consists of four inter-related dimensions: information exchange/interface, overlapping problem-solving, information tolerance, and attitudes. In addition, the measured dimensions of CE are significant predictors of task and

process success. The findings also suggest that the upstream engineering/R&D and downstream manufacturing functions are cognitively and culturally the same. Finally, the results suggest that the dimensions of CE are influenced by various integrative mechanisms, communication technologies & tools, barriers, and cognitive and cultural differences.

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Oscar Hauptman, Associate Professor of Operations Management and Management of Technology

Thesis Committee:

Donald Gerwin, Professor of Operations Management and Management of Technology

Moses N. Kiggundu, Professor of Organizational Behaviour and International Business

**School of Business
Carleton University**

*Dedicated to
my parents Sultan and Gulbanu,
with love*

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Chapter 1

INTRODUCTION AND PROBLEM STATEMENT

1.1. Introduction

Winds of change are blowing through industries ranging from automobiles to consumer electronics. Faced with intense international competition, demanding sophisticated customers, shorter product lifecycles, rapid technological change, and the need to continuously and quickly develop new products, companies are increasingly turning to the effective management of product development to either meet or beat their competitors (Bart 1993; Miller et al. 1989; Taft and Barclay 1993; Ulrich, Sartorius, Pearson and Jakiela 1993).

For the past four decades, the majority of companies developed new products using a bureaucratically programmed approach whereby different functional specialists each performed a set of tasks sequentially and in isolation from one another (Chapman, Bahill and Wymore 1992, p.326; Kagona et al. 1985; Liker, Fleischer and Arnsdorf 1992; Linton et al. 1991; Turino 1992, p.1). Organizational policies and structures were therefore designed with the principle of exclusion in mind and naturally, this encouraged functional specialists to make decisions favouring their own disciplines (Carter and Baker 1991, p.37; Clark and Fujimoto 1991, p.244; Dean and Susman 1989; Kamath, Mansour-Cole and Apana 1993; Liker and Fleischer 1992; Link 1986; Schein 1984; Zahra and Ellor 1993). Consequently, the design was often tossed back

and forth "over-the-wall" between design and manufacturing because of information incompleteness and the mismatch of product and process design parameters. This approach to product development therefore led to a number of negative outcomes including long development lead times, poor design quality, high product costs, high reject rates, and antagonism between design and manufacturing engineers (Liker and Fleischer 1992; Malinik 1991; Port 1990).

Today, more and more companies are finding that sequential engineering is not effective enough for designing and developing new products which must meet world-class standards of price, performance, and quality. To compete in the new business environment, companies need to change the basic structure of their product development process. Several empirical and qualitative studies (Clark and Fujimoto 1991; De Meyer 1992; Iansiti 1993a; Imai, Nonaka, and Takeuchi 1985; Liker and Fleischer 1992) indicate that integrated problem-solving by design and manufacturing is the most effective way to quickly design and develop low cost, high quality, high performance new products. This approach to product development is commonly referred to as concurrent engineering (CE). There are numerous examples both in the academic and public press literature of companies increasingly using CE (Crittenden 1992; Millson, Raj and Wilemon 1992; Rosenblatt and Watson 1991; Sprow 1992; Taft and Barclay 1993; Turino 1992, p.17-20; Zahra and Ellor 1993).

According to the CAIS technical report, CE is "a fundamentally new way of looking at how products - as well as their enabling technologies and manufacturing,

testing, and support processes - are conceived, specified, and developed" (Linton et al. 1991). It is a significant departure from sequential engineering as it involves changes both to the timing of upstream/downstream activities and to the frequency and type of information exchange between engineering functions.

The basic principles underlying CE include common goals, complete visibility of design parameters, mutual consideration of all decisions, collaboration to resolve conflicts, teamwork, and continuous improvement (Carter and Baker 1991; Linton et al. 1991; Painter, Mayer, and Cullinane 1991; Schrage 1993; Thurston 1993; Turino 1992). To achieve the CE promises of reduced development lead time, improved design quality, and reduced product cost, a unified organizational culture must exist. However, creating such a culture is by no means easy (Adler 1992; Ancona and Caldwell 1992; Beatty and Gordon 1988; Dougherty 1989; Lawrence and Lorsch 1967; Liker, Fleischer and Arnsdorf 1992).

1.2. Problem Statement

Concurrent engineering (CE) has received wide spread attention in the academic, public press, and trade journals. Most of the research to date has focussed on the impact of the co-located team implementation of CE on traditional project success variables (Fujimoto 1989). Of course this research provides very strong evidence of the advantages of incorporating integrated problem-solving as the basis for structuring product development activities. However, the existing body of CE literature is lacking

on four fronts: First, the literature has not examined the implementation of CE in a multi-location new product development (NPD) environment - that is, when key decision makers (e.g., design and manufacturing engineers) are geographically dispersed; Second, it is unclear from the literature whether a fixed degree of overlapping problem-solving, as a matter of management policy, is effective for different types of NPD tasks; Third, there is no research examining behavioral responses of the various functions, and their causes, towards uncertainty and equivocality in NPD; and Fourth, the literature has not systematically examined the use of communication-related information technologies in CE and in its global context.

Growing pressures on manufacturing companies to effectively leverage total company resources has resulted in these companies adopting a globally distributed manufacturing strategy (Bartlett and Ghoshal 1991; Burton 1993; De Meyer 1993; Motorola 1991; Nagel and Dove 1991; Port 1990; Rosenthal and Subramaniam 1994; Trygg 1991). For instance, MiniStor Peripherals, a well-regarded San Jose maker of compact disk drives for portable computers, has recently moved the manufacturing for its entire product line to Singapore while research and engineering is still done in California. With CE proving "effective" when design and manufacturing are co-located, the natural question is therefore, can the CE approach to executing NPD tasks be implemented when upstream (design engineers) and downstream (manufacturing engineers) are geographically separated? Stated more formally, the purpose of this study is to find answers to the following research questions:

- (1) can a globally dispersed team seamlessly develop new products using CE and if so, how effective is global CE (GCE) when measured using the yard stick of an effective functional overlapping problem-solving approach;
- (2) which managerial responses in terms of integrative mechanisms and communication technologies & tools are most effective for GCE;
- (3) to what extent does project scale impede CE and GCE;
- (4) is a fixed degree of overlapping problem-solving effective for various NPD tasks; and
- (5) what are the differences in attitudes, cognitive styles, and culture between design and manufacturing specialists that affect their effectiveness when dealing with task uncertainty and equivocality.

The contribution of this research to the existing body of knowledge is to further develop and refine the understanding of structuring NPD tasks using integrated problem-solving both in a single and multi-location environment. A model based on the existing literature is developed to study how single and multi-location manufacturing firms deliver new products to market using CE principles. Once empirically validated, this model will provide managers with prescriptions on how to more effectively manage the design and development of new products.

1.3. Outline of the thesis

This thesis is organized into chapters with specific sections. Chapter 2 reviews three specific domains of the management literature - new product development, project management, and organization theory - which serve as the foundation for the

conceptual model. Specific hypotheses are presented in chapter 3. The research methodology is described in chapter 4 and data analysis and results are presented in chapter 5. A discussion of results is included in chapter 6, followed by chapter 7 - the conclusion.

Chapter 2

LITERATURE REVIEW AND THE CONCEPTUAL MODEL

2.1. Overview

To study how manufacturing firms design new products for manufacture using Concurrent Engineering principles and the resulting success they achieve by introducing these products to market, a foundation is needed. To form the foundation for this thesis, reference is made to three specific domains of the management literature. These are: (1) new product development (NPD); (2) project management; and (3) organization theory (OT).

The model that is developed to better understand the design and development of new products is based on these three domains of the management literature. The NPD literature is used to understand the process by which new products are conceived, specified, designed, developed, and serviced. The project management literature is used to identify the determinants of successful product development projects (e.g., Cooper and Kleinschmidt 1987; Hayes, Wheelwright, and Clark 1988; Klimstra and Potts 1988; Larson and Gobeli 1988; Rothwell 1972) as well as measures of project success. Concurrent Engineering (CE) and the managerial and technological responses required to support it are addressed by the OT literature. In this domain, reference is made to the information processing perspective (Daft and Lengel 1986; Fujimoto 1989; Galbraith 1973; Thompson 1967), structural contingency theory (Pfeffer 1982), media

use theory (Culnan and Markus 1987; Rice 1980; Steinfield 1986; Svenning and Ruchinskas 1984), and information richness theory (Daft and Macintosh 1981; Daft and Lengel 1984; Daft, Lengel, and Trevino 1987).

Taken together, these domains of the management literature form the basis of the theory-based model that is developed. Before explaining the model in detail, it is necessary to review the literature in each of these domains.

2.2. New Product Delivery

2.2.1. The Relationship Between Design and Production

The process of designing and developing new products can be viewed as the set of activities, tools, methods, and procedures by which customer needs are translated into deliverable products (Carter and Baker 1991, p.148). This process involves capturing customer needs which are later translated into product requirements, functional subsystem specifications, design drawings, prototypes, and finally physical products. Throughout the product development cycle, many technical specialists such as design engineers, manufacturing engineers, and test engineers are involved together with customers, marketing representatives, suppliers, vendors, purchasing, and distributors - just to name a few.

There are essentially two systems that converge to produce a final product. The first is the design system and the second is the production system. According to Shirley (1992, p.83), design is "the process of specifying the characteristics of an

artifact in sufficient detail to allow it to be fabricated and to have confidence that its performance is acceptable to a set of a priori goals".

Simply put, what occurs in this design system is the following: First the users general product requirements (i.e., innovative styling, roominess, nice writing flow) and performance requirements (i.e., performs computations quickly, consumes less power, etc.) are captured. Next, these are translated into properties of the object (the product) that can be realized within the design and engineering process. Decisions concerning the form, fit, and functionality of the product take place in the design system by numerous design/engineering specialists, each performing a unique task. For instance, in the case of designing an automobile, advanced engineers would be responsible for long term development, systems engineers for system specifications, component (product) engineers for detailed specifications of a single component, product designers for developing detailed designs, and drafters for developing detailed drawings.

The production system involves the mobilization and configuration of people, parts, materials, equipment, and control systems to produce the intended product. There are a number of activities performed in the production system some of which include receiving and storage of raw materials, transportation of materials to assembly cells which may have flexible manufacturing systems capable of manufacturing a range of similar products, assembly of the product, test, inspection, and packaging of the final product. Using the same example of an automobile, it is evident that in the production system, numerous specialists are also involved. Process design engineers would be

responsible for designing the manufacturing process, plant manufacturing engineers for implementing, maintaining, and improving the manufacturing process in the plant, resident engineers for facilitating design changes, and test engineers for testing the product once it has been manufactured.

The design and production systems are very much interconnected. For instance, Downey (1969) has estimated that during the first 20% of the time spent in product design, 80% of the manufacturing costs of the product are determined. Here manufacturing costs refer to material costs, labour costs, logistic, and support costs. A more recent study at Rolls-Royce (Corbett 1986) revealed that design determines 80% of the final production cost of some 2,000 of the companies components. Stated differently, these two studies indicate that early design decisions about the product not only determine a large portion of manufacturing costs, but they also significantly reduce the range of feasible solutions - in terms of designing the production system on which the product will be manufactured - available to manufacturing personnel.

2.2.2. Stages of Product Delivery

There are numerous models used to describe the different activities which take place during the design and development of products. Although the names and level of specificity of the various phases (or stages) vary from industry to industry, and also among firms in the same industry, there is general agreement on the major stages. The model used in this study to describe the product development process is based on the

collective efforts of four researchers whose work will now be reviewed.

Cooper (1983) developed a seven stage model to describe the process by which industrial new products are designed and developed. The first stage, **Idea**, involves definition of a product idea. A product idea results from matching technological possibilities with expected market demand. **Preliminary Assessment** is the second stage and includes both preliminary market assessment (i.e., market feasibility) and preliminary technical assessment (i.e., technical feasibility). The third stage is **Concept**. The purpose of this stage is to better identify what the product is, who it is aimed for, and how it will be positioned against competitors' products. **Development** is the fourth stage in this model and the outcomes resulting from here include construction of a prototype and a formal marketing plan.

Stage five is **Testing**. Here the products design and features are validated by testing prototypes to ensure no technical flaws exist. Field testing of the product may occur in this stage. The sixth stage is **Trial**. Trial (or otherwise known as pilot production) involves testing the production methods that will eventually be used for full scale production. Modification of the production system takes place here to ensure the product is produced according to specifications and to ensure a "smooth" transition to volume production. **Launch** is the final stage in this model and involves startup of full production at the planned rate.

Based on his research of the world automobile industry, Fujimoto (1989) has also developed a model to describe product development. This model consists of four

major stages (Concept Generation, Product Planning, Product Engineering, and Process Engineering). According to Fujimoto (1989, p.602), "product development begins with the creation of product concepts".

In the **Concept Generation** stage, information on future market needs, technological possibilities, and economic feasibility is merged and translated into a product description that embodies the experience the product will deliver to the customer. A product concept emerging from this stage specifies how basic functions and features of the product will attract target customers.

Product Planning is the second major stage in this model. It follows the concept study and precedes product engineering. In this stage, the product concept is translated into product targets and specifications. The original product concept evolves in this stage because of the many tradeoff decisions among concept, specification, choice of components cost targets, and styling.

In the **Product Engineering** stage, information on product outlines such as concepts and technical targets is translated into a set of detailed parts and drawings (blueprints). At a microscopic level, there are essentially three separate activities performed here. The first involves developing detailed blueprints for the major subsystems and components. Prototypes are then built in job shop settings. Next, these prototypes are tested against established targets, evaluated, and then design modifications are recommended.

Process Engineering is the final stage by which product design information is

converted to physical products. Some of the activities performed here include planning of the overall production system (in terms of outsourcing plans and workforce plans) and individual level production lines/cells, designing tools and equipment, constructing/installing tools and equipment, NC part programming, and worker training.

By contrast, Fabbicino (1992) developed a three phase model to describe how electronic systems are designed and developed. Electronic systems refer to products consisting of a significant hardware and software component each of which needs to be designed and developed. The phases in this model include: (1) **Concept and Planning**; (2) **Development and Verification**; and (3) **Product Launch**.

The objective of the **Concept and Planning** phase is to specify as completely as possible the market for the product, the actual product, and the process for manufacturing the product. **Development and Verification** involves designing both the product and the manufacturing process. The last phase, **Product Launch**, involves achieving volume production at the planned rate.

The models reviewed so far essentially take the position that product development consists of a set of intertwined tasks beginning with a definition of what the product will be. Recent work by Gerwin (1993) builds on the models discussed, by including a preliminary phase dealing with long term strategic issues.

Gerwin (1993) studied four of North America's largest multinational computer and telecommunications firms. The model he developed to describe their (the companies) view of the development process includes five phases. The first phase is **Strategic**

Planning and New Technologies. Formulating long run strategies (from two to five years) for entire product families as well as individual functions is the emphasis here.

Market Requirements is the second phase and involves preliminary market evaluations to determine how technology can be matched to customer demand. The third phase is **Product Concept Definition**. A detailed product concept specifying the major functions and features of the product is the output of this phase. Phase four deals with developing technical specifications, drawings, and prototypes and finally, the last phase deals with preproduction and rampup.

The descriptive model of product development used for this study consists of seven stages. There are basically two differences between the model used for this study and the ones just reviewed. Firstly, the models reviewed do not formally emphasize enough the importance of having a "foolproof" concept. Etlie (1992) notes that concept generation/development is a unique stage that has not received the attention that it should. An unproven concept or one that is not well defined leads to confusion and is difficult to work with. Secondly, the model used for this study incorporates both front-end and back-end activities and presents a reasonably complete picture of the entire product development process. Following is a brief discussion of the seven stages. Table I highlights the relationship between the product development model used for this study and those reviewed above.

Strategic Planning and New Technologies is the first stage in this model.

Investigation of new technologies and long term product planning are carried out here.

Table I
Relationship Between Various Models

<u>Models Reviewed</u>				<u>NPD Model Developed</u>
<u>Cooper '83</u>	<u>Fujimoto '89</u>	<u>Fabbicino '92</u>	<u>Gerwin '93</u>	
			- Strategic Planning & New Technologies	• Strategic Planning/ New Technologies
<div>- Idea</div> <div>- Preliminary Assessment</div> <div>- Concept</div>	<div>- Concept Generation</div>	<div>- Concept & Planning</div>	<div>- Market Requirements</div> <div>- Product Concept Definition</div>	• Concept Generation
	<div>- Product Planning</div>			• Concept Develop.
<div>- Development</div> <div>- Testing</div>	<div>- Product Engineering</div>	<div>- Development & Verification</div>	<div>- Specs and Prototyping</div>	• Product Engineering
	<div>- Process Engineering</div>			• Process Engineering
<div>- Trial</div>			<div>- Pre-production & Ramp-up</div>	• Ramp-up to Prod.
<div>- Launch</div>		<div>- Product Launch</div>		• Volume Production

Concept Generation is stage two and the activities occurring here include idea generation, performing initial market and technology studies, and specifying a detailed outline of the functions and features the product will have.

Concept Development is stage three. Once the product outline has been specified and tested (i.e., early filters), decisions need to be made about optimizing the product concept so as to maximize the product experience to targeted customers.

In **Product Engineering** (stage four), high-level system designs and detailed subsystem and component designs are completed. **Process Engineering** is stage five and the activities performed here include planning for the production system and constructing designs for tooling and equipment. Stage six is **Rampup to Production**. Pilot production takes place here enabling optimization of the production system. The last stage is **Volume Production** and the objective here is to achieve the planned rate of production.

2.2.3. Product Development Tools and Techniques

Product development is a complex task requiring the execution of a set of collective efforts. Numerous functional specialists are involved in performing analysis and making decisions. According to Bebb (1992), there are over 200 design tools, practices, procedures, and methods which can be used during the design and development of products. A comprehensive discussion of each of these "design aids" is beyond the scope of this study however, a brief discussion of an assortment of these

"design aids" follows.

Joint competitive analysis is a technique used by firms to determine how their current product offerings compare to the existing and anticipated product offerings of competitors. Value analysis is a procedure used to determine what the major functions and features of a product should be. Value engineering is a technique that can be used to translate product functions and service requirements into product cost and materials guidelines.

Tradeoff analysis is a process of analyzing design choices through what-if scenarios. It is used for instance to determine which features, among a number of alternative features, to select to incorporate into the product. This selection procedure may be made according to cost criteria.

Simulation refers to the modelling of a system by a representation in which the variables change over time (Law and Kelton 1991, p.109). As an analysis tool, simulation has all but eliminated the need for breadboard design - a method to evaluate a design using physical components electrically interconnected with some form of hand-wired connections. One example of the use of simulation is in VLSI (Very Large Scale Integration) circuitry design.

The techniques of VLSI allow IC (or chip) manufacturers to combine several hundred thousand or several million electronic components on a single chip. With increasing pressure to design more powerful (i.e., more electronic components) and compact chips, sophisticated tools such as simulation are used to test alternative

designs and perform analysis to ensure that state-of-the-art chips deliver high performance, yet do not violate thermal and physical properties. Specific instances of the different types of simulation used in VLSI circuitry design include: (i) logic simulation for gauging functionality; (ii) fault simulation for determining the detectability of a failure; and (iii) analog simulation for verifying design parameters.

Design for assembly (DFA) is an analysis process intended to reduce the assembly costs of a product by simplifying the product design. Boothroyd and Dewhurst (1987) note that DFA has two objectives. The first is to minimize the number of parts and the second is to ensure that the remaining parts can be easily assembled.

DFA can be conducted manually or with software. It has been noted in the literature that this technique has been widely used for component parts and medium-sized products and not at the system level for large scale products (Stoll 1988; Ulrich, Sartorius, Pearson and Jakiela 1993). One of the possible reasons for this is that DFA requires extensive knowledge of all parts and their relationships; large amounts of information need to be processed when using DFA and it is likely that this processing is more effectively performed at the subsystem or component level.

Quality function deployment (QFD) is a technique used in product development for designing products that meet customer requirements. It was developed in 1972 at Mitsubishi's Kobe shipyard and it is estimated that there are close to 100 firms in both Japan and the United States who are currently experimenting with it (Griffin and Hauser 1992). QFD uses four "houses" to integrate the informational needs of various

functions involved in product development. It is best known by the first "house" which is the House of Quality (Hauser and Clausing 1988). QFD focuses on the customer and essentially involves capturing customer desires (attributes) and translating them into engineering design attributes.

2.3. Project Management

Success in product development is a crucial management issue for the modern firm, however, realizing and sustaining it is not an easy task (Barclay 1992; Calantone, di Benedetto and Divine 1993; Ettlie 1992; Taft and Barclay 1993). This section reviews empirical and conceptual research which identifies the major determinants of successful product development projects as well as measures of success.

Cleland and King (1983, p.187) have formally defined project management as, "a combination of human and nonhuman resources pulled together in a 'temporary' organization to achieve a specific task." A further review of the literature reveals that the terms project manager, program manager, product manager, and project leader are used interchangeably and all refer to the same concept of bringing people together within similar or different departments, divisions, or even companies to work on a specific task (or project). Project managers, whose basic task is to coordinate across functional subunits within the product development group, essentially bring about project management as defined above.

2.3.1. Determinants and Measures of NPD Success

This section first reviews the relevant engineering management literature followed by the design-production literature to identify those factors that contribute to successful product development projects.

The earliest work in studying new product development focused on providing detailed descriptions of each phase of the development process (Morison 1966; Sorenson 1971; Baruch and Kiser 1973). Researchers then began to study successful and unsuccessful projects. One of the first studies of new product success was conducted by Myers and Marquis (1969). This landmark study of 567 product and process innovations developed by 121 firms in 5 manufacturing industries established the importance of designing products to satisfy perceived user needs rather than to take advantage of state-of-the-art technology. In this study, they showed that only 21 percent of the successful projects were associated with technology push strategies and the vast majority of the remainder were associated with market pull (or market-derived) strategies.

The Scientific Activity Predictor from Patterns of Heuristic Origins (SAPPHO) study was the first industry comparative study of product success and failure (Rothwell 1972). Researchers of this study were able to discriminate between successful and unsuccessful projects on the basis of five underlying factors including understanding user needs, effectiveness of marketing, efficiency of development (i.e., minimize design and production defects), effective use of resources external to the firm, and importance

of project champions (or strong project leaders). Subsequent European studies, modeled after SAPPHO, were conducted by: (i) Szakasits (1974) - a study of Hungarian electronic products; (ii) Gerstenfeld (1976) - a study of West German products; and (iii) Kulvik (1977) - a study of Finnish products. These studies confirmed the major findings of the British SAPPHO study - that there exists a pattern of factors that differentiates successful from unsuccessful projects.

Other studies by American and Canadian researchers have also identified major influencing factors on product success. Rubenstein et al. (1976) studied 103 U.S. projects in various industrial firms and concluded that internal management factors such as improving inter-functional harmony had a major impact on project success. Cooper's and Kleinschmidt's (1987) study of 203 Canadian product winners and losers was based on Cooper's Project NewProd (Cooper 1979). These researchers wanted to identify the organizational and project team factors that contributed towards project success. Up-front product planning, marketing and technology synergy, and development of high value products as perceived by customers were the important success factors reported by these researchers.

This study by Cooper and Kleinschmidt is interesting since it suggests that to succeed, new products should be developed by taking advantage of the expertise available from R&D and production, and not just from marketing. It however, did not study the interfaces between functional subunits involved in product development or the importance of key sponsors.

In summary, the engineering management literature reviewed provides insight into the underlying pattern that differentiates between successful and unsuccessful projects. However, for the purpose of this thesis, this literature falls short on a number of counts. First, none of the literature reviewed focuses on the process of product development. There is no guarantee that underlying factors associated with successful projects are indicative of an "effective" product development process. Second, concurrent engineering projects are not studied in the literature reviewed. This is important since this thesis studies projects which incorporate CE principles. Third, the measure of "success" used in the studies is based on financial considerations only (i.e., a successful project is one which generated profits while an unsuccessful project resulted in financial loss). This is limiting since companies today compete on multiple dimensions. Fourth, "newness" is conceptualized using the classical low-level dichotomy - this does not allow for the disentanglement of newness based on concept, technology, and market.

The design-production literature focuses on the process of product development and identifies types of variables associated with project success. In this literature, project success is measured in terms of schedule, cost, and quality. For the purpose of this thesis, one major benefit of reviewing this literature is that it provides valuable insight into process based success factors of development projects.

Hayes, Wheelwright, and Clark (1988) have identified four determinants of high-performing development projects: (1) approach to product development, (2) approach

to conflict resolution, (3) project structure, and (4) manufacturing capability. These authors operationalized "high-performing" in terms of the traditional project success variables of schedule, cost, and quality found in this literature. These four determinants will be discussed briefly below.

The most effective approach to product development is through overlapping problem-solving (Clark and Fujimoto 1991; Fujimoto 1989; Iansiti 1993a). Development lead time is directly affected by the nature of engineering problem solving. Overlapping upstream (product engineering) and downstream (process engineering) activities means that product design and manufacturing process design can occur simultaneously.

Three rules that these authors have proposed to resolve conflicts include surface conflicts as early as possible, resolve conflicts through mutual adaptation, and resolve conflicts at the lowest competent level. The most effective project structure is one with a "heavyweight" project manager.

Manufacturing capability is defined as the ability of manufacturing personnel (from engineers to line operators) to partake in problem solving and organizational learning.

Empirical studies conducted by other researchers investigating the success of new product development projects report similar types of variables. Imai, Nonaka, and Takeuchi's (1985) study of five innovative products developed by Japanese companies identified overlapping development phases and self-managed development teams as important factors contributing towards a quick and flexible development process.

Florida and Kenny (1991) in their study of successful Japanese projects discuss the importance of job rotation as a factor contributing towards project success. In another study of over 330 new products in the electronics industry, Zirger and Maidique (1990) found top management support to be a factor influencing project outcomes.

Although project structures have been identified as an important determinant of project success, research into the appropriateness of various project structures is conflicting. For example, Allen and Hauptman (1990) in their study of project structures developed a conceptual model proposing that in rapidly changing technical areas, functional structures are more effective than project team structures at maintaining state-of-the-art knowledge. Logically what this means is that when knowledge is quickly changing, a project structure which maintains the technical proficiency of its members should result in outputs that measure high on technical performance. This however was not the case according to Larson and Gobeli (1988). In their study of 540 development projects, they found that over 70 percent of the projects exhibiting superior technical performance used a non-functional (i.e., either a balanced matrix, project matrix, or project team) project structure. Although it appears that conceptual and empirical research are at odds, it is important to point out that one of the possible reasons for this discrepancy is that the firms sampled by Larson and Gobeli (1988) may not be in industries characterized by rapid changes in knowledge.

To summarize, the design-production literature identifies a number of important project based factors contributing towards the success of product development projects.

The next section discusses the underlying theory which forms the basis for the managerial and technological responses required to support product development using CE principles. Following this, the conceptual model is presented.

2.4. Organization Theory Literature

2.4.1. Information Processing Perspective

The view of an organization as an information processing system has received considerable attention in the literature on organization theory (Connolly 1977; Daft and Macintosh 1981; Daft and Lengel 1986). Organizations as open systems continually process information (Mackenzie 1984) in order to accomplish internal tasks, to coordinate activities, and to interpret the external environment.

One important distinction that has been cited in the literature is the difference between individual information processing and organizational information processing. According to Tushman and Nadler (1978), individuals are involved in information processing whenever they gather, interpret, and synthesize information in response to problems.

Organizational information processing however is more than this (Daft and Weick 1984) as it involves information sharing and the need to cope with differences (Daft and Lengel 1986). Individual stakeholders in organizations may have different interpretations of the same events and this makes group decision making difficult. Organizational information processing therefore involves interactions among

participants to share information so that a group consensus can emerge.

This study emphasizes information as a key concept in analyzing the success manufacturing firms are achieving by using concurrent engineering (CE) principles to design new products for manufacture. The information processing paradigm, which has been widely used by researchers in a number of disciplines to study for example R&D management (Allen 1977; Marquis 1982), marketing (Kotler 1984), consumer behaviour/marketing (Galbraith 1973), and organization (Tushman and Nadler 1978), enables the examination of the creation, communication, and use of information. This is important in dealing with the current research topic since a major theme is to use the information processing perspective to investigate organization information processing among individuals involved in designing and developing new products using CE.

A number of researchers (Eastman 1972; Fujimoto 1989; Rosenthal and Tatikonda 1992; Slusher and Ebert 1992) have used the information processing perspective to study a variety of issues in new product development. Using this perspective as an analysis tool, the design and development of new products is essentially viewed as a set of information processing tasks where knowledge of market needs and technological opportunities are translated into information assets for production. This means that each stage (i.e., from the time the product is planned to actual production which represents the physical embodiment of the product concept) of the descriptive model of product development used for this study involves the processing of information.

The term information processing has been used thus far without establishing a formal definition. In his research of the world automobile industry, Fujimoto (1989, p.75) defines information processing as, "activities which change the state of information, including information content, media, and location". It is important to note that this definition consists of both information creation and information transmission. Information is created whenever its content changes so that it represents something different while staying in the same media (e.g., engineering design changes on the same blueprint). Information is transmitted whenever the same information (and media) is simply moved to different locations (e.g., sending detailed drawings from product engineering to process engineering) or whenever the same information, representing the same thing, is copied to different media (e.g., a CAD drawing translated into programmable code for NC machines).

An interesting question arises in analyzing this definition of information processing and that is: are the two concepts of information creation and information transmission related in a way such that information is created once it has been transmitted (i.e., information transmission refers to the same information representing the same thing but in different media)? A review of the literature reveals that there may be different answers depending on the rigidity with which the information creation definition is applied.

In the first case where the information creation definition is strictly applied, information transmission does not lead to information creation since the process of

information transmission only results in the use of new (or different) symbols with the relationships among the symbols and their representative domains remaining unchanged. The second case however focuses on information creation from the perspective of the individual consumer of information and in so doing, it regards information creation as a possible outcome of information transmission. In this case, the position is that individuals impose conceptual schemes on the information they consume and therefore new meaning is created (the extent of which depends on the individual) simply by using different symbols in different media.

In summary, the information processing perspective as an analysis tool to study organizations has its roots in Galbraith's (1973) work. For the purpose of this study, this perspective views new product development as a process by which intangible ideas and data on markets and technology are transformed into "new" knowledge (or information) for commercial production. Product development activities are therefore information transactions whereby information is retrieved, screened, used, transmitted, shared, synthesized, created, and disseminated. From this perspective, the final output of product development is not a physical product but rather an information base about the product.

2.4.2. Review of the Relevant Theories

This section reviews three theories which form the basis for the conceptual model. These theories are: (1) structural contingency theory; (2) media use theory; and (3)

information richness theory.

Survival is a basic goal of all organizations. Huber (1984) notes that, "organizations whose structures, processes, and technologies are well suited to their environments have a greater likelihood of survival than do those whose structures, processes (and technologies) are poorly suited to their environment". This statement logically follows from the research associated with the contingency theory of organizational scientists (Burns and Stalker 1961; Lawrence and Lorsch 1967; Duncun 1973). According to Pfeffer (1982, p.147) contingency theory (or structural contingency theory) has been widely used to explain different organizational designs.

Contingency theory, which has an emphasis on efficiency, argues that the design of the organization depends on various contextual factors. Galbraith (1973) nicely summarizes the two basic premises of the theory as: (1) there is no one best way to organize; and (2) any (one) way of organizing is not equally effective (with other ways of organizing). As an organizations environment changes, contingency theory argues that it is necessary to redesign internal processing capabilities such as structure and technology in order to attain a certain level of performance (Galbraith 1977; Lawrence and Lorsch 1967; Tushman and Nadler 1978).

When the environment changes to a state that is incompatible with the existing organizational design, organizations can respond by adopting any one of four strategies (Huber 1984): (1) they can adapt to the changed demands to attain a new equilibrium state; (2) they can move to a different environment; (3) they can change the

environment to make it compatible with the existing organizational design; or (4) they can do nothing (i.e., rely on buffers). If organizations adopt either the first or second strategies, contingency theory proposes that survival depends on organizational designs which are sensitized to the external environment. Pursuing strategy four, according to the theory, will eventually lead to the demise of the organization. Strategy three is clearly proactive, however, according to the theory, the adoption of this strategy is all but ruled out since the environment is a constraint to which the organization must adapt (Pfeffer 1982, p.148).

Researchers (Culnan and Markus 1987; Rice 1984; 1992; Steinfield 1986) have determined that media use is influenced by a number of factors including accessibility, availability, personal style, time and cost advantages, and communication requirements of the task. Media use theory is used to explain media use behaviour. It proposes that individuals choose media through a matching process which first involves assessing the communication requirements of the task then selecting that communication medium (or channel) with the communication capabilities to meet the requirements specified by the task. According to Williams (1977), efficient (time and cost advantages) communication takes place when the medium has neither more nor less communication capability than required by the task.

The basis of media use theory is the rational choice model (Fulk, Schmitz, and Steinfield (1990). The four premises of this model are: (1) individuals make choices independently of the choices made by other individuals; (2) choice-making involves

cognitive evaluations of media attributes and message requirements; (3) individuals objectively evaluate characteristics of the task and media and then make rational choices in deciding what is an optimal match - i.e., it therefore logically follows that different people in the same situation will use the same media; and (4) individual behaviour is efficiency-motivated.

In order to further understand the evaluation and selection process associated with communication media, information richness theory is used. Researchers (Daft and Macintosh 1981; Daft and Lengel 1986; Daft, Lengel, and Trevino 1987) have determined that a key criterion for media choice is ambiguity (or equivocality). One of the characteristics on which communication media differ is in their ability to facilitate understanding (Daft and Lengel 1986; Hauptman 1992). From this perspective, media are arrayed along a continuum of "information richness" based on four criteria:

1. Speed of feedback - instant feedback allows questions to be asked and corrections to be made.
2. Multiple cues - an array of cues (i.e., physical presence, voice inflection, body movement, words, graphics, and numbers) may be part of the message.
3. Richness of language carried - the range of meaning that can be conveyed with language symbols.
4. Personalness of the source - a message will be conveyed more fully when personal feelings and emotions infuse the communication.

Information richness theory proposes that "rich" media should be used for

ambiguous tasks, while "lean" media should be used to complete unambiguous tasks. There is some empirical evidence providing support for the basic information richness proposition. For instance, Daft, Lengel, and Trevino (1987), in their study of 95 managers of a large petrochemical company found that those managers showing a high correlation between media richness and message (or task) equivocality had higher performance ratings than did managers showing a weak correlation between richness and equivocality. There are two major limitations of this study. First, media use was associated with hypothetical communication incidents and second, the generalizability is limited since the sample included a single company.

Another study which provides support for the information richness proposition is the work by Rice (1992). In his meta-level study of new media (e-mail, v-mail, electronic databases, and videoconferencing) use in day-to-day work settings, Rice (1992) found modest support for the theory. There is however one major methodological problem with his study and that is he did not study use of the same media across all firms in his sample. For example, to study e-mail, his data comes from a small, decentralized federal agency office while his data for v-mail is based on respondents from a large insurance organization.

2.5. Development of the Conceptual Model

2.5.1. Introduction

This section develops the model (see figure 1) that is used to study how single and

Figure 1:
Conceptual Model

multi-location manufacturing firms deliver new products to market using concurrent engineering (CE) principles and the resulting success they achieve. The deductive model is based on a contingency perspective which follows the general assumption that no single organizational design is universally superior (Galbraith 1973). Thus the basic idea behind the model is that when new product development (NPD) projects are managed in ways contingent on the special characteristics of each project, a greater likelihood of success exists.

A number of researchers (Adler 1992; 1993; Andreasen 1987; Coughlan 1992; Daft and Weick 1984; Iansiti 1993b; Morley and Pugh 1987; Slusher and Ebert 1992) support this line of reasoning and recent empirical studies (Ancona and Caldwell 1992; Bart 1993; Clark and Fujimoto 1991; De Meyer 1992; Tyre and Hauptman 1992) support the existence of a contingency relationship. Managing NPD projects in different ways logically implies the creation of different organizational designs. This thesis argues that developing "new" products (i.e., products based on new concepts and which incorporate unproven technologies) is a different task than for example, developing products which are line extensions and which incorporate proven technologies. For projects characterized by a greater degree of novelty, the choice of product design parameters are more sensitive to the choice of process design parameters and vice versa (Adler 1992; 1993; Coughlan 1992). According to the theory of dispositions (Olesen 1991), when the relationship between product and process design parameters is strong, decisions taken in one functional area greatly

affect the efficiency of activities in another functional area. Therefore, in order to efficiently and effectively determine the optimal match between product and process design parameters, a greater level of overlapping problem-solving should be initiated.

It is important to point out that both novelty and interdependence are sources of uncertainty (Daft and Lengel 1986; Galbraith 1973; Iansiti 1993b; Lawrence and Lorsch 1967; Tushman and Nadler 1978; Tyre and Hauptman 1992). When novelty is high, the resulting interdependence that is created through overlapping problem-solving requires the deployment of highly integrative coordinating mechanisms (e.g., teams). In order for this (teams) highly integrative coordinating mechanism to effectively manage interdependence (and therefore coordinate work), integrative mechanisms such as co-location, status parity, top management support, and group based rewards/evaluations are needed to reduce differentiation.

For less new products, "new" design tasks are similar to past design tasks. This is because less new products are a function of earlier products in their families. Consequently, this means that less information processing is required since the choice of the majority of product and process design parameters are pre-determined from earlier products in the line. To determine the values of the remaining design parameters, full overlapping problem-solving may be unhelpful and wasteful. Coughlan (1992) studied the influence of early manufacturing involvement on performance and found that full overlapping problem-solving results in more manufacturability-related changes for less new products. One possible explanation for

this phenomena might be that manufacturing have a strong tendency to alter the values of pre-determined design parameters to more closely reflect what they feel these values should be.

Project scale refers to the location of the output, of a product development effort, on a hierarchical ladder of systems, subsystems, and components. As the scale of a project increases, a complicated network of interactions is created - there are direct interactions between components in a single subsystem and between components across subsystems at various levels. An increase in project scale not only increases coordination requirements (Tushman 1978) but, in the case where each individual has to know the details of the decisions being made by other individuals in the project, it also increases the total amount of information that has to be processed by individuals. However, individuals have limits on the amount of information they can process (Rao and Jarvenpaa 1991) and therefore, there is a need to progressively sub-divide large scale projects. Stated differently, modularity simplifies the information processing requirements of individuals.

To summarize, the model states that in order to attain the results promised by CE, a "fit" is needed between the various dimensions of managerial responses and the specific context in which new product development (NPD) is executed. Integrative mechanisms and communication technologies and tools, derived from organization theory and project management, are the two dimensions of management responses used to support varying degrees of overlapping problem-solving. The degree of overlapping

problem-solving is determined by the context of NPD, which is defined by the characteristics of the task and the constraints. Traditional project success variables, cooperation, and participants' satisfaction with the development effort are among the dependent variables studied in the model. Before describing the model further, the concepts of "fit" and product "newness" are discussed followed by a review of the literature associated with traditional product development and CE.

2.5.2. Conceptualizing Fit

Researchers (Blalock 1965; Van de Ven 1979; Van de Ven and Drazin 1985; Venkatraman 1989) have argued that in order to strengthen the relationship between theory building and theory testing, a correspondence must exist between the concept of fit that is used and its mathematical formulation. For this reason, it is therefore important to specify the particular conceptualization of fit used in the model.

Fit as a moderator has been widely used in organizational research (Leonard-Barton and Deschamps 1988; Liker and Fleischer 1992; Rusinko 1992; Tyre and Hauptman 1992). This is mainly because of its conceptual link to theory specifying that the impact of a predictor varies across different levels of a moderator. The basic idea behind fit as a moderator is that when two variables interact, the impact the predictor has on a criterion variable is dependent on the level of a third variable (the moderator).

In the model, overlapping problem-solving is viewed as the primary moderating variable influencing the relationship between task characteristics and project

outcomes/results. Varying degrees of overlap which are appropriate for different NPD contexts, must be supported by the "right" integrative mechanisms and communication technologies and tools. Thus the two dimensions of management responses are also viewed as having a moderating effect. Media Use Theory and Information Richness Theory are used to determine which communication related information technology are appropriate for specific degrees of overlap.

It is important to mention that the deductive model is doing two things. Firstly, it is testing for the existence of fit and secondly, it is testing the effect of fit.

2.5.3. Conceptualizing Newness

Task characteristics help define the context in which NPD is executed. One of the more important factors shaping the task characteristics of a NPD project is "newness". This term newness has been conceptualized in a number of ways in the literature. In the technical innovation literature, newness is related to innovativeness. A common categorization of innovation used here is "radical" or "incremental" (Freeman 1982; Dewar and Dutton 1986; Barczak and Wilemon 1991).

Radical innovation represents significant change for the firm and often opens up new markets and applications (Dewar and Dutton 1986; Henderson and Clark 1990). Radical innovations include products completely new (in terms of concept) to the firm (Johne and Snelson 1989), products based on new technology (Bart 1988; Tushman and Nadler 1986), and new ventures unrelated to existing businesses (Bart 1988). New

product families or the addition of an entirely new product line is usually the outcome of a radical innovation.

Incremental innovation in contrast introduces relatively minor changes to an existing product (Bart 1988; Ettlie, Bridges, and O'Keefe 1984). These innovations are related to the firms current products and businesses and generally take the form of product modifications, upgrades, and line extensions (Johne and Snelson 1989).

A further review of the literature has identified a number of other ways in which researchers have conceptualized newness. For instance Heany (1983) conceptualized product newness in terms of style changes, product line extensions, product improvements, new products for the current market, and new products for a new market. Yoon and Lilien (1985), who dichotomized products according to original versus reformulated, and Rusinko (1992), who dichotomized according to new versus enhancement, each used a two category typology of product newness. Meyer and Roberts (1988) conceptualized product newness in terms of minor improvement, major enhancement (of an existing product), new but related technology, and new but unrelated technology.

In their study of technological change in the production process, Tyre and Hauptman (1992) conceptualized newness along the technology dimension. They operationalized newness of the production process in terms of technical complexity and the degree to which the new process diverged from the existing systemic practices.

One common theme emerging from reviewing these studies is that newness (of the

product or process) is a multi-dimensional concept. For example, product newness has three dimensions - technology, concepts, and markets - whereas process newness has only two - technology and concepts. A reason why newness has been conceptualized differently in the literature is because different researchers have emphasized different dimensions. In this thesis, newness is conceptualized along the technology and concepts dimensions.

2.5.4. Interdependence and Coordination

This section introduces the various types of interdependence and typology of coordinating mechanisms found in the organization theory (OT) literature. The underlying interdependence that exists between participating departments in product development and the associated coordinating mechanism employed to manage them to ensure success at designing new products for manufacture using CE, is specifically discussed in the section on integrative mechanisms.

According to Thompson (1967, p.54), there are three different types of interdependencies: (1) sequential - outputs of one subsystem serve as inputs to another subsystem (i.e., there is a linear one-way flow); (2) pooled - each subsystem is supported by a common resource base and collectively, these subsystems contribute toward the attainment of the systems goal; and (3) reciprocal - outputs of each subsystem serves as the input of another subsystem and vice versa (i.e., there is a two-way flow).

This concept of interdependence is not proprietary to the OT domain; it is used in the Software Engineering (SWE) literature labelled as "coupling". The concept of coupling was first described by Stevens, Constantine, and Myers (1974) as part of the "structural design" approach to software design and a common definition of coupling found in the SWE literature is: the degree of dependence between software modules (Fairley 1985, p.148). In comparing the treatment of interdependence and coupling, an interesting point emerges and that is, in the OT literature, interdependence is viewed as something that is tolerated and managed by way of coordinating mechanisms. In contrast, the SWE literature, which has as its goal the design of software products so that the number and complexity of interconnections between modules is minimized, views coupling, and especially content coupling (where one module modifies the local data values of another module), as something that should be minimized.

Coordination is conceptualized in the OT literature as a means of achieving concerted action in situations where interdependence among differing tasks exist (Thompson 1967). Researchers (March and Simon 1958; Thompson 1967; Van de Ven, Delbecq, and Koenig 1976) have identified four generic coordinating mechanisms, each of which differ along the three dimensions of: (i) the type of interdependence they support; (ii) the amount of information processing they provide; and (iii) the integration among participants they require. These coordinating mechanisms are now briefly discussed, with each successful mechanism representing higher levels on each of the dimensions just discussed.

Standardization or rules is the first and, most impersonal coordinating mechanism. Essentially what this mechanism refers to is standards, guidelines, and rules which are comprehensive and accurate enough so that they can in some cases, enable product development and process design staff to operate independent of each other. Adler (1992) notes that standards can be a powerful coordinating mechanism if the organization can develop an explicit characterization of its manufacturing capabilities in the form of producibility design rules. For example, in the design of printed circuit boards (PCBs) - a glass epoxy-type board on which discrete components such as resistors, capacitors, and ICs are mounted - rules can specify parameters such as the width and spacing of the lines that can be reliably printed onto the PCB and the pad sizes required to solder components to the board effectively. It is important to note that in the design and manufacture of PCBs, if the manufacturing process is changed significantly from traditional through-hole technology (which was used in the past) to surface-mount technology (a new technology for this particular design), then this coordinating mechanism will need to be supplanted by more integrative forms.

The second mechanism is plans and schedules which proves effective when guidelines cannot guarantee a fully producible product. In this case a sign-off is scheduled to give manufacturing a chance to verify the producibility of the specifications. The sign-off procedure is more interactive than standards or rules and gives manufacturing the opportunity to signal that it accepts responsibility for making a product to design specification. In this procedure, manufacturing also reserves the

right to veto the specifications as infeasible.

Mutual adjustment is the third coordinating mechanism which is used when rules and sign-off procedures do not suffice. It can take the form of design reviews whereby design engineers and manufacturing personnel meet to adjust the product and process designs before too much effort has been expended. Engineering change orders (ECOs) are another form of mutual adaptation. In this case, when manufacturing receives the detailed drawings, it can send back a list of changes that have to be made in order to make the design more producible. ECOs are discussed in more detail in a later section of this chapter.

The most integrative and personal coordinating mechanism is the team. This mechanism can be viewed as the most ambitious form of Design for Manufacturability (DFM) - a variety of ways to improve product development - and allows for the real-time joint optimization of product and process design choices. This will be discussed in more detail, in the context of CE, later in this chapter.

In summary, research on interdependence and coordinating mechanisms reveals that more integrative and personal forms of coordinating mechanisms should be used as interdependence increases from sequential to reciprocal (McCann and Galbraith 1981; Thompson 1967).

2.5.5. Traditional Product Development

For the past four decades, companies have developed new products using a

bureaucratically programmed approach whereby different functional specialists are responsible for performing specific tasks at different points in time (Chapman, Bahill and Wymore 1992, p.326; Kagona et al. 1985; Liker, Fleischer and Arnsdorf 1992; Linton et al. 1991; Turino 1992, p.1). A new product development project using this sequential (or traditional) engineering approach can more or less be described in the following way.

Once the major product functions are specified, design engineers develop preliminary, detailed specifications of all subsystems and component parts. Prototypes are then built and tested to determine the operational feasibility and manufacturability of the product. Through design reviews, manufacturing learns about the product and then begins designing the overall manufacturing process which, may include discussions with equipment vendors and parts suppliers to subcontract portions of tooling and equipment manufacture. Furthermore, manufacturing complains that tolerances are too tight and certain shapes are difficult to machine and therefore issues engineering change orders (ECO's). Design then makes those changes that least interfere with the product functioning and vetoes those that cause the design to unravel. Manufacturing receives another set of blueprints and begins initial production. Problems are discovered in early production and manufacturing subsequently issues ECO's to design engineers who by this time, have moved on to another product design project. These ECO's are therefore not given a high priority by design engineers so manufacturing secretly makes the changes or ship products that are not within

tolerances.

The description above highlights some of the predominant characteristics of traditional product development which include: (i) sequential interdependence between design and manufacturing (Thompson 1967); (ii) linear problem-solving consisting of one-way, batch transfer of highly certain information (Clark and Fujimoto 1989); (iii) little integration between design engineering and manufacturing thus promoting a "we-they" attitude; (iv) coordination between design engineering and manufacturing in the form of ECO's; and (v) management of ECO's with an eye towards checks and balances rather than fast implementation in the early stages of product development (Clark and Fujimoto 1991, p.121).

According to Andrew (1975), ECO's are issued to improve product design, reduce costs, simplify tooling, facilitate assembly, rectify an inadvertent or intentional omission, and introduce new features. Trygg (1990) reports that 40 to 50 percent of all ECO's in the companies he studied, were a result of "knowledge gaps" between design engineering and manufacturing. ECO's can thus be viewed as a behavioral response to an "ineffective" product development process. They not only cost in terms of time, productivity, and money (Bebb 1990; Clark and Fujimoto 1991, p.121; Hayes, Wheelwright and Clark 1988, p.279; Mital and Morse 1992; Rusinko 1992, p.61), but also encourage a "redo-until-right" mentality that plagues traditional product development even after the product is released and well into production (Sullivan 1987; Turino 1992, p.3). One of the major causes contributing to ECO's is the

existence of different engineering cultures (e.g., product performance and aesthetics versus manufacturing feasibility and cost) encouraging functional specialists to make decisions favouring their own disciplines (Carter and Baker 1991, p.37; Clark and Fujimoto 1991, p.244; Dean and Susman 1989; Liker and Fleischer 1992; Link 1986; Schein 1984; Zahra and Ellor 1993).

2.5.6. Concurrent Engineering

This section reviews the concurrent engineering (CE) literature. Emphasis is placed on defining CE, understanding why companies are experimenting with it, identifying how it differs from sequential engineering, reviewing the different conceptualizations of CE found in the literature, and reviewing recent empirical studies.

Today, more and more companies are finding that sequential engineering is not effective for designing and developing new products which must meet world-class standards of price, performance, and quality. Because sequential engineering operates on the principle that new product development tasks can be divided into mutually exclusive speciality domains, product and process design parameters which are inherently interconnected, are not determined simultaneously. Consequently, this leads to long development lead times, poor design quality, high product costs, high reject rates, and antagonism between design and manufacturing engineers (Liker and Fleischer 1992; Malinik 1991; Port 1990).

CE (or simultaneous, or parallel, or producibility engineering) is commonly defined

in the literature as the integrated and parallel design of products and their related processes, including manufacturing, test, and support. It is an approach to product development with which companies are increasingly experimenting (Crittenden 1992; Millson, Raj and Wilemon 1992; Rosenblatt and Watson 1991; Sprow 1992; Taft and Barclay 1993; Turino 1992, p.17-20; Zahra and Ellor 1993). This is mainly because (CE) promises improved design quality, shorter development lead time, reduced costs (e.g., product design, fabrication, delivery, and support), fewer late engineering change orders, fewer prototypes, reductions in scrap and rework, and improved production efficiency (Garrett 1990; Jo, Parsaei, and Wong 1991; Kim 1991; Kusiak and Wang 1993; Olesen 1991; Painter, Mayer, and Cullinane 1991; Sharon 1992; Van Voorhis 1993; Vesey 1991).

There are four major characteristics that differentiate CE from sequential engineering. First, the principles behind CE emphasize collaboration, communication, cooperation, and consensus. According to the CALS/CE Technical Report (Linton et al. 1991), the CE principles include common goals, complete visibility of design parameters, mutual consideration of all decisions, collaboration to resolve conflicts, teamwork, and continuous improvement. Second, CE is characterized by reciprocal interdependence (Thompson 1967) which simply describes the mutually constraining relationship that exists between upstream and downstream functions. Third, CE involves functional overlapping problem-solving which shortens lead time not so much by reducing the duration of upstream/downstream tasks but rather by simultaneously

executing them. As noted by Clark and Fujimoto (1991, p.210), overlapping problem-solving must be matched by changes in the nature and frequency of information flow, the timing of upstream/downstream tasks, and the attitude throughout the organization towards dealing with preliminary information. Fourth, the distribution of ECO's in CE is skewed towards the earlier stages of product development, when the cost of change is relatively low, and tails off once volume production has begun.

In recent years CE has received widespread attention, however, it is important to note that the ideas behind CE are not altogether new. For instance, Gladman (1968) was one of the first to emphasize that products should be designed "right-first-time". The idea of parallel problem-solving in development was first described by Abernathy (1971) and has been stressed as a critical element contributing to the success of Japanese new product development efforts (Imai, Nonaka, and Takeuchi 1985; Clark and Fujimoto 1991).

CE is conceptualized in the literature in two different ways. Susman and Dean (1992) conceptualize CE as part of design for manufacturability (DFM) which they define as a variety of efforts to improve the product development process. Under this conceptual scheme, there are three different forms of early manufacturing involvement in product development. These are informant, contributor, and simultaneous process design.

As an informant, manufacturing provides design with information (e.g., machine tolerances) so that it is taken into account during product design. What this does is

reduce the designers' ignorance of manufacturing capabilities therefore resulting in fewer mismatches.

The second form of DFM is contributor. Here manufacturing is more active since it suggests ways for design engineers to design the product for ease of manufacturability. For example, manufacturing can tell design whether certain angles or dimensions are easier (or harder) to machine. Manufacturing's role as a contributor requires that it is also an informant and thus the benefits derived as an active contributor surpass those of an informant alone.

In simultaneous process design, manufacturing is involved in designing the process at the same time that design is engaged in designing the product. This integrated problem-solving requires frequent, two-way flow of preliminary information which heightens the need for effective coordination and communication.

There are two major shortcomings with Susman and Dean's conceptualization of CE. Firstly, they treat CE in binary terms and therefore fail to distinguish between varying degrees of overlap that may exist between upstream and downstream functions in different companies. Secondly, they emphasize overlapping between design and manufacturing and altogether omit any mention of overlapping of R&D with design and manufacturing in concept development.

Clark and Fujimoto (1991, p.79) conceptualize CE in terms of a continuum whereby varying degrees of overlap between product and process engineering exists. Through this conceptualization, it is possible to determine how product and process

engineering activities - subsystem/component specification, detailed designs, prototype construction, process design, tool making, and pilot production - vary in terms of their timing of execution in different companies.

To address the research questions in this thesis, Clark and Fujimoto's view of CE is used because it is conceptually more correct as it deals with the notion of "how much overlap". Furthermore, it provides insight when using the information processing perspective as an analytic tool to study new product development.

Empirical studies dealing with CE have mostly focused on the impact of CE on various performance measures. Early studies have shown that the earlier manufacturing is involved in product development, the better the product performance (Gerstenfeld 1976; Langowitz 1989). Smith (1990), in a study of body development in the automobile industry, reports that CE has led to significant cost reductions in body development. A study by the Institute of Defense Analysis (reported in the CALS/CE Technical Report) of leading U.S. companies that have applied CE principles reports that CE has led to the following: (i) reductions in product development lead time of up to 60%; (ii) reduced field failure rates of up to 83%; (iii) significant reductions in prototype construction; and (iv) significant reductions in scrap and rework.

More recent work by Clark and Fujimoto (1991) and De Meyer (1992) have examined the relationship between the degree of overlapping problem-solving and improvements (or reductions) in development lead time. In their study of 29 car development projects from Europe, Japan, and the U.S., Clark and Fujimoto (1991)

report that Japanese projects exhibited a significantly higher degree of simultaneity (or overlap between upstream and downstream functions) than either the European or American projects. They also report that there is a stronger, negative association between degree of simultaneity and development lead time among the Japanese car development projects. In his study of 224 large European manufacturers, De Meyer (1992) found that "high performers" - those companies that scored above average values on the performance improvement (in development lead time) measure - exhibited a significantly higher degree of parallel problem-solving in development.

Four observations emerge from a review of the CE literature. First, the studies to-date emphasize the use of CE principles among manufacturing firms where design and manufacturing are co-located. There are no empirical or qualitative case studies examining how multi-location manufacturing firms design and develop new products using CE. A recent comparative case study by Trygg (1991) attempts to develop the knowledge in this area. Trygg (1991) studied the impact of distance between design and manufacturing on the use of integrative mechanisms in three Swedish manufacturing firms. His conclusion was that different integrative mechanisms were used in different product development contexts. Although he did not directly examine CE projects, his work is important as it indicates that manufacturing firms are experimenting with multi-location product development and that they are searching for effective ways to overcome the constraints imposed by geographical separation.

Second, the existing CE literature does not examine the relationship between degree

of overlap as a management response and project characteristics such as scale, scope, novelty, and technology. It is unclear whether a fixed degree of overlap, as a matter of management policy, is effective for different types of NPD tasks. Third, the issue of how design and manufacturing engineers deal with uncertain and ambiguous information and the extent to which their behaviours are governed by differences in cognitive styles is unknown and clearly important if companies want to manage attitudinal differences which may impede the successful implementation of CE. Fourth, implementing CE is a major effort that requires the creation of a unified organizational culture supported by organizational designs that are significantly different from those found in sequential engineering.

2.5.7. Task Uncertainty and Equivocality

Organizations process information in order to reduce task uncertainty and equivocality so as to attain an acceptable level of performance (Daft and Lengel 1986). According to Perrow's (1967) classification of work-unit technologies, task variety and task analyzability are the two dimensions of task uncertainty. Task variety has been defined as the frequency of unexpected and novel events that occur in the conversion process (Van de Ven and Delbecq 1974). What this means is that when a task is characterized as high variety, individuals cannot predict problems or activities in advance. With low variety tasks, individuals are considerably certain about the occurrence of future activities.

Task analyzability basically refers to how individuals respond to problems. An analyzable task is one in which the individual follows a formal and well defined search procedure to solve problems (Ghani 1992; Hauptman 1992; Tyre and Hauptman 1992). In the case of an unanalyzable task, individuals have to think about how to solve problems since there is uncertainty about cause and effect relationships.

There are numerous studies relating the amount and nature of information processing with task uncertainty (e.g., Meissner 1969; Gaston 1972). Studies by Van de Ven and Ferry (1980), Daft and Macintosh (1981), and Ghani (1992) have shown that there is a positive relationship between task variety and the amount of information processed. As far as the relationship between task analyzability and the amount of information processed, a positive relationship also exists. It is important to note that in the case where tasks are not analyzable, Daft and Macintosh (1981) and Ghani (1992) have shown that rich information as opposed to amount of information is important.

Uncertainty and equivocality are characteristics of a task or process. Galbraith (1977) has defined uncertainty as, "the difference between the amount of information required to perform the task and the amount of information already possessed by the organization." Under conditions of high uncertainty, organizations acquire more information to solve known problems.

Equivocality refers to the existence of multiple and conflicting interpretations about an organizational situation (Weick 1979; Daft and Macintosh 1981; Slusher and Ebert 1992). When tasks are unequivocal, a uniform interpretation exists among project

participants. Equivocality however leads to confusion, duplicated efforts, and delays in development lead time. Studies (Kreps 1980; Lengel and Daft 1984) have shown that one of the reasons individuals process information is to reduce equivocality.

2.5.7.1. Relationship Between Uncertainty/Equivocality and CE

The information processing perspective is used to link CE to task uncertainty/equivocality. Daft and Lengel (1986) suggest that NPD consists of uncertain and equivocal tasks. A major source of uncertainty and equivocality identified in the literature is interdependence (Tushman and Nadler 1978).

One fundamental characteristic of complete overlapping problem-solving is that design engineering and manufacturing begin and complete their tasks at roughly the same time. As mentioned earlier, for this to occur, communication of design information must be intense, frequent, two-way, and begin as early as possible. What this means to the respective functions is that they are now reciprocally interdependent since each is constrained by the decisions of the other or has information that the other needs to perform its tasks (Susman and Dean 1992).

Several authors (Clark and Fujimoto 1991; Rusinko 1992, p.57) note that a relationship exists between degree of simultaneity and task interdependence. That is, as the degree of overlapping problem-solving between upstream and downstream functions increases, interdependence among the two functions also increases which, gives rise to greater uncertainty and equivocality. What this means is that different

integrative mechanisms must therefore be employed under varying degrees of simultaneity in order to effectively manage uncertainty and equivocality.

2.5.8. Integrative Mechanisms

As a managerial response, integrative mechanisms lead to effective overlapping problem-solving by reducing differentiation. This section reviews the integrative mechanisms identified in the literature and the following section discusses communication technologies and tools.

Implementing concurrent engineering (CE) principles to execute NPD tasks requires the creation of a unified organizational culture that fosters cooperation, collaboration, consensus, and communication among different engineering functions. To accomplish this, differentiation - which is a manifestation of different functional subcultures (Adler 1992; Craig 1991; Gertsen 1991; Liker and Fleischer 1992; Sackmann 1992) - needs to be reduced and the reciprocal interdependence (Thompson 1967) caused by overlapping activities needs to be managed.

Differentiation is used in the literature to refer to differences across functions on such dimensions as technical orientation, professional background, values, goals, frames of reference, jargon, and rewards (Adler, McDonald and MacDonald 1992; Crittenden 1992; Dougherty 1992; Galbraith 1977; Lawrence and Lorsch 1967; Sackmann 1992; Van de Ven 1986). Stated differently, it refers to the collective difference: in visible artifacts, values, and basic assumptions among functional

specialists. Differentiation is a source of equivocality that not only acts as a barrier to interfunctional communication (Dougherty 1989), but it also leads to conflicting goals (Pfeffer 1981) which in turn motivate suboptimal product and process design decisions, turf wars, and power struggles.

Integrative mechanisms are identified in the literature as organizational policies and practices aimed at reducing differentiation by creating a unified organizational culture (Rusinko 1992, p.29). In so doing, they promote interfunctional communication which is necessary both to process information so that uncertainty and equivocality can be reduced and to achieve concerted action among different functions. Status parity, job rotation, group based rewards and evaluations, co-location, project structure, leadership style, and top (or senior) management support are among the integrative mechanisms identified in the literature (Crawford 1992; Emmanuelides 1992; Gertsen 1991; Henke, Krachenberg and Lyons 1993; Millson, Raj, and Wilemon 1992; Rusinko 1992; Stalk and Hout 1990a).

Coordinating mechanisms emphasize interdependence management and not necessarily differentiation reduction, therefore, they are more limiting than the larger set of integrative mechanisms in terms of the outcomes they produce. For the purpose of this thesis, integrative mechanisms are viewed as a larger set which includes as a subset, the coordinating mechanisms discussed earlier. Now that the relationship between integrative and coordinating mechanisms is established, a brief discussion of the integrative mechanisms follows.

Traditionally, manufacturing have been accorded a lower level of status than design engineers. Status differences on such visible dimensions as working environment and pay levels, when analyzed at deeper levels - values and basic assumptions - indicate the existence of incompatible engineering subcultures. Such cultures lead to confrontation especially since design engineers are viewed as elitists dealing in the domain of abstraction while manufacturing as the working class concerned with the bread and butter of the company - machining processes and manufacturing efficiency. Additionally, they lead to mistrust and communication disharmony (Gertsen 1991; Jewell and Reitz 1988; Walton and Dutton 1969) making it impossible to implement CE.

Creating status parity by reducing status differences with respect to work facilities, education, salary, and influence in general reduces differentiation, thereby making it easier to effectively coordinate design and manufacturing activities.

Job rotation is effective at reducing differentiation and interfunctional conflict (Garvin 1993; Walton and Dutton 1969). It enables design and manufacturing to become familiar with each others responsibilities, competencies, and limitations. In particular, through job rotation, manufacturing understands the implications of their decisions on product functionality while design understands the needs, concerns, and challenges of manufacturing. A number of additional outcomes of job rotation include: (1) more informal and personal means of communication by rotated individuals (Adler, McDonald and MacDonald 1992; Galbraith 1973), (2) increased creativity through

multiple perspectives (Johns and Snelson 1985); and (3) increased credibility among rotated functions, thus minimizing the "not-invented-here" syndrome (Moenaert, Deschoolmeester, DeMeyer and Souder 1992; Van Voorhis 1993).

Group based rewards and evaluations are a powerful integrative mechanism that lead to changes in the pattern of individual behaviour. In sequential engineering for example, design engineers are evaluated and rewarded on the basis of creativity and innovation, but not necessarily on a manufacturable design. Fostering cooperation and collectivism therefore requires a different evaluation and reward system - one that does not encourage only functionally and individually based outcomes. A number of researchers (Adler 1989; Ancona and Caldwell 1992; Crittenden 1992; Katz and Allen 1988; Lawler 1988, p.605; Painter, Mayer, and Cullinane 1991; Tushman and Nadler 1978) argue that group based rewards and evaluations are effective antecedents for increasing interfunctional cooperation and collaboration and subsequently, for increasing information processing.

Bringing design and manufacturing together in the same work area is one of the most powerful integrative mechanisms at breaking down cultural barriers. Co-location not only promotes development of common experiences, which subsequently reduce interfunctional conflict (Walton and Dutton 1969), but it also increases informal communication (Emmanuelides 1992; Whitney 1988) that results from the greater opportunity for interaction and collaboration (Carter and Baker 1991, p.41). An increase in informal communication can increase the frequency and timeliness of

information transfer. Furthermore, co-location increases the likelihood that individuals will use face-to-face media for equivocal tasks.

Many researchers (Allen and Fusfeld 1975; Gertsen 1991; Hauptman 1986; Linton et al 1991; Painter, Mayer, and Cullinane 1991; Pinto, Pinto and Prescott 1993; Port 1990; Smith and Reinertsen 1991; Van Voorhis 1993) advocate the use of co-location to promote communication. In the case of CE, their line of reasoning is that dedicated multi-disciplinary teams with co-located members reduce differentiation among team members and subsequently provide the environment for successfully achieving overlapping problem-solving.

The project team structure was popularized by Peters and Waterman (1982) as being superior to the "matrix" structure for developing new products. Focused team perspective, team identity, project ownership, high levels of commitment/integration, speed in product development, and ease of cross-functional coordination are among the project team attributes identified in the literature (Henke, Krachenberg, and Lyons 1993, Katz and Allen 1985; Larson and Gobeli 1988; Schiller 1994). A trade-off involving project teams is the efficient use of resources. "Matrix" structures capture the benefits and minimize the liabilities of functional and project team structures.

Organizational structures are arrayed along a continuum which ranges from the functional organization to the pure project team organization. Matrix structures are a mixed organizational form in which normal hierarchy is overlayed with some form of lateral authority (Larson and Gobeli 1987). Galbraith (1971) has identified three

matrix structures - functional, balanced, and project - which lie between the functional and pure project organizational structures. One fundamental characteristic of matrix structures is that project participants report simultaneously to both project and functional managers.

With the advantages of project team structures and the disadvantages of functional structures, it would appear that project teams should be the organizational structure of choice for NPD projects. This however is not the case. Recent empirical and qualitative studies (Larson and Gcbeli 1987; 1988; Taylor 1991) indicate that there is strong support for both the project matrix - an organizational structure in which the project team leader has direct authority to make decisions while the role of functional managers is limited to providing advisory support - and project team structures. Furthermore, Larson and Gobeli (1987; 1988) report that the project matrix compares favourably with project teams on traditional project success variables.

Related to the discussion on project structure is leadership style. A project leader leadership style emphasizing high levels of team member participation pushes decision-making and conflict resolution down to the level of team members. One characteristic of this leadership style is that team members, instead of the project team leader, are responsible for making and implementing critical product and process design decisions. Galbraith (1973) argues that delegation of decision-making authority must vary with task uncertainty in order to achieve greater effectiveness. Emmanuelides (1992) reports that higher levels of autonomy and decision-making responsibility in

development teams is related to reduced product development time. It is not clear from this study whether this relationship holds across different project characteristics.

Top or senior management support in the form of verbal endorsements and resources (e.g., travel and development budget, personnel) is cited as an important variable for NPD success (Hayes, Wheelwright, and Clark 1988; Taft and Barclay 1993). Insufficient support from top management minimizes the influence of the integrative mechanisms identified above. For example, inadequate resources allocated to teams hampers the execution of tasks (Emmanuelides 1992). Most of the empirical studies have emphasized the relationship between resources and project success. Gupta and Wilemon (1990) found that a lack of resources was an important reason for delays in development. Rusinko (1992) however found no evidence to support her hypothesized positive relationship between top management support and project success.

2.5.9. Communication Technologies and Tools

This section reviews the communication technologies and tools that can be used to support concurrent engineering by facilitating human interaction. The communication technologies that will be reviewed include electronic mail, voice mail, facsimile machines, conference calls, videoconferencing, group decision support systems, and groupware. A review of the tools include CAD, CAE, and CAM. Before reviewing the above, a formal definition of information is established and a brief review of

traditional communication channels is presented.

2.5.9.1. Information and Communication

This section reviews the literature on information and communication in order to distinguish between these two terms/concepts. A formal definition of information is then presented which draws on the information literature reviewed.

There is considerable overlap between the notions of information and communication and thus it is important to have a clear understanding of each. The term information is widely used in various disciplines with each one defining it differently. For example, researchers in Psychology (Shannon and Weaver 1949; Garner 1962) define information to mean something that reduces uncertainty and improves the prediction of outcomes.

In the field of Information Theory, information is defined as that which alters an individual's mental representation of reality (Helvey 1971). A common definition found in the Information Systems literature is that information is simply data that is meaningful to the user (Ahituv and Neumann 1990). Yet again, the Artificial Intelligence (AI) field defines information differently.

AI is the branch of computer science that is concerned with two basic ideas. First, it involves studying the thought processes to understand what intelligence is and second, it deals with representing those processes via machines (computers or robots). The AI literature defines information in a very broad sense (Stonier 1989). At one

extreme, information is an individual datum of which the simplest datum is an on/off switch (i.e., binary digit). At a higher level, patterns of information (datum) comprise knowledge and patterns of knowledge, wisdom. Additionally, this literature draws a clear distinction between information and intelligence; the latter referring to the process (thinking and reasoning) of using information to make further sense of it or to solve problems (Turban 1990, p.401).

In order to understand the notion of communication, it is helpful to review the literature associated with communications theory. Communications theory is mainly concerned with the physical characteristics of information and the mechanics of its transmission (MacKay 1969). Shannon and Weaver (1949) proposed a model of communication which states that messages are coded at the source, transmitted through a channel, and decoded at the receiving end. A communications channel (or medium) is defined as the means by which information is moved from one point to another (Chakrabarti et al. 1983). Simply put, communication thus refers to the movement (between remote agents) of some message via some medium (Ellis, Gibbs, and Rein 1991; Morrison and Liu Sheng 1992; Safoutin and Thurston 1993).

According to communications theory, a breakdown in communication may occur as a result of improper coding/decoding of a message and/or loss of information resulting from extraneous noise such as interruptions, overloaded channels, and multiple discordant stimuli (Rao and Jarvenpaa 1991). Hsia (1977) first suggested the use of redundancy - the transmission of the same message via multiple

channels - as one way to reduce loss of information. One major problem with redundancy, apart from cost in terms of time and money, is that the benefits are constrained by the limits of an individual's ability to process information (Rao and Jarvenpaa 1991).

This thesis uses the information processing perspective as an analysis tool and therefore it is necessary for the formal definition of information to be consistent with its implied meaning by this tool. The approach taken to establish a formal definition was to survey the use of this term in various disciplines (using the information literature above) and to draw upon these uses as the basis for a definition.

For this thesis, information is defined as: the use of a finite number of elements to represent, through the use of symbols (abstract or physical) or data, a concept or object, with the intended purpose of conveying meaning over a defined period of time. Using this definition, each of the following is viewed as information: (i) high-level specification document; (ii) blueprint; (iii) prototype; (iv) bill of materials; (v) source code for NC machine; and (vi) final product.

2.5.9.2. Traditional Communication Channels

Channels of communication (or media) differ not only in the type and quantity of information they can carry, but also in the richness of communication they can support (Daft and Lengel 1986; Daft, Lengel, and Trevino 1987; Hauptman 1992; Rice 1992). Daft and Lengel (1986) define information richness as the ability of information to

change understanding within a time interval. What this means is that communication channels (traditional or electronic) that can facilitate insight and rapid understanding, are considered rich. As mentioned in a previous section of this chapter, media are arrayed along a continuum of information richness based on four criteria. The traditional communication channels identified in the literature, in order of decreasing richness are: (1) face-to-face; (2) telephone; (3) addressed written documents; and (4) formal unaddressed documents. A brief discussion of each of these follows.

Face-to-face is the richest media because it allows rapid mutual feedback; it has the capacity to allow simultaneous communication of multiple cues such as head nods, eye contact, and other nonverbal behaviour; it allows communication via natural language; it conveys emotion; and it can be highly personal. Moreover with this medium, a message can be adjusted, clarified, and reinforced instantly. Research by Kiesler, Siegel, and McGuire (1984) has demonstrated that this medium is highly effective at converging initial differences of opinion into a shared position. De Meyer (1991; 1993) in his work on global R&D communication, notes that a certain level of confidence to promote effective teamwork among members of a worldwide development project can only be built through personal face-to-face contact.

The telephone medium is considered less rich than face-to-face. It allows rapid feedback, can be personal, uses natural language, and can communicate audio cues such as tonal inflection. One important point is that cues such as eye contact and body language are not supported by this medium. Furthermore, the telephone medium can

be plagued by "telephone tag" where parties reciprocally and repeatedly call back and forth, only to find the other party to be unavailable (Huber 1984).

Addressed written communications such as letters, notes, and memos are lower still on this information richness continuum. Feedback is usually slow and only written information is conveyed, thus this medium does not support visual and voice cues. It is interesting to note that this medium can communicate cues through the use of stationary and formality of language chosen, which allows messages to be tailored to individual recipients. These properties make this medium richer than formal unaddressed documents.

Formal unaddressed documents are lowest in richness and examples include standard reports, bulletins, and fliers. This medium can communicate quantifiable information and usually has a wide audience.

2.5.9.3. Communication Technologies

This section reviews the electronic means of communication which includes electronic mail, voice mail, facsimile machines, conference calls, videoconferencing, group decision support systems, and groupware. Huber (1984) predicted the important role this electronic medium would play in the design of post-industrial organizations. Researchers (Adams et al. 1993; Allen and Hauptman 1990; De Meyer 1991, 1993; Housel and Andrews 1987; Morrison and Liu Sheng 1992; Rice 1992; Zmud et al. 1990) have since found growing evidence that electronic media are commonplace in

organizations and moreover, they are having a major impact on intra and inter organizational communication.

Despite their advantages, electronic media exclude sensory information, feelings, and context. A number of researchers have reported that electronic media are more effective when complemented by traditional media (De Meyer 1991, 1993; McKenney, Doherty, and Sviokla 1986; Steinfield 1984, 1985; Weick 1985). This thesis therefore views electronic media not as substitutes for traditional media, but rather as complements to them. The combination of electronic and traditional media therefore increases the range of communication options available to firms for structuring their organizational tasks.

1. Electronic Mail

An electronic mail (E-mail) system is defined as a computer-based system that facilitates the transmission, receipt, and storage of written correspondence, messages, and text-based information (Adams, Todd, and Nelson 1993; Bannon 1986; Morrison and Liu Sheng 1992; Sproull and Kiesler 1986). Anyone with a computer account can create and send information to anyone who has a mailbox on that computer or on any other computer to which it is connected through a computer network (i.e., LAN or WAN). Once a message is received, a recipient can read it, edit it, save it, delete it, move it to another computer file, forward it to others, or reply to the sender.

Three general characteristics of E-mail systems identified in the literature include:

(1) it is an asynchronous, point-to-point mode of communication - senders and receivers do not have to be simultaneously present on the system thus, people can interact over an extended period of time; (2) it is fast in comparison to paper-based communication; and (3) it is text-based which means that messages do not have a picture or sound component, only text.

The first large scale computer communications network was the ARPANET. It was established in 1966 by the Department of Defense to allow computer scientists at many locations to use special computing resources operating at only one location.

ARPANET was instrumental in the development of the Ada computer programming language (Bannon 1986). What is interesting about ARPANET is that over time, most of the traffic (or communication) over the network evolved from machine-to-machine to researcher-to-researcher and thus it is regarded as the first large E-mail network.

Today, ARPANET has over hundreds of thousands of users at over 1300 locations.

Research into E-mail systems has mostly focused on its impact on communication processes. For instance, a 1978 study at Digital Equipment Corporation, which observed the use of the companies E-mail system by its employees, reports that E-mail not only increased the speed of decision-making but, it also resulted in a 5 to 15 percent increase in productivity (Crawford 1982). Groppa (1983), in his study of managers at Manufacturers Hanover Trust, reports that using E-mail saved users about three hours a week mostly by eliminating unreturned phone calls.

Sproull and Kiesler (1986), in a field study of E-mail use in a Fortune 500

company, report that while E-mail increased the amount and speed of information exchange, it also changed information distribution patterns. These researchers report the following interesting results: (1) sixty-two percent of the messages received by users contained information that receivers believed would not be obtained without E-mail; (2) users preferred the E-mail system for sending "bad" news; (3) E-mail was preferred to the telephone medium for solving problems and negotiating; and (4) message traffic within the product development group was significantly different than within the R&D group (i.e., 31 messages a day per person versus 20).

Other studies on the effects of E-mail systems report similar results. Steinfield (1986) found that E-mail systems lead to accessing higher quality information, improved productivity, and improved connectedness to others. Recent work by Adams et al. (1993) indicates that E-mail systems increase the number of people in the organization with whom individuals communicate and they improve coordination within the organization. Rice (1992) in his study of a federal agency office found that for analyzable tasks, the relationship between E-mail use and effectiveness was positive and statistically significant while for unanalyzable tasks, this relationship did not exist.

II. Voice Mail

A voice mail (V-mail) system is defined as a computer-based system where users of a standard telephone can receive messages left in a mailbox, send messages to individuals or groups, and save or delete messages (Adams et al. 1993; Paznik 1987).

V-mail systems are asynchronous and support oral communication only. Apart from eliminating "telephone tag", some of the advantages of V-mail systems identified in the literature include: (1) they have a simple interface and are therefore easy to use; (2) messages can be recorded after hours and from any time zone; (3) the technology is ubiquitous; and (4) they allow individuals to get information more quickly.

The literature on V-mail is not as well developed as for E-mail. One important characteristic of V-mail systems identified by researchers is that they are considered richer than E-mail systems, but less rich than the telephone medium (Ochsman and Chapanis 1974; Rice and Love 1987; Zmud, Lind, and Young 1990).

In a comparative study of E-mail and V-mail systems, Rice and Steinfield (1991) report that while there are common uses between the two systems, there are also differences. For example, they found that E-mail systems were more often used to communicate nonwork related messages. Recently, Adams et al. (1993) compared E-mail and V-mail usage in 12 organizations and report some interesting results. Among their findings, they report that users considered the V-mail medium to be more personal and more effective (in terms of less junk mail) but, not the primary mode of communication in their organization. Based on their findings, Adams et al. concluded that in the organizations they studied, E-mail is considered an alternative communications channel to traditional media but, V-mail systems are simply viewed as a back up to the telephone.

Rice (1992) has studied V-mail usage in the context of a media/task/performance

relationship. In his longitudinal study of V-mail implementation in a large insurance organization, he found some support (directional) for his hypothesis of a media/task/performance relationship. That is, for unanalyzable tasks, he found a positive correlation between usage (of V-mail) and effectiveness. In a separate study of a chemical company in the U.S. that had been using V-mail systems for over three years, Rice found evidence (statistically significant) to support his hypothesis that use of information-rich media is more strongly associated with positive performance in unanalyzable task environments than in analyzable task environments.

III. Facsimile Machines

The ancestor to the modern desktop facsimile (FAX) machine was based on analog technologies. These machines, which were used for specialized applications such as transmitting fingerprints, did not gain in popularity because transmission was slow and the quality of the image was poor. The Japanese are credited with advancing FAX technology. Infact, they introduced the first digital FAX in the sixties (Rosenwald 1988).

FAX transmission is asynchronous and can occur either via the standalone FAX machine or via add-on products for microcomputers. In the latter case, FAX images are displayed on a video display from which they can be edited and thereafter printed on a local or remote printer. For the purpose of this thesis, the emphasis is on FAX transmission as a medium of communication using FAX machines.

A review of the literature reveals that this medium supports text and graphics communication and is highly effective for transmitting time critical information. There is little empirical research dealing with this medium of communication, however, Adhikari (1993) reports that today, FAX transmission is second only to E-mail as the most important application in meeting the electronic messaging needs of companies. De Meyer (1991) also reports on the widespread use of FAX machines. In his study of fourteen large multinational corporations, he notes that six months after their introduction in the market, FAX machines were standard equipment in all the firms in his sample.

IV. Teleconferencing

Teleconferencing is defined as telecommunications support to facilitate group interaction among geographically dispersed individuals (Ellis, Gibbs and Rein 1991; Housel and Andrews 1987). It enables individuals to communicate electronically via audio and/or video signals which can be transmitted by telephone lines, microwaves, fiber optic cables, coaxial cables, satellites, or any combination of these transmission modes. Two types of teleconferencing examined in this thesis which support synchronous or real-time interaction are audio-only (or conference calls) and videoconferencing.

Conference calls are the simplest, least expensive, and most widely used of the two types of teleconferencing. In their study of sixty-two organizations, Olgren and Parker

(1983) report that a significantly larger number of firms consistently used conference calls over videoconferencing as part of their business activity. This study only reported aggregate results of usage and did not examine the use of the different types of teleconferencing for various tasks and therefore its results need to be interpreted with caution.

There are two types of conference calls and both use telephone lines to connect from a few individuals to a complicated network of a large number of individuals. In a "dedicated" conference call, telephone lines are leased to form a permanent and dedicated network among a large number of individuals. On the other hand, "dial-up" conference calls use existing telephone lines and are set up through an operator. The major benefit of a dedicated conference call is that audio transmission quality is very good and tends not to degenerate as locations are added.

Videoconferencing which is the richest electronic medium (De Meir 1991; Fulk, Schmitz and Steinfield 1990; Rice 1992; Short, Williams and Christie 1976) allows groups at two or more geographically dispersed locations to conduct simultaneous interactive meetings with audio-visual support. The two types of videoconferencing identified in the literature are slow-scan (or captured-frame) and full-motion compressed video.

Slow-scan videoconferencing is the least expensive and sophisticated (in terms of technology embodied) of the two. It uses telephone lines to transmit still images, however, one major drawback with this is that transmission time is directly

proportional to the level of the picture resolution desired. In contrast, full-motion videoconferencing transmits real time pictures by using a "Codec" (short for coder-decoder). A codec uses powerful motion algorithms and inter-frame storage capacity to compress the band width necessary to transmit full-motion video. What this means is that whole video pictures do not have to be continuously transmitted each time, but rather, only the changes in the images need to be continuously transmitted, thus enabling the use of lower cost, low capacity transmission channels.

A full-motion videoconferencing facility consists of a room designed for participants who sit around a conference table and are surveyed by a voice-activated video camera which transmits images to another location. A display monitor showing the picture of the speaking participant at another location is included as well as possibly wall monitors showing images of participants who are not speaking.

Research into videoconferencing has not focused on factors influencing successful implementation but rather on the use of this medium for different task activities. A review of the literature on the number of North American installations reveals that Wang, Digital, IBM, Kodak, J.C. Penney, Boeing, and AT&T are some of the U.S. companies where it is used (Housel and Andrews 1987; Morrison and Liu Sheng 1992). Loblaw Cos. Ltd. and Royal Bank of Canada are among some 330 Canadian companies (of which close to 100 made the decision to implement videoconferencing in 1992) currently using videoconferencing for various tasks such as training sales personnel and conducting on-campus interviews (McFarland 1993).

Dutton, Fulk, and Steinfield (1982) in their study of AT&T's videoconferencing facility found that this medium was used for a number of diverse tasks (listed in order of decreasing frequency of use) such as exchanging information, exchanging opinions, and gaining consensus. One major shortcoming of this work is that it did not focus on the effectiveness of this medium for varying task activities. In a separate study, Egidio (1988) found that videoconferencing is best suited for regularly occurring meetings aimed towards the presentation or exchange of neutral information between colleagues in different locations. Recent work by Rice (1992) in his study of the effectiveness of videoconferencing use in a single American industrial company found positive and statistically significant support for the relationship between videoconferencing use and effectiveness for both high and low analyzability tasks.

V. Group Decision Support Systems

There are many definitions of the term group decision support system (GDSS) identified in the Information Systems literature. Huber (1984) defines it as a set of software, hardware, language components, and procedures that support a group of people engaged in a decision-related meeting. Other researchers (Alavi 1993; Dennis et al. 1988; DeSanctis and Gallupe 1985; Kraemer and King 1988) define it as an integrated computer-based system that facilitates solution of semi- and un-structured problems by a group having joint responsibility for making decisions. While the former definition emphasizes GDSS components, the latter emphasizes the application

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of GDSS for varying task situations. Two important points that emerge in analyzing these definitions are that they do not incorporate spatial considerations of group members nor do they emphasize the communications dimension of GDSS.

For the purpose of this thesis, a GDSS is defined as an integrated system combining computer, communication, and decision technologies (e.g., Electronic Brainstorming for supporting idea generation, an Issue Analyzer for helping group members identify and consolidate key focus items, Alternative Ranking and Voting for managing private ballots cast by group members) to support problem formulation and solution of various tasks by a centralized or dispersed group. All GDSS's support synchronous interaction and have as their goal the following: to improve the productivity of decision-making/problem-solving meetings either by speeding up the decision-making/problem-solving process or by improving the quality of the resulting decisions (Cass, Heintz and Kaiser 1992; Nour and Yen 1992; Nunamaker et al. 1989).

GDSS implementations vary depending on whether group members are centralized or dispersed. In the case of centralized groups, GDSS's are implemented as electronic meeting rooms that contain several networked workstations, large computer-controlled public displays and audio/video equipment. An example of a centralized GDSS is the PlexCenter Planning and Decision Support Laboratory at the University of Arizona (Applegate, Konsynski and Nunamaker 1986). The implementation of GDSS for dispersed individuals differs from centralized GDSS in that individuals are networked through a local area decision net (LADN) and they communicate via teleconferencing.

and/or through shared public displays at individual workstations. Co-oP (Bui and Dolk 1986) is an example of such a system.

A review of the GDSS research reveals that there are no studies examining GDSS use among individuals involved in new product development. The research that exists deals with: (i) developing frameworks for further study (Huber 1984); (ii) the practical aspects of GDSS use (Gallupe and DeSanctis 1988; Kull 1982; Nunamaker, Applegate and Konsynski 1987); and (iii) laboratory/field studies (Alavi 1993; Cass, Heintz and Kaiser 1992; Gallupe and Cooper 1993; Nunamaker et al. 1989; Straub and Beauclair 1987; Zigurs, Poole and DeSanctis 1988). A thorough review of all the GDSS research is beyond the scope of this thesis, however, a few of the experimental and field study results are presented below.

Experimental research (Gallupe, DeSanctis and Dickson 1988; Steeb and Johnston 1981) into centralized GDSS suggests that GDSS enhances information exchange and helps improve the quality of decisions. Nunamaker et al. (1989), in their field study of a centralized GDSS installed at an IBM manufacturing plant in the U.S., report that multi-functional groups using GDSS for unanalyzable tasks such as strategic planning showed high process effectiveness. One major shortcoming of this study is that the authors did not measure "effectiveness" for varying task situations and only reported aggregate results.

The research into dispersed GDSS is not as well developed as for centralized GDSS. Gallupe and McKeen (1990) report that subjects in GDSS-dispersed settings

took longer to make decisions than those in non-GDSS face-to-face meetings. One of the possible explanations for this result may be that the nature of the communication connection among remote sites influences decision time. In a separate study, Valacich et al. (1991) report that dispersed groups outperformed (in terms of the number of alternatives generated) face-to-face groups in problem-solving, and cite increased task focus among GDSS-dispersed individuals as a possible explanation.

VL Groupware

The term groupware was first defined by Johnson-Lenz (1982) in terms of its components - a computer-based system plus the social group processes. Ellis, Gibbs and Rein (1991) have built on this definition and defined groupware as computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment. An important characteristic of groupware is that it provides a shared environment for individuals engaged in a common task.

The examples of groupware identified in the literature indicate that this medium supports synchronous interaction among centralized or dispersed individuals through the use of real-time group editors (Bannon 1986; Brandt 1994; Kirkpatrick 1993). These multi-user editors allow a group of people to edit the same object at the same time. This is accomplished through the use of "locking" where only one individual has write access at a point in time, and "concurrency control" (i.e., a groupware module

designed to resolve conflicts between participants' simultaneous operations).

There is little empirical research examining groupware usage and its impact on enhancing group effectiveness. Ellis, Gibbs and Rein (1990) in their study of an experimental groupware system report that the system was used for various managerial tasks in both centralized and dispersed settings. These researchers however did not examine the effectiveness of groupware for various tasks in both centralized and dispersed settings.

2.5.9.4. CAD/CAE/CAM Tools

This section briefly reviews CAD/CAE/CAM tools and highlights some of the relevant research. It is important to note that a thorough review of all the CAD/CAE/CAM research is beyond the scope of this thesis.

Computer-Aided Design (CAD) is defined as computer-based tools which assist in the creation and/or modification of engineering designs. Central to a CAD system is a computerized database for storing part geometries. Computer-Aided Engineering (CAE) refers to computer-based tools used to analyze and evaluate designs. Computer-Aided Manufacturing (CAM) consists of computer-based tools to program, direct, and control production equipment in the fabrication of manufactured items. According to Gerwin (1982), CAM systems technology includes Computer Numerical Control (CNC) machines, Direct Numerical Control (DNC) machines, and Flexible Manufacturing Systems (FMS). CAD/CAE/CAM tools, which are classified as

Advanced Manufacturing Technologies, are designed to increase the productivity and flexibility of manufacturing firms (Gerwin, Kumar and Pal 1992).

Individually CAD, CAE, and CAM have the potential to increase the productivity of design engineers and designers, to produce high quality designs, to reduce development lead time, to improve communication among functional specialists, and to streamline inefficient production processes (Beatty and Gordon 1988; Liker, Fleischer and Arnsdorf 1992; Robertson and Allen 1993; Rosenthal and Tatikonda 1992). Fully integrated CAD/CAE/CAM systems which bring about a seamless and continuous flow of information from design engineering to manufacturing have the greatest potential to improve the product development efforts of manufacturing firms (Adler 1989; Blackburn 1991; Pine, Victor and Boynton 1993). Empirical research conducted at Toyota Motor Corporation, which reports that such systems led to a 25% reduction in lead time of the design and development of body panels (Takahashi and Okamoto n.d.), supports this claim about integrated CAD/CAE/CAM.

Recently, Liker, Fleischer and Arnsdorf (1992) studied CAD/CAE/CAM utilization in six Fortune 100 companies and concluded that such integrated systems alone do not bring about the integration of design engineering and manufacturing which is needed to maintain high utilization rates and that new working relationships emerging from CAD/CAE/CAM implementation must be supported by new organizational structures and coordination mechanisms. As far as research directly examining CAD/CAE/CAM use in manufacturing firms designing new products for manufacture using concurrent

engineering (CE) principles, little empirical research exists, however several authors (Jo, Parsaei and Wong 1991; Painter, Mayer and Cullinane 1991; Shina 1991; Siegenthaler 1991) have emphasized the importance of these tools to facilitate CE.

2.5.10. Constraints

This section reviews the constraints that impede the effective functioning of a geographically dispersed team engaged in designing and developing new products using CE. Distance, time-zone differences, and national culture are the constraints found in the literature (Adler, McDonald and MacDonald 1992; Allen 1977; Bartlett and Ghoshal 1991, p.44; Clark and Fujimoto 1991, p.328; Hofstede 1980, p.391; Pinto, Pinto and Prescott 1993; Rosenthal and Subramaniam 1994).

Much of the academic and public press literature has focused on the implementation of CE using co-located teams. With the increase in competition for both domestic and international markets, multinational corporations and the like are increasingly asking themselves how they can better leverage the entire companies' resources to meet and beat the competition and to satisfy demanding customers. Examples of manufacturing companies engaging in multi-location NPD are identified in the academic and public press literature as one answer to effectively leverage total company resources (Motorola 1991; Port 1990; Trygg 1991). However, there are no empirical or qualitative case studies examining the special problems companies are facing in distributed NPD using CE and ways of effectively minimizing them. The

conceptual model attempts to provide some answers in the form of unique sets of management responses contingent on the NPD context. Following is a discussion of each of the constraints which collectively help define the NPD context.

2.5.10.1. Distance

CE involves changes to the timing of upstream and downstream activities and to the frequency/type of information transfer between engineering functions. Effective communication is critical and made easier in a co-located team by face-to-face discussions. In a distributed environment, distance poses an obvious constraint which minimizes the number of face-to-face encounters for resolving contentious issues and for making joint decisions. Research by Allen (1967, 1970; 1977) indicates that distance is a barrier to informal (face-to-face) communication. Subsequent research by Hauptman (1986), Tomlin (1979), and Trygg (1991) corroborated this. For example, Trygg (1991) reports that design and manufacturing engineers located at the same site used more face-to-face communication than design and manufacturing personnel located in different cities.

Clearly one way of overcoming distance as a constraint is by using communication related information technologies. Trygg (1991) reports that the incidence of information technology (IT) use was greatest among distributed design and manufacturing functions. In the R&D management literature, De Meyer (1991; 1993) also reports increased reliance on IT (i.e., electronic media) among a global network of

R&D laboratories.

2.5.10.2. Time-Zones

Related to the discussion on distance as a constraint is time-zone differences because of the obvious relationship between distance and time-zone differences. As a constraint, time-zone differences reduce the set of feasible electronic media options. In the case of point-to-point synchronous communication, they clearly make it difficult and inconvenient for individuals performing largely interdependent tasks to synchronize their biological and work-day clocks. Of course, this may mean greater reliance on asynchronous communication, but there is a potential trade-off of less confusion.

2.5.10.3. Culture

Successfully implementing a globally dispersed team that seamlessly develops new products using CE is challenging because of distance and time-zone constraints. National culture is yet another constraint making this task even more complex and difficult. For the purpose of this thesis, the treatment of national culture is limited to its influence on the behaviour of individuals in a distributed team. A thorough discussion of national cultures is therefore beyond the scope of this thesis.

According to Hofstede (1980a; 1991, p.4), national culture is defined as the influence of a national environment on the collective mental programming - patterns of thinking, feeling, and acting - of individuals in a nation. The influence of the national

environment on mental programs occurs over time. It is important to point out that although national culture refers to the characteristics of a collective set and therefore not all members of the set necessarily share the same characteristics, this thesis, for the purpose of convenience, takes the position that individuals of a particular nation possess the dominant elements of the characteristics of the collective set. In other words, collective properties are ascribed to inhabitants of a nation.

National culture influences the values and behaviours of individuals (Hofstede 1980a) and in so doing creates particular frames of reference among individuals of a nation. In this way, it is clearly a source of differentiation which makes integration of individuals of different cultures difficult (Bartlett and Ghoshal 1991, p.44). In relation to CE what this means is that individual team members with dissimilar national cultures, *ceteris paribus*, may find it more difficult to accomplish tasks, resolve differences, and make joint decisions than team members with more similar national cultures.

Chapter 3

HYPOTHESES

3.1. Introduction

The discussion in the preceding chapter centred on developing and describing a theory-based model. The contingency perspective is an important element of this model. In this chapter, specific hypotheses relating to the model are presented. Figure 2 shows the main relationships among the attributes in this model.

3.2. Main Hypotheses To Be Tested

- Hypothesis 1 (H1):** Integrative mechanisms will be positively related to CE orientation.
- Hypothesis 2 (H2):** Communication technologies and tools will be positively related to CE orientation.
- Hypothesis 3a (H3a):** There will be a difference in cognitive styles between engineering/R&D and manufacturing.
- Hypothesis 3b (H3b):** Differences in cognitive styles between engineering/R&D and manufacturing will be negatively related to CE orientation.
- Hypothesis 4a (H4a):** There will be cultural differences between engineering/R&D and manufacturing.
- Hypothesis 4b (H4b):** Cultural differences between engineering/R&D and manufacturing will be negatively related to CE orientation.
- Hypothesis 5 (H5):** Barriers between engineering/R&D and manufacturing will be negatively related to CE orientation.

Figure 2:
Main Relationships Among the Attributes

- Hypothesis 6 (H6):** Difficulty of the NPD project as measured by project characteristics will be positively related to the task difficulty of team members.
- Hypothesis 7 (H7):** Task difficulty of team members will be negatively related to project outcomes.
- Hypothesis 8 (H8):** Task difficulty of team members will be positively related to CE orientation.
- Hypothesis 9 (H9):** CE orientation will have a positive moderating effect on the relationship between task difficulty and project outcomes.

Chapter 4

RESEARCH METHODOLOGY

Chapter 4 discusses the methodology that was used for this study.

The design and development of new products using concurrent engineering (CE) principles was operationalized through specific projects. Therefore, the unit of analysis for this study was a new product development CE project. This chapter is organized into three sections; each one emphasizing a particular aspect of the research methodology. The sections are: (1) research setting and sample; (2) data collection methods; and (3) development of measures of variables.

4.1. Research Setting and Sample

The data for this study was collected from American, Australian, Canadian, and European companies in the automobile, chemical, computers, electronics, shipbuilding, and telecommunications industries. These companies have varying degrees of experience with CE - implemented using both co-located multifunctional teams and teams having distributed members.

This research included a total of approximately 14 companies. The sample size was between 40 and 50 projects, however, the projects were unevenly distributed among the companies because of availability and accessibility constraints.

Companies were contacted by telephone to elicit their participation in the

research project. Having done this, the following criteria were used to select the projects:

- (1) the projects should have taken no more than two years to complete (duration) and must be at most one year old (time since completion);
- (2) the composition of the project team must include a representative from engineering/R&D, a representative from manufacturing, and a project leader; and
- (3) in the case of a distributed team, key decision makers (i.e., personnel from engineering/R&D, manufacturing, and marketing) must not be located at the same site.

4.2. Data Collection Methods

The data for this study were collected in a single stage questionnaire survey. The questionnaire was pretested through semi-structured interviews with representatives from two manufacturing companies in the Ottawa-Carleton region because of easy accessibility. Both companies have designed and developed new products using CE and therefore, were considered representative of the manufacturing firms in the intended sample.

A 1-2 hour interview was conducted with representatives from each of the two manufacturing companies. An interview schedule touching on the issues suggested by the conceptual model was developed. One characteristic of this interview schedule is that it allowed the researcher flexibility to explore interesting and relevant topics that surfaced during the interview. The general flow of the interview was to ask the

interviewee general background questions about the CE project followed by specific questions regarding, for example, the amount of overlapping problem-solving between engineering functions. In cases where generalizations were provided, the researcher prompted the interviewee for specific details and examples.

The purpose of this preliminary stage was two-fold. First, it allowed the researcher to pre-test the theory-based model to ensure that it accurately describes "real world" phenomena. Second, it served as an important opportunity for pre-testing the usefulness of existing items found in the literature. Interviews were conducted with a project leader in each of the companies. Where possible, interviews were also conducted with a design engineer and a manufacturing engineer from each company. Collectively, all 3 interviewees in each company were involved in or are currently involved in completing the same new product development CE project.

Data collection for this research involved the design and implementation of two structured, self-administered, mail-out questionnaires. The Project Leader questionnaire is a shortened version of the Engineering/R&D and Manufacturing Representative questionnaire. Among the qualities that make a mail survey appropriate for this study are its ability to obtain a large amount of information from a large number of sources in an economical manner, and its generalizability to a broad population. It was believed that project participants who worked directly on the projects were in the best position to answer detailed questions about the project.

Once complete, the mail survey's were sent to a specific contact person (a

"minder") as designated by each company. This person was responsible for distributing both the Project Leader and Engineering/R&D and Manufacturing Representative questionnaires to the respective project participants - a project leader, a design engineer, and a manufacturing engineer - involved in the same CE project. Completed questionnaires were gathered by the "minder" (or company contact person) and returned unopened, directly to the researcher. Data collection was completed by the end of February 1994.

Survey instructions asked respondents to use a single CE project as the basis to complete the respective questionnaires. The answers to common questions in all three questionnaires helped reduce the bias that can occur when perceptual data is reported by a single respondent. The Engineering/R&D and Manufacturing Representative questionnaire was organized into nine parts. The first part requested project information. Subsequent parts focused on constraints, cognitive styles, product development methods, integrative mechanisms, communication technologies & tools, cultural differences, project outcomes/results, and personal background information. The specific questions in this questionnaire can be found in Appendix 1. The exclusion of three parts - constraints, cognitive styles, and culture - from the Project Leader questionnaire made it a shortened version of the larger Engineering/R&D and Manufacturing Representative questionnaire.

For the mail surveys, data was collected through a combination of closed-ended questions, mostly 5-point ordinal scales, maps, tables, graphical

descriptions, and questions with binary or numerical answers. The survey's were designed to ensure that respondents answer the questions as quickly and accurately as possible, and therefore, respond to and complete the respective surveys (Dillman 1978). Both questionnaires were designed so that they can be completed in a maximum of 60 minutes.

In each questionnaire layout and design, procedures were used to increase the reliability and internal validity of the data. For example, questions measuring a construct were randomly placed among questions related to other constructs. Furthermore, the values of positive/negative and greater/lesser responses on 5-point scales were randomly reversed throughout the questionnaires.

4.2.1. Scale Development

There are no scales in the literature to measure some of the variables in the model. Therefore, a step-by-step process was used to develop new multi-item measures having high reliability and validity. The reason a multi-item approach was used is because there is a possibility that different respondents may attribute slightly different meanings to particular items. The goal of a multi-item approach is to reduce the effects of individual items by cancelling them out with other items, thus resulting in a more pure indicant of the conceptual variable.

Measures were developed by first specifying conceptual definitions of variables. For each variable, candidate items were generated. The semantic content of these

items were assessed by experienced researchers and pre-test subjects. Only those items that best fit the definitions of the constructs were retained. When eliminating items, care was taken to ensure that the remaining items provided adequate coverage of the domain content. The reason some items had to be eliminated is because of the requirement to keep measures as brief as possible during administration into the field.

4.2.2. Pretesting the Instrument

Draft versions of each of the questionnaires were pre-tested in the field. Different subjects were used to pre-test each draft version of the Engineering/R&D and Manufacturing Representative questionnaire. Respondents and expert academics were given the opportunity to comment on general issues of validity and reliability, to comment on instrument deficiencies, and to make suggestions for improvement. After many revisions, the final version was completed; it is included in Appendix 1.

4.2.3. Administering the Instrument

For the purpose of this research, the "minder" or company contact person played a key liaison role in administering the instrument and returning to the researcher, by the deadline specified, completed questionnaires. Because companies have agreed in advance to participate in this study, a high response rate is expected. In all cases, the "minder" was given explicit instructions as to the types of projects that needed to be considered for this study. Although it is quite likely that manufacturing firms differ in

their use and description of various job titles, the "minder" was informed as to the specific respondents required for this study.

Each mail-out questionnaire was accompanied by a cover letter. Many of the survey practices that are generally believed to increase survey response rates were used in preparing the survey-related materials (Dillman 1978). For example, the cover letter was personalized and anonymity was guaranteed via reporting of aggregate results. In addition, the reporting of aggregate results was offered to respondents and the value of the respondents' participation was emphasized. Since this study is part of a larger project undertaken by the Research Program in Managing Technological Change in Manufacturing at Carleton University, letterhead of the sponsoring research program was used.

The cover letter outlined the objectives of the study, the value of the results to the respondents, and specific instructions on where completed questionnaires should be sent (to the "minder"). This letter also included the name and telephone number of members of the research team should respondents have questions about the survey. It is important to point out that although the "minder" played a key liaison role between project participants and the researcher, s/he was not be responsible for answering respondents' queries.

4.3. Measures of Variables

The conceptual model that is developed is based on the idea that new product

development (NPD) projects should be managed in ways contingent on the special characteristics of each project. When a "fit" exists between the various dimensions of managerial responses and the specific context in which NPD is practiced using CE principles, the results promised by CE are more easily attained. Following is a discussion of the measures of the attributes in the model and the indicators of those measures. A full composition of variables is included in Appendix 2.

4.3.1. Task Characteristics

Task characteristics consists of categories of variables and relationships among them. The perceptions of design and manufacturing specialists towards task difficulty and the major determinants of these perceptions are examined in task characteristics.

Project characteristics is the attribute responsible for determining perceptions. The project content categorization of variables collectively determines the characteristics of the project. The following variable measures constitute the project content categorization: (1) project scale; (2) project scope; (3) product novelty; and (4) process/product technology.

Project Scale. This variable determines the location of the output, of a product development effort, on a hierarchical ladder consisting of large scale systems, major subsystems, and component parts. A large scale system is defined as a system which consists of a large number of different and significant subsystems that interact in a nonsimple way. A large scale system is therefore the parent node on this hierarchical

ladder. An automobile is an example of such a system. A component part is simply defined as a single disjointed element. Moreover, component parts form the lowest rung on this hierarchical ladder. A muffler is an example of a component part. A major subsystem consists of a number of component parts which collectively interact to perform a single function. The exhaust system of an automobile is an example of a major subsystem. Two items were used to measure this variable; one was an open-ended question and the other asked respondents to rate the scale of the project in which they were involved.

Project Scope. This variable refers to the number of different types of expertise that provided critical inputs to complete the project. A single item was used to measure project scope.

Product Novelty. Rather than using the classical low-level dichotomy (i.e., radical versus incremental innovation) to capture the "newness" of a product, an ordinal scale was used. Respondents were asked to select one description (from among five) which most accurately described the product they developed. For example, the descriptions focused on whether the product was based on an entirely new concept (e.g., "cab-forward" design), whether the product represented an extension of an existing product line (e.g., in the IBM PS/2 family of products, the Model 90XP/486 is an extension of the 486 line), or whether the product resulted in the creation of a new family of products.

Process/Product Technology. This variable was measured by the presence of

two factors - process technology and product technology. Process technology was disentangled in terms of equipment, materials, and methods and a multi-item measure was used to measure this factor. To measure the novelty of the product technologies that were embodied in the final product, a single item measure was used.

This research is not a longitudinal real-time study and therefore care needs to be taken in measuring perceptions towards task difficulty (i.e., task uncertainty and task equivocality). The very nature of CE leads to a transformation from sequential interdependence to reciprocal interdependence (Thompson 1967). Measurement of perceptions towards task uncertainty must therefore be made when engineering/R&D and manufacturing representatives were concurrently engaged in their respective tasks. Task uncertainty is a construct which was measured by two variables - **variety** and **analyzability**. Some of the items used to measure these variables were based on Withey's (1983) work, however, they were appropriately worded to reflect the nature of the product development domain. A five-item measure was used to measure task variety. The task analyzability measure consisted of 5-items in total - 3 were worded to reflect the analyzable nature of the task and 2 items were worded to reflect the unanalyzable nature of the task.

Equivocality (or ambiguity) is simply defined as lack of mutual understanding. Perceptions of task equivocality were measured at that point in time when engineering/R&D and manufacturing representatives first engaged in concurrent problem-solving. The work by Daft and Lengel (1986) is the primary reference from

which a measure based on six items was developed.

4.3.2. Management

Management consists of three dimensions - CE orientation, integrative mechanisms, and communication technologies and tools. The CE orientation attribute consists of moderating variables which affect the direction and/or strength of the relationship between task characteristics and project outcomes/results (Baron and Kenny 1986; Tyre and Hauptman 1992; Venkatraman 1989)

Concurrent Engineering Orientation

For the purpose of this study, CE is operationalized as a cross-functional overlapping problem-solving approach. CE orientation was measured through four variables - three of these focused on dimensions of the interface during integrated problem-solving and one focused on CE behaviours (or attitudes). The **overlap** variable measured the amount of overlapping problem-solving between engineering/R&D and manufacturing. A 5-item measure with one item reversely scored was used to measure various aspects of overlapping problem-solving. In addition, a single item was used to elicit the percentage of overlapping problem-solving between upstream and downstream functions.

To measure the frequency of information transmission, a single variable with one item was used. The direction of communication was measured by asking

respondents to indicate their degree of agreement with the following statement:

"communication between engineering/R&D and manufacturing during the project was 2-way".

Behaviours (or attitudes) such as willingness not to release or to incorporate preliminary information are clearly incompatible with the requirements of CE. To measure the behaviour of engineering functions engaged in CE, a single variable was used. One open-ended question and two multi-item measures were used to measure this behaviour variable.

Integrative Mechanisms

Status parity, job rotation, group based rewards and evaluations, co-location, project structure, leadership style, and top management support are the variables used to measure the respective integrative mechanisms. **Status parity** refers to the degree of equality between respective individuals in different functions. To measure this variable, individuals were asked to compare themselves to their counterpart (design or manufacturing) on educational level, working environment, experience level, and organizational position.

Job rotation was measured by asking respondents to indicate their total years of experience in various functions (e.g., design/engineering/R&D, manufacturing/production, etc.).

Group based rewards and evaluations were measured by asking respondents to

indicate the percentage influence of group outcomes both on their rewards and on their performance evaluations.

To measure **co-location**, respondents were asked to circle, on a world map, the names of those functions located at the same site.

Project structure was measured by two multi-item measures. One measure assessed the position of the respondents' organizational structure on a continuum of generic organizational structures. The second measure consisting of eleven items measured the relative influence of the project team leader and functional managers on a variety of issues (e.g., controlling costs).

A four item measure was used to measure **leadership style**. Respondents were asked to indicate their degree of agreement with each of four statements. A sample statement includes, "the projec. leader made the team responsible for resolving internal conflicts".

Top management support was measured by the presence of two factors. These are endorsement and resources. The items to measure endorsement asked respondents to indicate the extent to which top management overtly communicated their support for the project to team members. Resources were measured by asking respondents if the allocated resources - in terms of development budget, travel budget, and development time - were adequate to complete the project.

Communication Technologies and Tools

Communication technologies and tools support varying degrees of overlapping problem-solving between engineering functions by facilitating human interaction. Furthermore, different communication media differ in their ability to facilitate understanding. To measure the deployment, use, richness, and effectiveness of various media (traditional and electronic) and tools (organizational integration and productivity enhancement) respondents will be asked to complete two separate tables.

In the first table, respondents were provided with a list of media and tools. They were asked to check (in a column labelled **Access**) those items in the list to which they had access during the project. Subsequently, respondents were asked to indicate, using a 5-point scale with anchors labelled (1) once a month and (5) at least once a day, how frequently during the project they used those items "checked" in the **Access** column. These values were recorded in a column labelled **Frequency**. Previous work by Allen (1977) is the source of scales.

Media richness refers to the capacity of a communication channel to transmit rich information. To assess the richness of various media and tools, respondents were asked two questions regarding those items in the list to which they had access. The questions asked respondents to evaluate items in terms of providing quick feedback and clarifying a misunderstanding. A 5-point scale was used and responses for each question were recorded in columns labelled **Feedback** and **Clarify**.

The second table asked respondents to evaluate using a 5-point scale, the

effectiveness of various media and tools to complete nine tasks ranging from structured (e.g., transferring technical information) to unstructured (e.g., resolving conflicts).

Because of the complexity of this question, it was feasible to ask respondents to evaluate only a subset of the items presented in table one. These six items (five media and one tool) in table 2 were selected on the basis of their usefulness to companies. In addition, some of the items represent leading-edge electronic media about which little empirical research exists.

4.3.3. Constraints

Cognitive styles, culture, and barriers are the attributes which collectively make up the constraints. It is important to note that the barriers attribute differentiates between CE - where team members are co-located at the same site - and global concurrent engineering (GCE) - where team members are geographically dispersed. For the purpose of this thesis, it was assumed that team members co-located at the same site were at the very least located in the same building and may infact have been located in the same work area.

Cognitive styles is a construct referring to the subjective process through which individuals perceive, organize, and change information during the decision-making process (Turban 1990, p.65). The model of cognitive styles used in this research is based on the work of McKenney and Keen (1974). This model assumes that modes of thinking and problem-solving develop through training and experience and that these

modes can be classified along an information gathering and an information evaluation dimension.

Information gathering refers to the perceptual process through which the mind organizes the verbal and visual stimuli it encounters. **Preceptive** and **receptive** are the two variables used to measure information gathering. Preceptive individuals focus on relationships among the items and attempt to generalize from them to learn about the environment. By contrast, receptive thinkers focus on details to derive specific knowledge about the environment. A multi-item measure was used to measure each of these variables. Information evaluation refers to the way in which individuals solve problems. The two variables used to measure this dimension are **systematic** and **intuitive**. Systematic individuals are very concerned with getting into a problem and using a deductive approach. However, intuitive individuals have a tendency to use a trial-and-error approach to solve problems. To measure these variables, a multi-item measure was used.

The word "culture" can refer to a society, organization, profession, or family. For the purpose of this thesis, the word **culture** (unless stated otherwise) refers to national culture. Hofstede (1980a; 1991, p.4) defines national culture as the influence of a national environment on the collective mental programming - patterns of thinking, feeling, and acting - of individuals in a nation. The five dimensions on which national cultures differ are:

(1) Power distance - this is a characteristic of social systems and indicates the

extent to which a society believes that power is unequally distributed;

(2) Uncertainty avoidance - indicates the extent to which a society feels threatened by uncertain situations and takes actions to overcome them;

(3) Individualism/Collectivism - indicates the extent to which ties between individuals in a society are weak (i.e., personal accomplishment is emphasized) or strong;

(4) Masculinity/Femininity - this refers to personal interaction style and indicates the extent to which the socialization pattern is aggressive/assertive versus nurturing; and

(5) Confucianism - indicates the extent to which a long-term orientation prevails in a society.

The culture attribute was measured by five variables. These are small power distance (i.e., equality), weak uncertainty avoidance (i.e., tolerance of uncertainty), individualism (i.e., personal accomplishment), "masculinity" (i.e., aggressiveness), and confucian (i.e., long-term orientation). Using a 5-point scale, respondents were asked to indicate their degree of agreement with a series of statements. Four item measures were used to measure each variable.

The barriers attribute consists of physical distance and time-zone differences. A world map was used to ask respondents to record specific spatial information. For example, respondents were asked to indicate where key individuals from engineering/R&D, manufacturing, and another function (e.g., marketing) were located

during the project. After indicating the country and town/city in which these key individuals were located, respondents were asked to record, on lines connecting the locations of the three functions, any time-zone differences. In addition, physical distance - walking, driving, or flying - was recorded on these lines to measure the amount of geographical dispersion. Items focusing on an estimation of the number of trips between each of the three functions identified on the map were used as well.

4.3.4. Project Outcomes/Results

The three dependent variables measuring the outcomes/results of new product development projects which used CE principles are: (1) project success; (2) cooperation; and (3) participants' satisfaction with the project.

Project success is a task related outcome measured on four dimensions. These are product cost, overall product quality, project budget, and overall development lead time. Individuals were asked to rate the relative importance of achieving each goal and to rate using a 7-point scale, the success of the project in meeting each of the four goals. It is important to note that although objective measures are desirable, self-report measures of success are not upwardly biased (Churchill 1985).

Cooperation and satisfaction are both process related outcomes. **Cooperation** refers to the working relationship of team members involved in a CE project. A 3-item measure was used to measure this variable.

To measure the **participants' satisfaction** with the project, respondents were

asked to indicate their degree of agreement with each of three statements. A sample statement includes, "I enjoyed working with this team".

Data Analysis and Results are presented in Chapter 5.

Chapter 5

DATA ANALYSIS AND RESULTS

5.1. Introduction

This chapter consists of four main sections: (1) a discussion of the survey response rates; (2) a discussion of threats to external and internal validity; (3) a discussion of how the conceptual model variables were constructed from individual questionnaire items; and (4) a discussion of the statistical analysis performed to test the hypotheses.

5.2. Survey Response Rates

A total of fourteen international manufacturing companies were solicited for participation in this study. The primary contact person in each company nominated one or more new product development concurrent engineering (CE) projects and, where appropriate, also provided the names of project team members. The project sample for this study included a total of 54 projects within 14 firms (Table II). Appendix 3 includes a profile of the companies by geographical region and a sample of project descriptions is given in Appendix 4.

The project sample response rate was based on the number of complete or nearly complete project teams that responded to the questionnaires. A project was classified as "complete" if all three respondents per project returned the questionnaires

Table II
Profile of Companies By Industry

Company Name	Industry	# Projects Studied
A	Automobile	6
B	Automobile	5
C	Automobile	3
D	Chemicals	2
E	Computers	4
F	Electronics	4
G	Electronics	4
H	Electronics	4
I	Electronics	3
J	Electronics	1
K	Shipbuilding	5
L	Telecommunications	9
M	Telecommunications	3
N	Other	1
		--
Total		54

Notes: Company J was unable to participate in this study.
 Company B has withdrawn 1 project.
 Company C has returned completed questionnaires for 1 project only.
 Company N remained anonymous thus preventing industry classification.

and "nearly complete" if responses were received from 2 out of 3 respondents. Out of the effective starting set of 54 projects, responses were received from 50 projects, indicating a project sample response rate of 93%. Of the 50 useable projects, 36¹ were classified complete and 8² nearly complete. Of the remaining 6 projects, 3 had questionnaires returned by only an engineering/R&D representative and 3 had questionnaires returned by only a project leader. In this study, the latter 3 projects were excluded from hypotheses testing, therefore, the sample size was 47 projects.

As discussed in chapter 4 (Section 4.2.), this study employed multiple respondents - 3 respondents per project - and therefore a total respondent sample of 162 persons was identified. Questionnaires have been received from 128 persons, indicating a respondent response rate of 79%. A summary of respondent response rates is given in Table III.

Table III
Respondent Response Rates

Project Leader	Engineering/R&D Rep	Manufacturing Rep
85.2% (n=46)	81.5% (n=44)*	70.4% (n=38)**

* 3 projects had 2 design reps; only single reps were included in the count.

** 1 project had 2 mfg reps; only single reps were included in the count.

¹No design reps were available for 2 projects thus rendering these projects complete.

²Completed questionnaires were received from both a project leader and a specialist in 7 out of 8 projects; questionnaires were received from both specialists in the other project.

5.2.1. Missing Values and Interrater Reliability

An examination of the Project Leader questionnaires and the Engineering/R&D and Manufacturing Representative questionnaires revealed that systematic missing data was not a major concern. For the 46 Project Leader questionnaires, missing values were scattered randomly throughout cases and questionnaire items. For the 86 Engineering/R&D and Manufacturing Rep questionnaires, the pattern of missing values was largely non-systematic for the questionnaire items relevant to the main model studied in this thesis. However, it is important to mention that questionnaire items relating to the allocation of top management resources (2.7, 5.2a, 5.2b) exhibited systematic missing values, therefore, they were simply dropped from subsequent analysis since deletion of cases was not a viable option given the small sample size. Since the pattern of missing values was randomly distributed throughout questionnaire items for both sets of questionnaires, the mean substitution method recommended by Tabachnick and Fidell (1989) was used.

As mentioned in the previous chapter, the unit of analysis for this study was a CE project. Since data was collected from multiple respondents, interrater reliability across respondents on the same project had to be evaluated prior to the aggregation of individual responses for each questionnaire item. It has been noted in the literature that there are difficulties associated with the analysis of multiple response data (Seidler 1974) and that few recognized techniques exist to assist researchers analyzing such data.

For the purpose of this study, interrater reliability was evaluated for each item using One-Way Analysis of Variance to detect significant differences between the various groups of responses (Table IV). In many cases, however, the t-test for

Table IV
Differences in Mean Scores Among Project Leader,
Engineering/R&D and Manufacturing (N = 132)

Item	Project Leader	Eng./R&D	Mfg.	F ₂
mfinvolv - 4.6a ¹	3.87	3.62	3.62	0.76
mffeed - 4.6b ¹	3.65	3.34	3.69	1.35
mfcost - 4.6c ¹	3.28	2.94	3.10	1.05
mfpurch - 4.6d ¹	2.91	2.62	2.67	1.26
r_dend - 4.6e	4.11	3.91	4.13	0.62
teamgood - 8.3a	3.70	3.55	3.72	0.48
workwell - 8.3c	4.11	3.94	4.03	0.38 ^{**}
hightrst - 8.3e	3.78	3.72	3.79	0.09
enjoy - 8.3b	4.22	4.06	4.28	0.96
streslow - 8.3d	2.57	2.55	3.13	4.37 [*]
likepart - 8.3f	4.02	4.02	4.28	2.40 ^{**}
makedec - 4.1a	3.50	3.60	3.51	0.12
impdec - 4.1b	3.41	3.70	3.69	1.72

Notes: ¹ items recoded; * p < 0.05; ** Kruskal-Wallis (corrected for ties) test statistic.

Equality of Means (two-tailed) was used for those items appearing only in the Engineering/R&D and Manufacturing Rep questionnaire. These results are given in Appendix 5.

As indicated in Table IV and Appendix 5, disagreement across respondents for each questionnaire item was judged to be sufficiently low (i.e., there was disagreement on 2 items) at $\alpha = 5\%$. For this reason, a project score was calculated for each item by averaging individual responses. Before discussing how the conceptual model variables were constructed from questionnaire items, it is important to discuss threats to validities.

5.3. Threats To External and Internal Validity

As with any piece of research, this study also suffers from limitations. The results of this study are limited because of sources of external and internal invalidity.

Despite a high project response rate, two threats to external validity are: (i) the use of convenience sampling and (ii) the unequal distribution of CE projects among the companies in the sample. These sources of external invalidity threaten the generalizability of the thesis results to other companies in the same industries.

Another source of external invalidity is the choice of industries. The consequence of studying companies in the automobile, chemical, computer, electronics, shipbuilding, and telecommunications industries is that the results of this study cannot, from a statistical point of view, be generalizable beyond these industries. However, it

is important to note that the focus of this study is on the use of CE in new product development. The underlying problems encountered by various companies, in different industries, in their use of CE do not vary significantly and therefore, the results of this study can be generalizable to companies in industries beyond the sample.

Missing values, interrater unreliability, and measurement issues contribute to internal invalidity. As indicated in the previous section, missing values were largely non-systematic, thus rendering them as a weak threat to internal validity. Similarly, high interrater reliability is not a threat to internal validity.

Using a newly developed instrument is a source of internal invalidity. The disadvantages of using an insufficiently validated instrument are clear and it is quite likely that they may be compounded by using a new instrument. The next section will show that the questionnaire survey developed for this study exhibits superior psychometric properties, therefore the instrument is not a major threat to internal validity.

5.4. Measures of Variables

Once team scores were obtained by averaging across the members of the group, the entire survey instrument underwent thorough measurement analysis, including principal components factor analysis (varimax rotation) for construct validity and

calculation of Cronbach's alpha³ for internal consistency reliability. Specific measures of each variable used in hypotheses testing are given below.

5.4.1. Task Characteristics

The task characteristics attribute consisted of two inter-related categories of variables. The perceptions of team members towards task difficulty and the major determinants of these perceptions - project characteristics - were measured here. Before measurement analysis was performed on the project characteristic items, some of the items (1.5, 1.6a, 1.6b, 1.6d) were recoded in order to maintain similar directionality. It is important to note that after recoding, high scores on all the project characteristic items indicated high levels of the particular item.

The correlation matrix of the project characteristic items (1.2, 1.4, 1.5, 1.6a, 1.6b, 1.6c, 1.6d) was factor analyzable as measured by the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (0.73); the Bartlett test of sphericity was also significant at $p < 0.000$. Three factors emerged accounting for 69.9% of the variance; items measuring "newness" clustered together while scale and scope loaded on distinct factors (Appendix 6). Based on this analysis, three measures of project characteristics were developed. The five items loading on the same factor were formed into a single

³The Cronbach's coefficient alpha indicates the internal consistency reliability of a scale. In general, a multi-item measure can be judged to be reliable when the value of its Cronbach alpha exceeds 0.70. Alpha's greater than or equal to 0.60 can be considered reliable; this is acceptable practice with exploratory research (Nunnally 1978).

scale ($\alpha = 0.79$) by averaging them. The inter-item pearson correlations for this scale appear in Appendix 7.

Items measuring the two dimensions of task uncertainty - variety (4.3a to 4.3e) and analyzability (4.4a to 4.4e)⁴ - were also factor analyzed. After eliminating items which cross-loaded on multiple factors, two distinct factors with eigenvalues greater than 1.0 emerged (Appendix 8). Four items measuring variety were averaged to form a single scale score ($\alpha = 0.75$). In addition, a single scale score for analyzability was obtained by averaging two items. Convergent and discriminant validity results for task uncertainty appear in Table V.

Equivocality (or ambiguity) is defined as lack of mutual understanding. The six equivocality items (4.5a to 4.5f) were recoded⁵ before factor analysis was conducted. All six items loaded on a single factor (eigenvalue = 3.42), accounting for 57.1% of the variance (Appendix 9), and therefore they were averaged to form a single scale. The resulting scale had a Cronbach alpha of 0.84 and an average inter-item correlation of 0.48. Inter-item pearson correlations for this scale appear in Appendix 10.

5.4.2. Management

As discussed in chapter 4 (Section 4.3.2.), management consists of three

⁴Items 4.4a, 4.4c and 4.4e were recoded to reflect the unanalyzable nature of the task; high scores indicated high levels of the particular item.

⁵After recoding, high scores indicate high levels of the particular item.

Table V
Convergent and Discriminant Validity of
Variety and Analyzability (N = 50)

Item	1	2	3	4	5	6
VARIETY						
1. revise_1	-					
2. schedu_1	0.35	-				
3. confli_1	0.48	0.42	-			
4. crises_1	0.30	0.48	0.52	-		
ANALYZABILITY						
5. method_1	0.10	0.26	0.25	0.33	-	
6. previo_1	-0.03	-0.07	-0.15	-0.13	0.32	-

Notes.

1. Variety:

Cronbach alpha = 0.75.

Mean intra-scale correlation of items = 0.43.

2. Analyzability:

Cronbach alpha = 0.48⁶.

Intra-scale correlation of items = 0.32.

3. Mean inter-scale correlation (absolute value) of items = 0.16.

dimensions - CE orientation, integrative mechanisms, and communication technologies and tools. For the main model studied in this thesis, CE orientation is the dependent (or endogenous) variable.

⁶This scale, although not used for the present study, has potential merit for future research.

Concurrent Engineering

The CE orientation items (4.2, 4.6a to 4.6e, 4.7a to 4.7c, 4.8, 4.9a to 4.9f) were subjected to a principal components (varimax rotation) analysis to identify an underlying pattern. The item correlation matrix was factor analyzable (KMO = 0.61, Bartlett's test of sphericity was significant at $p < 0.000$) and the resulting factor analysis produced four distinct factors. The eigenvalues for the four factors were 4.60, 2.71, 1.84 and 1.43. As indicated in Appendix 11, the total variance explained by this factor solution was 66.1%. The value of the primary loadings for each item was in the range of 0.46 to 0.88, moreover, the factor solution produced few cross-loadings. Items relating to information exchange (4.7a to 4.7c, 4.8) and structure (4.2, 4.6e) clustered together, as did items relating to overlapping problem-solving (4.6a to 4.6d)⁷. In addition, items relating to information tolerance (4.9c to 4.9f) loaded on the same factor while "willingness of engineering/R&D to share incomplete and uncertain information with manufacturing" and "willingness of manufacturing to share incomplete and uncertain information with engineering/R&D" clustered together.

On the basis of this analysis, four measures of CE orientation were developed. Flow of product design information, flow of manufacturing information, amount of overlapping problem-solving, completeness of process design when engineering/R&D ended their active involvement in the project, 2-way communication, and frequency of

⁷Items were recoded - high scores indicated high levels of overlapping problem-solving.

upstream/downstream communication were averaged to form a single scale called CEINTDIM. The Cronbach alpha for this scale was 0.83 and the mean inter-item correlation was 0.45. Details of this scale appear in Table VI. The second measure called CEOPS (alpha = 0.76, mean inter-item correlation = 0.44) was developed by averaging the scores on four items (4.6a to 4.6d). Appendix 12 contains additional information about this measure.

Table VI
Inter-Item Pearson Correlations for
CEINTDIM Measure

Item	Corrected Item-Total Correlation	1	2	3	4	5	6
1. prdinf_1	0.65	-					
2. prcinf_1	0.74	0.79	-				
3. overla_1	0.41	0.29	0.39	-			
4. r_dend_1	0.53	0.40	0.42	0.20	-		
5. comm2w_1	0.67	0.49	0.65	0.41	0.38	-	
6. oftenc_1	0.62	0.44	0.47	0.33	0.57	0.52	-

Notes: Cronbach alpha = 0.83; N = 47.

As discussed, four items relating to information tolerance were combined to form a single scale called CEINFTOL (alpha = 0.75). The items and corrected item-

total correlations were: (1) "willingness of engineering/R&D to revise decisions based on incomplete and uncertain information from manufacturing" (0.46); (2) "willingness of manufacturing to revise decisions based on incomplete and uncertain information from engineering/R&D" (0.59); (3) "willingness of engineering/R&D to incorporate ambiguous information from manufacturing" (0.53); and (4) "willingness of manufacturing to incorporate ambiguous information from engineering/R&D" (0.63). Inter-item pearson correlations for this scale appear in Appendix 13. The fourth measure called CEATITD was formed into a single scale ($\alpha = 0.85$) by averaging two items having an inter-item correlation of 0.74.

Integrative Mechanisms

Status parity, job rotation, group based rewards and evaluations, co-location, project structure, leadership style, and top management support were the integrative mechanisms studied in this thesis. It is important to note that for this thesis, coordinating mechanisms (i.e., project structure) were viewed as a subset of integrative mechanisms.

The four-item (5.3a to 5.3d) status parity measure was recoded before measurement analysis was performed. The resulting three-point scale (0=no difference, 2=great difference) was not reliable ($\alpha = 0.39$), therefore, a single scale score for status parity could not be computed; the individual items - EDLEVEL, WORKENV, EXPLEVEL, and ORGPOSIT - comprising the measure were used in subsequent

analysis.

The job rotation (JOBROTN) measure - the total number of years of upstream/downstream rotation - was developed by taking the sum of the number of years engineering/R&D spent in the manufacturing function and the number of years manufacturing spent in the engineering/R&D function. The two items (5.5a, 5.5b) measuring group based rewards and evaluations were factor analyzed and the resulting single factor solution - eigenvalue = 1.76 - accounted for 88.1% of the variance. Therefore these two items were averaged to form a single scale score ($\alpha = 0.87$, inter-item correlation = 0.76) called EVALREWD. Co-location^b of engineering/R&D and manufacturing was measured by one item (2.2b).

Leadership style consisted of four items ($\alpha = 0.62$) with a mean inter-item correlation of only 0.27. The items and corrected item-total correlations were: (1) "the project leader encouraged the team to make critical decisions" (0.68); (2) "the project leader encouraged the team to implement critical decisions" (0.17); (3) "the project leader made the team responsible for resolving internal conflicts" (0.34); and (4) "the project leader encouraged the team to resolve problems with the rest of the organization." (0.45). Eliminating the second item raised the alpha to 0.69 therefore a single scaled called LEADER was formed by averaging the scores on three items (Appendix 14).

^bThis item was coded as a binary variable (0 = no co-location, 1 = co-location).

The correlation matrix of the top management support items was factor analyzable (KMO = 0.52. Bartlett's test of sphericity was significant at $p < 0.000$). All four items (5.1a to 5.1d) focusing on endorsement clustered together on the same factor (Appendix 15), therefore a single scale (alpha = 0.81, mean inter-item correlation = 0.52) called MGMTSUP was developed by averaging these items. Table VII contains the details of this scale.

Table VII
Inter-Item Pearson Correlations for
MGMTSUP

Item	Corrected Item-Total Correlation	1	2	3	4
1. overt _t _1	0.59	-			
2. overt _b _1	0.61	0.56	-		
3. freq _{tm} _1	0.56	0.48	0.30	-	
4. freq _{bu} _1	0.76	0.44	0.70	0.64	-

Notes: Cronbach alpha = 0.81; N = 47.

The coordinating mechanisms were measured by two categories of items - the first category (5.6a to 5.6d)⁹ emphasized organizational structure (e.g., functional

⁹Item 5.6b was recoded - high scores indicate high levels of the item.

matrix) while the second category (5.4a to 5.4k) assessed the relative influence of the project leader and functional manager on a variety of issues. Each category was subjected to a principal components (varimax rotation) analysis to identify an underlying pattern.

The item correlation matrix of the organizational structure items was factor analyzable (KMO = 0.54, Bartlett's test of sphericity was significant at $p < 0.01$) and the rotated factor solution produced two distinct factors (Appendix 16). Items relating to the role of the functional manager and the responsibility of the project leader clustered together, as did items relating to reporting structure and the role of the project leader¹⁰. A single scale (alpha = 0.61, inter-item correlation = 0.45) called PRJSTRUC was developed by averaging the scores on two items (5.6c, 5.6d).

According to the KMO measure of sampling adequacy (0.72) and the Bartlett test of sphericity (significant at $p < 0.000$), the correlation matrix of the eleven influence items was factor analyzable. Three distinct factors emerged accounting for 65% of the variance. Furthermore, the eigenvalues for the three factors were 3.50, 2.34, and 1.30 (Appendix 17). The value of the primary loadings for each item was in the range 0.52 to 0.86 and with a few exceptions, the cross-loadings were low. Five items (5.4b to 5.4d, 5.4f, 5.4i) relating to influence on administrative/organizational issues loaded on the first factor; relative influence on selecting team members,

¹⁰This two-item measure had a Cronbach alpha value of -0.39, a result of the negative correlation between the items.

conducting performance evaluation, and defining the reward system clustered together, as did relative influence on directing work flow activities, making technological decisions, and making decisions about tools and methods.

Based on this analysis, three measures of influence were developed. Relative influence on setting schedules, making budget re-allocation decisions, controlling costs, deciding what needed to be accomplished, and ensuring project completion were averaged to form a single scale called ADMORG. This scale had a Cronbach alpha value of 0.78 (Table VIII). The second measure called STSALPRO ($\alpha = 0.73$,

Table VIII
Inter-Item Pearson Correlations for
ADMORG Measure

Item	Corrected Item-Total Correlation	1	2	3	4	5
1. setsch_1	0.67	-				
2. makebu_1	0.67	0.70	-			
3. ctrlco_1	0.55	0.41	0.53	-		
4. accomp_1	0.46	0.44	0.35	0.27	-	
5. projco_1	0.47	0.38	0.30	0.41	0.37	-

Notes: Cronbach $\alpha = 0.78$; $N = 47$.

mean inter-item correlation = 0.48) was formed by averaging the scores on three items

(5.4a, 5.4g, 5.4h). Inter-item pearson correlations for this scale appear in Appendix 18. Averaging items 5.4j and 5.4k led to the third measure called TECHTOOL which had a Cronbach alpha value of 0.73¹¹ and an inter-item correlation of 0.58.

Communication Technologies and Tools

Part 6 of the Engineering/R&D and Manufacturing Representative questionnaire focused on various issues pertaining to communication technologies & tools. For this study, emphasis was placed mainly on the deployment of various media and tools (6.1a to 6.1s)¹².

Two measures were developed to measure deployment of media and tools. The first index (INDXMEDI) was formed by combining the access scores for electronic mail, voice mail, fax machine, conference call, videoconferencing, group decision support system, face-to-face, telephone, and mailed documents. The resulting 9-item index had a range of 0 to 9 where high scores indicated greater deployment of electronic and traditional media.

To measure the deployment of productivity enhancement tools - CAD, CAE, CAM - and organizational integration tools - EDI, QFD, IGES, PDES, ISO 9000 standards - an index called INDXTOOL was developed by combining the scores on

¹¹Alpha for the initial three-item measure was 0.68. Item 5.4e was dropped to raise the alpha.

¹²Items 6.1g and 6.1n were dropped because of systematic missing data.

eight items (6.1k to 6.1s); the range of this index was 0 to 8.

5.4.3. Constraints

Cognitive styles, culture, and barriers collectively made up the constraints. Principal components (varimax rotation) analysis¹³ was performed on the cognitive styles items (3.1a to 3.1j, 3.1a to 3.1f) to elicit an underlying pattern. After eliminating complex¹⁴ items and poorly defined factors, a two factor solution emerged. Items relating both to the systematic mode of problem-solving and to the receptive mode of information gathering loaded on the first factor (eigenvalue = 2.60) while items relating both to the intuitive mode of problem-solving and to the preceptive mode of information gathering loaded on the second factor (eigenvalue = 1.74).

Two measures of cognitive styles were developed based on this two factor solution (Appendix 19). Look for a method for solving the problem, define the constraints of the problem early, conscious approach, insist on a complete examination of the data, and suspend judgement were averaged to form a single scale called SYSRECEP (alpha = 0.65). The second measure called INTPRECT had a Cronbach alpha value of 0.66. Four items - rely on hunches, jump from one step in analysis, look for cues, jump from one section of the data to another - were averaged to create this scale. Convergent and discriminant validity for both measures appear in Table IX.

¹³This analysis was performed at the level of the individual respondent.

¹⁴A complex item is correlated with several factors (Tabachnick and Fidell 1989, p.602).

Table IX
Convergent and Discriminant Validity of
Cognitive Styles (N = 86)

Item	1	2	3	4	5	6	7	8	9
INTPRECT									
1. hunches	-								
2. onestep	0.29	-							
3. cues	0.36	0.19	-						
4. jump	0.26	0.39	0.54	-					
SYSRECEP									
5. plansolv	-0.27	-0.23	-0.01	0.07	-				
6. cnstearl	-0.02	-0.38	-0.09	-0.16	0.21	-			
7. conscius	0.01	-0.16	-0.17	-0.01	0.26	0.30	-		
8. complete	-0.23	-0.37	-0.21	-0.02	0.38	0.33	0.29	-	
9. suspend	-0.08	0.01	0.08	0.11	0.36	0.03	0.17	0.34	-

Notes.

1. INTPRECT:

Cronbach alpha = 0.66.

Mean intra-scale correlation of items = 0.34.

2. SYSRECEP:

Cronbach alpha = 0.65.

Mean intra-scale correlation of items = 0.27.

3. Mean inter-scale correlation (absolute value) of items = 0.13.

The five dimensions of culture were also factor analyzed to ensure construct

validity¹⁵. A careful examination of the initial factor solution revealed that only two dimensions of culture - "masculinity" (7.1d, 7.1i, 7.1n, 7.1s) and confucianism (7.1e, 7.1j, 7.1o, 7.1t) - were well defined¹⁶. The two factor solution with marker variables appears in Appendix 20.

Since a two factor solution was pursued, two measures of culture were developed. The MASCULIN (alpha = 0.68) scale consisted of three items with a mean inter-item correlation of 0.43. The items and corrected item-total correlations were: (1) "performance is what counts" (0.49); (2) "money and material things are important" (0.42); and (3) "one admires the successful achiever" (0.59). The second measure CONFUCIN (alpha = 0.48) was formed by averaging the scores on two items - 7.1j and 7.1o. Convergent and discriminant validity for both measures appear in Table X.

Two items (2.3, 2.4) were used to measure the barriers between engineering/R&D and manufacturing. A single variable called DISTANCE (0 = no distance, 3 = flying distance) measured the geographical separation between the two functions - a distance of 0 indicated co-location at the same site (i.e., same building) whereas walking (1), driving (2), or flying (3) distance indicated the extent of global concurrent engineering. The TIMEZONE variable measured the absolute value of the difference in time-zones between engineering/R&D and manufacturing.

¹⁵Factor analysis was performed at the level of the individual respondent.

¹⁶small power distance, weak uncertainty avoidance, and individualism were not construct validated. In addition, the scales developed for the respective dimensions were not reliable - 0.22, -0.12, 0.23.

Table X
Convergent and Discriminant Validity of
Culture (N = 86)

Item	1	2	3	4	5
CONFUCIN					
1. reciproc	-				
2. saveface	0.32	-			
MASCULIN					
3. perfcts	0.04	-0.11	-		
4. money	-0.20	-0.12	0.32	-	
5. success	-0.11	0.01	0.54	0.42	-

Notes.

1. Confucin:

Cronbach alpha = 0.48¹⁷.

2. Masculin:

Cronbach alpha = 0.68; Mean intra-scale correlation of items = 0.43.

3. Mean inter-scale correlation of items (absolute value) = 0.09.

5.4.4. Project Outcomes/Results

The success measures were subjected to principal components analysis to confirm the task (items 8.2a to 8.2d)¹⁸ and process (items 8.3a to 8.3f) dimensions of success. The correlation matrix of success items was factor analyzable (KMO = 0.74,

¹⁷ This scale was dropped from subsequent analysis but has potential for future research.

¹⁸ Items were recoded as a 5-point scale centred at 3 where high scores indicated success.

Table XI
Convergent and Discriminant Validity of Success (N = 47)

Item	1	2	3	4	5	6	7	8	9
CBUDLT									
1. prodco_1	-								
2. budget_1	0.51	-							
3. leadti_1	0.63	0.44	-						
COOPSAT									
4. teamgo_1	0.16	0.16	0.00	-					
5. workwe_1	0.18	0.32	0.07	0.52	-				
6. hightr_1	0.02	0.15	0.04	0.54	0.56	-			
7. enjoy_1	0.22	0.19	0.10	0.52	0.74	0.43	-		
8. stresl_1	0.17	0.13	-0.02	0.37	0.32	0.41	0.28	-	
9. likepa_1	0.11	0.00	-0.04	0.36	0.53	0.33	0.52	0.16	-

Notes.

1. CBUDLT:

Cronbach alpha = 0.77.

Mean intra-scale correlation of items = 0.53.

2. COOPSAT:

Cronbach alpha = 0.82.

Mean intra-scale correlation of items = 0.44.

3. Mean inter-scale correlation of items (absolute value) = 0.12.

Bartlett's test of sphericity was significant at $p < 0.000$) and the rotated two factor solution (Appendix 21) confirmed the multi-dimensional nature of success. Items

relating to cooperation and satisfaction clustered together on the first factor (eigenvalue = 3.44) while items relating to project goals¹⁹ loaded on the second factor (eigenvalue = 1.92). This analysis supported the development of two measures of success: the first, COOPSAT (alpha = 0.82), was an average of six items and the second, CBUDLT (alpha = 0.77), was an average of three items. Table XI contains convergent and discriminant validity results for both measures.

5.5. Data Analysis and Results

As indicated in Figure 2, hypotheses 1 through 5 were the central focus of this research. Descriptive statistics of the measures discussed in the previous section to test these hypotheses appear in Table XII²⁰. It is important to note that a total of three additional variables were created to specifically test H3b (DFSYSREC, DFINTPRE) and H4b (DFMASCUL). Although these difference (absolute value) variables do not appear in Table XII, they were examined for potential problems²¹.

A variety of statistical procedures including discriminant function analysis, factor structure analysis and standard multiple regression were used to test the

¹⁹Item 8.2b (quality) was dropped as it did not correlate highly with either of the two factors.

²⁰Descriptive statistics specific to media and tools appear in Appendix 22.

²¹The sampling distribution of each variable was found to be normal - K-S Z values were respectively 0.87, 1.32, and 0.76; (2-tailed) $p > 0.05$.

Table XII
Descriptive Statistics of Main Variables

Variables	# of Scale Items	Mean	Standard Deviation	Cronbach's Alpha	K-S Z ^a
ceintdim	6	3.84	0.64	0.83	0.89
ceops	4	3.29	0.65	0.76	0.91
ceinftol	4	2.65	0.61	0.75	1.13
ceatitd	2	3.65	0.79	0.85	1.25
edlevel	1	0.64	0.53	-	2.53 ^{*1}
workenv	1	0.32	0.52	-	2.97 ^{*2}
explevel	1	0.92	0.55	-	2.54 ^{*1}
orgposit	1	0.62	0.57	-	2.21 ^{*1}
jobrotn	1	4.30	5.63	-	1.72 ^{*3}
evalrewd	2	3.64	1.46	0.87	1.18
leader	3	3.55	0.60	0.69	1.45 ^{*4}
mgmtsup	4	3.23	0.63	0.81	0.89
prjstruc	2	3.77	0.76	0.61	1.19
admorg	5	3.47	0.71	0.78	0.72
stsalpro	3	2.72	0.89	0.73	1.07

(continued on next page)

Table XII (continued)

Variables	# of Scale Items	Mean	Standard Deviation	Cronbach's Alpha	K-S Z ^a
techtool	2	3.35	0.89	0.73	1.20
indxmedi	9	7.32	1.62	-	1.34
indxtool	8	4.00	2.07	-	1.09
sysrecep	5	3.67	0.59	0.65	0.90
intprect	4	2.95	0.66	0.66	0.88
masculin	3	3.54	0.67	0.68	1.46 ^{*1}
distance	1	1.89	1.18	-	1.71 ^{*5}
timezone	1	1.34	2.69	-	2.55 ^{*6}
coopsat	6	3.76	0.47	0.82	0.74
cbudlt	3	2.41	0.59	0.77	1.22

Notes: ^aKolmogorov-Smirnov Goodness of fit statistic; *p (2-tail) < 0.05.

¹no skewness at $\alpha=0.01$; ²70% indicated no difference.

³no job rotation on 32% of the projects; ⁴variable was negatively skewed.

⁵21.3% indicated no distance; ⁶68.1% indicated no timezone difference.

hypotheses²². In the remainder of this section results will be reported. A discussion of the implications of the findings will be presented in Chapter 6.

²²The level of analysis for hypotheses H1, H2, H3b, H4b, H5 is the project; the respondent is the level of analysis for H3a and H4a.

5.5.1. Differences in Cognitive Styles Between Engineering/R&D and Manufacturing

Linear discriminant function analysis²³ was used to determine whether the full set of cognitive styles items could serve as reliable predictors for classifying engineering/R&D and manufacturing and whether the classification accuracy of the discriminant function was better than chance prediction. Table XIII presents results of discriminant analyses between the two functions.

Table XIII
Discriminant Analysis for Engineering/R&D and
Manufacturing Based on Cognitive Styles

Discriminating Variables (unstandardized coefficients appear in Appendix 23):

Systematic:	plansolv	Intuitive:	probcont
	discalt		hunches
	cnstearl		onestep
	conscius		abandon
	refine		simult
Receptive:	complete	Preceptive:	cues
	details		relation
	suspend		jump

(continued on next page)

²³ According to Box's M test, the group covariance matrices were homogeneous - $p > 0.05$.

Table XIII (continued)

Classification Results

<u>Actual Group</u>	<u>N</u>	<u>Predicted Group Membership</u>	
		<u>1</u>	<u>2</u>
1. Design	47	41 (87%)	6 (13%)
2. Manuf.	39	16 (41%)	23 (59%)

Percent of Cases Correctly Classified: 74% (versus 50% random)

As indicated in Table XIII, the "hit ratio" of the discriminant function was 74%, suggesting that the function was effective since it outperformed chance prediction by a reasonably wide margin. A test (Wilks' Lambda) of the reliability of the function revealed that the function was not reliable at $\alpha = 0.10$. However, it is important to note that the total variance in the discriminant scores explained by group differences was 20%, therefore the need for further analysis of cognitive differences was justified.

A factor analytic approach was used to determine differences in factor structure between engineering/R&D and manufacturing. For this analysis, the items comprising the cognitive styles' measures - SYSRECEP and INTPRECT - were used as marker variables. A comparison of factor loadings for both functions appears in Table XIV.

A careful inspection of the loading matrices²⁴ in Table XIV revealed that both functions generated the same number of factors and that almost the same variables

²⁴The correlation matrices were factor analyzable.

Table XIV
Comparison of Factor Structures From Engineering/R&D
and Manufacturing on Cognitive Styles

	<u>Engineering/R&D</u>		<u>Manufacturing</u>	
	Factor 1	Factor 2	Factor 1	Factor 2
plansolv	-0.11	0.66	0.81	-0.08
cnstearl	-0.57	0.36	0.47	0.01
conscius	-0.52	0.34	0.60	0.07
complete	-0.38	0.71	0.71	-0.19
suspend	0.23	0.78	0.54	-0.11
hunches	0.26	-0.18	-0.26	0.77
onestep	0.69	-0.21	-0.37	0.59
cues	0.70	0.21	-0.01	0.80
jump	0.78	0.12	0.36	0.80
% variance	30.6	18.2	29.7	22.0

loaded highly on different factors for both groups - 60% of the variables defining factor 2 for engineering/R&D are among the variables defining factor 1 for manufacturing. Differences in factor structure were not unambiguously obvious from visual inspection therefore a formal procedure was used to remove doubts about the similarity of factor structures.

The pattern and magnitude of loadings were compared by computing Pearson's

r. The loadings for factor 2 in engineering/R&D and factor 1 in manufacturing correlated 0.74. This strong correlation of factors for both functions indicated that engineering/R&D and manufacturing were cognitively the same; the relative importance of factors and not the nature of factors is different. To further examine and identify differences in cognitive styles between the two functions, the pooled-variance t test²⁵ was used (Table XV).

Table XV
Differences in Cognitive Styles Between
Engineering/R&D and Manufacturing

	Means		T value	p (2-tailed)
	Eng/R&D (n=47)	Mfg (n=39)		
sysrecep	3.65	3.69	-0.28	N.S.
intprect	2.87	3.05	-1.22	N.S.

Note: N.S. means $p > 0.10$.

As indicated in Table XV, the differences in cognitive styles were not statistically significant, therefore, the null hypothesis of no difference could not be rejected. It is interesting to note that both measures of cognitive styles were not equally effective in detecting differences and moreover, for both measures, manufacturing scored higher. To identify the cognitive styles of engineering/R&D and manufacturing, the separate-variance t test was used (Table XVI).

²⁵ $p > 0.20$ for Levene's statistic.

Table XVI
Cognitive Styles of Engineering/R&D and Manufacturing

	N	Means		T value	p (1-tail)
		Sysrecep	Intprect		
Eng/R&D	47	3.65	2.87	6.17	0.0005
Mfg	39	3.69	3.05	4.45	0.0005

The results in Table XVI indicated that both functions are strongly mapped (statistically significant) to the systematic-receptive dimension. The cognitive mapping of engineering/R&D was in the opposite direction of that hypothesized. Chapter 6 includes a further discussion of these results.

To summarize, Hypothesis 3a stated that there will be a difference in cognitive styles between engineering/R&D and manufacturing. A direct test of differences on the individual dimensions of cognitive styles suggested that H3a cannot be supported, however, evidence from both discriminant function analysis and factor structure analysis suggested that the two functions are not cognitively the same. On the basis of the results presented in this section, the qualified conclusion is that there is a cognitive difference between engineering/R&D and manufacturing which is measurably small.

5.5.2. Differences in Culture Between Engineering/R&D and Manufacturing

Hypothesis 4a stated that there will be cultural differences between

engineering/R&D and manufacturing. To test this hypothesis, multiple statistical procedures were used. First, discriminant analysis was performed to determine whether the entire set of culture items could be used to reliably and effectively classify cases into groups when group membership was known. Second, a factor analytic approach using the construct validated culture items as marker variables was used to examine the factor structures of both functions. Third, the Wilcoxon-Mann-Whitney²⁶ test was used to directly test for the statistical significance of cultural differences.

The misclassification rate of a discriminant function is an index of its effectiveness. As indicated in Table XVII, the probability of misclassification was only 33%, clearly superior to chance prediction. It is important to note that the observed misclassification rate was not lower because for both engineering/R&D and manufacturing, the sampling distributions for the culture variables (predictors) were systematically non-normal²⁷.

A test of the reliability of the discriminant function revealed that it was not statistically significant at $\alpha = 0.10$. However, an examination of the characteristics²⁸ of the function revealed that group differences explained a large amount of variance in the discriminant scores.

²⁶This test has high power (i.e., the probability of not rejecting the null hypothesis when it is false is low).

²⁷For eng/R&D, only 1 item was normally distributed - K-S 1-sample, p (2-tailed) > 0.05; for mfg., 5 items were normally distributed - K-S 1-sample, p (2-tailed) > 0.05.

²⁸Eigenvalue = 0.28; canonical correlation = 0.47.

Table XVII
Discriminant Analysis for Engineering/R&D and
Manufacturing Based on Culture

Discriminating Variables (unstandardized coefficients appear in Appendix 24):

Power Distance:	inequal	Uncertainty Avoidance:	timefree
	ordinary		servctzn
	eqlright		hardwork
	pwrlegit		uncertok
Individualism:	takecare	Masculinity:	perfcnts
	private		money
	emotion		success
	individl		mendom
Confucianism:	longterm		
	reciproc		
	saveface		
	notspend		

Classification Results

<u>Actual Group</u>	<u>N</u>	<u>Predicted Group Membership</u>	
		<u>1</u>	<u>2</u>
1. Design	47	35 (75%)	12 (25%)
2. Manuf.	39	16 (41%)	23 (59%)

Percent of Cases Correctly Classified: 67% (versus 50% random)

The second statistical procedure used to examine cultural differences was factor structure analysis. As indicated in Table XVIII, the optimal number of factors for engineering/R&D and manufacturing was two. Furthermore, both factors for both groups were internally consistent and well defined. Visual inspection of the factor structures revealed some resemblance between factor 2 for engineering/R&D and factor 1 for manufacturing - the variables defining factor 2 for engineering/R&D are also among the variables defining factor 1 for manufacturing. The correlation between these two factors was 0.32²⁹, suggesting that the factor structures for both functions were not identical.

Table XVIII
Comparison of Factor Structures From Engineering/R&D
and Manufacturing on Culture

	<u>Engineering/R&D</u>		<u>Manufacturing</u>	
	Factor 1	Factor 2	Factor 1	Factor 2
perfents	0.03	0.88	0.87	0.01
money	0.73	0.02	0.78	-0.31
success	0.66	0.51	0.89	0.22
reciproc	-0.81	0.06	0.02	0.86
saveface	-0.01	-0.53	-0.04	0.88
% variance	36.6	22.1	43.4	33.2

²⁹Although there were variables with large loadings on the factors being compared, r was not higher partly because of the presence of only 5 marker variables.

As discussed in Section 5.4, a single reliable measure was developed for culture. The results of the Mann-Whitney test (Table XIX) indicated that cultural differences between the two functions were not statistically significant. It is important to note that manufacturing scored considerably higher than engineering/R&D on all the items comprising the MASCULIN measure, thus prompting a test of differences at the item level. A statistically significant difference was obtained on the item labelled money³⁰. Further discussion of these results is included in the next chapter.

Table XIX
Differences in Culture Between Engineering/R&D
and Manufacturing

	Mean Rank		Z	
	Eng/R&D ^a (n=47)	Mfg (n=39) ^b	(corr. for ties)	p (2-tailed) ^c
masculin	40.64	46.95	-1.18	N.S.

Note: N.S. means $p > 0.10$; ^amean for eng/R&D = 3.49; ^bmean for mfg = 3.60; ^cfor a 1-tail test, the location of the critical region would differ.

On the basis of the results presented, there is evidence suggesting cultural differences between engineering/R&D and manufacturing - upstream and downstream functions appear to be at different ends of the masculin dimension of culture. However, on the basis of statistical tests, these differences were not large enough to permit rejection of the null hypothesis of no difference. Therefore, hypothesis 4a

³⁰Z corrected for ties = -1.76, p (2-tailed) < 0.10.

cannot be supported.³¹.

5.5.3. The Test of Independent Variables and CE Orientation

Standard multiple regression was used to test hypotheses H1, H2, H3b, H4b and H5. As indicated in Table XX³², a total of 19 independent variables (IV) were developed to explain the variability in the different dimensions of CE orientation. Given the small sample size and large number of predictors, a decision had to be made regarding the selection of a regression strategy. Two major considerations were: (1) the case-to-variable ratio³³ and (2) committing specification error (Kmenta 1971).

Standard multiple regression was selected as the most appropriate regression strategy because the emphasis in this study was to assess relationships among variables and to test various models. Given the inadequate case-to-variable³⁴ ratio, the effective starting set of 19 IVs was reduced to 10 IVs - importance of IVs was assessed on the basis of both statistical and logical grounds. The basic assumptions for conducting regression analysis were examined before regression was performed.

³¹-This result must be interpreted with caution since small sample sizes may have contributed to statistically insignificant differences.

³²Pearson correlations between indicators of access and use and CE orientation are included in Appendices 25 and 26 respectively.

³³As a rule of thumb, this ratio must be at least 5 (Tabachnick and Fidell 1989, p. 603).

³⁴It is important to note that a large number of predictors reduces the power of significance tests of hypotheses.

Table XX
Pearson Correlations Between Independent Variables
and CE Orientation ($N = 47$)¹

Variables	CE Orientation			
	ceintdim	ceops	ceintfol	ceatitd
1. edlevel	0.21	0.27*	0.09	0.21
2. explevel	0.05	0.07	-0.13	0.03
3. workenv	-0.08	0.04	0.07	0.04
4. orgposit	0.02	0.18	0.26*	0.18
5. jobrotn	0.30**	0.10	0.11	0.15
6. evalrewd	0.42***	0.30**	0.15	0.36**
7. leader	0.53***	0.13	-0.28*	0.30**
8. mgmtsup	0.24*	0.20	0.10	0.19
9. prjstruc	0.40***	0.06	0.09	0.14
10. admnorg	0.24*	-0.04	-0.01	0.04
11. stsalpro	0.08	-0.05	0.01	0.01
12. techtool	0.06	-0.05	-0.14	0.10
13. indxmedi	0.28*	0.07	0.13	0.13
14. indxtool	0.37**	0.33**	0.23	0.30**

(continued on next page)

Table XX (continued)

Variables	CE Orientation			
	ceintdim	ceops	ceintfol	ceatitd
15. dfsysrec	-0.10	0.00	0.09	0.17
16. dfintpre	-0.08	-0.26 [*]	-0.14	-0.04
17. dfmascul	-0.02	-0.02	0.32 ^{**}	0.01
18. distance	-0.06	-0.00	0.02	-0.08
19. timezone	-0.24 [*]	-0.22 [*]	0.14	-0.20

Notes: ^{*}p < 0.10.

^{**}p < 0.05.

^{***}p < 0.01.

^{*}marginally insignificant at p < 0.10.

¹glossary of main variables is given in Appendix 27.

An examination of the correlation matrix of the 19 IVs revealed no significant multicollinearity³⁵ effects. For each of the regression models - M1 to M4 - residual scatterplots were examined for normality, linearity, and independence³⁶. No violations of regression assumptions were observed. The standard multiple regression results are presented in Tables XXI, XXII, XXIII, and XXIV.

³⁵As expected, there was a strong inverse relation ($r = -0.84$) between the distance and co-location variables; the latter variable was dropped.

³⁶The Durbin-Watson statistic values of 1.31, 1.84, 1.83, and 1.51 for each of the four models indicated no autocorrelation of errors.

Table XXI
Standard Linear Regression on CEINTDIM

Independent Variables	Model 1: CEINTDIM	
Constant	1.19*	
Orgposit	0.07	(0.13)
Leader	0.39**	(0.15)
Evalrewd	0.08	(0.06)
Prjstruc	0.21*	(0.11)
Indxtool	0.12***	(0.04)
Dfsysrec	-0.02	(0.18)
Dfintpre	-0.11	(0.14)
Dfmascul	-0.07	(0.19)
Distance	-0.05	(0.08)
Timezone	-0.04	(0.03)
R²	0.56	
Res. Degrees of Freedom	36	
F	4.62	
P	< 0.001	

Notes: Numbers are regression coefficients; "()" are standard errors.
Coefficients significant at: *p < 0.10; **p < 0.05; ***p < 0.01.

As indicated in Table XXI ($R\text{-squared} = 0.56$; $F = 4.62$; $p < 0.001$), the dimension of CE orientation relating to information exchange and changes to the upstream/downstream interface is a function of three variables. A participative project leader leadership style is positively and significantly related to the interface dimension ($T = 2.65$; $p < 0.05$). In addition, a project matrix organizational structure is positively and significantly related to the interface dimension ($T = 1.83$; $p < 0.10$) and deployment of both productivity enhancement and organizational integration tools is positively and significantly related to the interface dimension ($T = 2.97$; $p < 0.01$). This result indicates that both integrative and coordinating mechanisms play an important role in maintaining and sustaining the structural changes brought about by "concurrent engineering". It is important to note that there is directional support for the hypothesized effect of the constraints on the interface dimension of CE orientation. A further discussion of these results is presented in Chapter 6. The results in Table XXII indicate that a different set of variables is important for the CEOPS dimension.

The results of standard multiple regression on Model 2 ($R\text{-squared} = 0.40$; $F = 2.36$; $p < 0.05$) indicate that integrative mechanisms, coordinating mechanisms, cognitive differences, and barriers are important explanatory variables for the dimension of CE orientation relating to overlapping problem-solving. Group based evaluation and reward systems are positively and significantly related to early manufacturing involvement in product design ($T = 2.52$; $p < 0.05$). Deployment of both productivity enhancement and organizational integration tools is positively and

Table XXII
Standard Linear Regression on CEOPS

Independent Variables	Model 2: CEOPS	
Constant	3.43^{***}	
Orgposit	0.18	(0.15)
Leader	-0.10	(0.17)
Evalrewd	0.17^{**}	(0.07)
Prjstruc	-0.07	(0.13)
Indxtool	0.10^{**}	(0.05)
Dfsysrec	0.07	(0.21)
Dfintpre	-0.42^{**}	(0.17)
Dfmascul	-0.17	(0.23)
Distance	-0.10	(0.10)
Timezone	-0.07[*]	(0.04)
R²	0.40	
Res. Degrees of Freedom	36	
F	2.36	
P	< 0.05	

Notes: Numbers are regression coefficients; "()" are standard errors.
Coefficients significant at: ^{*}p < 0.10; ^{**}p < 0.05; ^{***}p < 0.01.

significantly related to overlapping problem-solving ($T = 2.21$; $p < 0.05$). Reducing cognitive differences on the intuitive-preceptive dimension is positively and significantly related to overlapping problem-solving ($T = -2.52$; $p < 0.05$). In addition, reducing time-zone differences is positively and significantly related to overlapping problem-solving ($T = -1.83$; $p < 0.10$). These results will be discussed further in the following chapter.

The results of Models 1 and 2 are significant in the predicted direction, however, some of the regression results for Model 3 ($R\text{-squared} = 0.38$; $F = 2.24$; $p < 0.05$) are significant in the opposite direction of that hypothesized. As indicated in Table XXIII, inequality in organizational position is positively and significantly related to tolerance of uncertain and ambiguous information ($T = 1.84$; $p < 0.10$); a result significant in the opposite direction of that hypothesized. A participative project leader leadership style is negatively and significantly related to information tolerance ($T = -1.83$; $p < 0.10$) - a result significant in the opposite direction of that hypothesized - and group based rewards and evaluations is positively and significantly related to information tolerance ($T = 1.92$; $p < 0.10$). In addition, high levels of both productivity enhancement and organizational integration tools is positively and significantly related to information tolerance ($T = 1.72$; $p < 0.10$). These results will be discussed in the following chapter.

Table XXIII
Standard Linear Regression on CEINFTOL

Independent Variables	Model 3: CEINFTOL	
Constant	2.95 ^{***}	
Orgposit	0.26 [*]	(0.14)
Leader	-0.30 [*]	(0.16)
Evalrewd	0.13 [*]	(0.07)
Prjstruc	-0.02	(0.13)
Indxtool	0.08 [*]	(0.04)
Dfsysrec	0.03	(0.20)
Dfintpre	-0.19	(0.16)
Dfmascul	0.32	(0.21)
Distance	-0.11	(0.09)
Timezone	0.05	(0.03)
R ²	0.38	
Res. Degrees of Freedom	36	
F	2.24	
P	< 0.05	

Notes: Numbers are regression coefficients; "()" are standard errors.
Coefficients significant at: *p < 0.10; **p < 0.05; ***p < 0.01.

As indicated in Table XXIV, the final CE orientation model focused on attitudes in CE. Model 4 ($R\text{-squared} = 0.37$; $F = 2.13$; $p < 0.05$) is a function of two variables. Group based evaluations and rewards is positively and significantly related to CE attitudes ($T = 2.11$; $p < 0.05$) and high levels of both productivity enhancement and organizational integration tools is positively and significantly related to CE attitudes ($T = 1.75$; $p < 0.10$). These results will be discussed further in Chapter 6.

Table XXIV
Standard Linear Regression on CEATITD

Independent Variables	Model 4: CEATITD	
Constant	1.84*	
Orgposit	0.23	(0.19)
Leader	0.25	(0.22)
Evalrewd	0.18**	(0.09)
Prjstruc	-0.01	(0.17)
Indxtool	0.10*	(0.06)
Dfsysrec	0.38	(0.26)
Dfintpre	-0.26	(0.21)
Dfmascul	-0.04	(0.28)
Distance	-0.09	(0.12)
Timezone	-0.04	(0.05)

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Table XXIV (continued)

Independent Variables	Model 4: CEATITD
R ²	0.37
Res. Degrees of Freedom	36
F	2.13
P	< 0.05

Notes: Numbers are regression coefficients; "()" are standard errors.
Coefficients significant at: *p < 0.10; **p < 0.05; ***p < 0.01.

In summary, standard multiple regression was performed to test various models for each of the four dimensions of CE orientation. The hypotheses were tested separately for each model and an evaluation of significance tests revealed that different explanatory variables emerged for each model.

5.5.4. The Test of CE Orientation and Task and Process Measures of Success

Although formal hypotheses were not developed to examine the relationship between CE orientation and task and process measures of success, standard linear regression was performed. The results of Table XXV indicated no multicollinearity effects among the four CE orientation variables and a further examination of residual scatterplots revealed no violations of basic regression assumptions. Regression was performed for each measure of success and the results appear in Table XXVI.

Table XXV
Pearson Correlations Between CE Orientation and
Task and Process Measures of Success (N = 47)

Variables	1	2	3	4	5	6
1. cbudlt	-					
2. coopsat	0.17	-				
3. ceintdim	0.20	0.36**	-			
4. ceops	0.07	0.15	0.37**	-		
5. ceinftol	0.34**	-0.16	0.04	0.28*	-	
6. ceatitd	0.25*	0.27*	0.43***	0.29*	0.19	-

Notes: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Model 5 (R-squared = 0.18; $F = 2.28$; $p < 0.10$) focused on task measures of success. The information tolerance dimension of CE orientation is positively and significantly related to success in meeting product cost, project budget, and project lead time goals ($T = 2.31$; $p < 0.05$). This result indicates that an important determinant of achieving CE goals is the acceptance and effective management of uncertain and ambiguous information by upstream and downstream engineering functions. This result is discussed further in the next chapter.

As indicated in Table XXVI, different dimensions of CE orientation are significantly relevant for process outcomes - cooperation and satisfaction. In Model 6

(R-squared = 0.19; $F = 2.44$; $p < 0.10$), the dimension of CE orientation relating to information exchange and interface changes is positively and significantly related to process success ($T = 1.69$; $p < 0.10$). Although statistically insignificant, the negative relationship between information tolerance and process success reveals, to some degree, the difficulties engineering/R&D and manufacturing experience with "concurrent engineering". A further discussion of these results is given in Chapter 6.

Table XXVI
Regression Results of CE Orientation and
Measures of Success

Independent Variables	Model 5: CBUDLT	Model 6: COOPSAT
Constant	0.92	2.93***
Ceintdim	0.16 (0.15)	0.20* (0.12)
Ceops	-0.12 (0.14)	0.04 (0.11)
Ceifftol	0.33** (0.14)	-0.17* (0.11)
Ceatitd	0.11 (0.12)	0.10 (0.09)

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Table XXVI (continued)

Independent Variables	Model 5: CBUDLT	Model 6: COOPSAT
R ²	0.18	0.19
Res. Degrees of Freedom	42	42
F	2.28	2.44
P	< 0.10	< 0.10

Notes: Numbers are regression coefficients unless otherwise indicated; numbers in brackets are standard errors; *marginally insignificant at $p < 0.10$. Coefficients significant at: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Chapter 6

DISCUSSION

6.1. Summary and Discussion of Cognitive Differences

Under the information processing perspective, new product development (NPD) is viewed as a complex process involving the generation and synthesis of information from specialized knowledge domains. Individual stakeholders involved in NPD are constantly gathering information and solving problems in order to make sense of their environments and to complete required tasks. Differences in modes of problem-solving (i.e., cognitive differences) between upstream and downstream engineering specialists were expected because: (1) formal engineering training is domain specific and (2) task types are heterogeneous.

As indicated in Chapter 5, no significant cognitive differences between engineering/R&D and manufacturing were found. Two general explanations for the lack of a significant difference are: (1) measurement error and small differences and (2) small sample sizes. Each of these explanations will be discussed below.

In this study, the work by McKenney and Keen (1974) was the source from which scales for measuring cognitive styles were developed. The context for which the original items were developed was significantly different from the present study. That is, the original items were conceived to measure cognitive differences between two different groups of professionals - managers and management scientists - while

this thesis explored differences within a single professional group - engineers. It is quite likely that the level of sensitivity of the items may be a function of the divergence of comparative groups. Related to the discussion of measurement error is the issue of small differences.

Failure to reject the null hypothesis does not necessarily imply homogeneity between the groups. In fact true differences, as opposed to chance deviations, may be relatively small so that statistical tests are unable to detect them. In this case other statistical procedures should be employed in order to corroborate or refute the results of significance tests of hypotheses.

The discriminant analysis results indicated that cognitive styles can be used to discriminate between engineering/R&D and manufacturing. Cognitive differences (in terms of the relative importance of factors) were found by factor structure analysis, suggesting that the two engineering functions "think" differently. One interesting finding from the discriminant analysis was that the discriminant function performed very well at correctly identifying engineering/R&D personnel - close to 90% were correctly identified. The rotation of manufacturing to upstream functions and the permanent assignment of less talented design engineers to the manufacturing function are two possible explanations for the discriminant functions inability to consistently identify manufacturing personnel.

The second explanation for a lack of a significant difference is small sample size. When sample sizes are small, only relatively large differences are detected by

statistical tests which lead to rejection of the null hypothesis. With a larger sample size, it is possible for cognitive differences to be significant. The discussion so far has centred on explaining the lack of a significant difference. A brief discussion of the results of the cognitive mapping of engineering/R&D and manufacturing follows.

In NPD, upstream engineering/R&D deal in the world of abstraction and product aesthetics while downstream manufacturing are concerned with machine operations and process efficiency. Although not formally stated, it was hypothesized that engineering/R&D would map to the intuitive-preceptive dimension and manufacturing to the systematic-receptive dimension. The results in Chapter 5 indicated that both upstream and downstream functions mapped strongly to the systematic-receptive dimension and that manufacturing "favoured" the intuitive-preceptive dimension.

For this study, it is quite likely that respondents identified as design engineers were in fact low level detailed design engineers involved in developing specifications for specific parts or components. The relative creative nature of the task for this group is clearly different than for high level design engineers involved in developing product architectures. Thus, for a particular discipline, it is possible for modes of problem-solving to be partly governed by the requirements of the task.

Another unexpected finding, although not statistically significant, was the tendency among manufacturing to favour the intuitive-preceptive dimension. Three explanations for this result are: (1) manufacturing's adoption of engineering/R&D's pattern of thinking as a result of upstream job rotation; (2) actual changes in modes of

problem-solving resulting from early manufacturing involvement in product design; and (3) manufacturing is characteristically intuitive-preceptive and that this mode of problem-solving manifests itself in a complex, multidimensional, low level knowledge environment..

6.2. Summary and Discussion of Cultural Differences

Differentiation refers to differences across functions on dimensions such as technical orientation, professional background, values, goals, and frames of reference (Galbraith 1977; Lawrence and Lorsch 1967). In addition to differences in modes of problem-solving, for this thesis, it was assumed that differences in national culture also result in differentiation. Hofstede's (1980a; 1991) work was used to develop scales for measuring the symbols, rituals, values, and basic assumptions of two different engineering functions engaged in NPD.

The cultural attribute most relevant in the context of NPD is "masculinity" - aggressive and assertive versus nurturing. The results in the previous chapter indicated that no significant cultural differences between engineering/R&D and manufacturing were found. However, the results do suggest that manufacturing is more masculine than engineering/R&D; a finding consistent with the popular "macho" image of manufacturing.

The lack of a significant difference can be explained in part by small sample size; similarity of cultures, context, and professional values; and information

technology (IT). These explanations will be discussed below.

As discussed in the previous section, small sample sizes can mask significant differences. In this study, it is suspected that one reason why cultural differences were not large is because of context similarities across functions - in this case product development - thus rendering the available sample size too small to detect significant differences.

A second explanation for the lack of a significant difference is similarity of national cultures. To begin with, the cultures of countries such as Australia, Canada, Denmark, England, Finland, and the United States are clearly more similar than dissimilar. The probability of significant differences to emerge, given the level of aggregation used for this thesis and country similarities, was low. Therefore, the results in the previous chapter were not all that surprising.

One interesting finding from the previous chapter is that although cultural differences were not statistically significant, results from discriminant analysis and factor structure analysis suggest that engineering/R&D and manufacturing are culturally dissimilar. The discriminant analysis result must be interpreted with caution since the function was not reliable, however, the function was effective - discriminant analysis predicted members of the two populations at a rate far better than chance (67% versus 50% random). Based on the above results, it is hypothesized that some intervening variable (i.e., IT) may be at play to reduce cultural differences.

The third and final explanation for the lack of a significant difference is

information technology. IT is unique in that it can serve as an organizational design variable. Through the adoption and widespread use of IT in organizations, individuals from geographically dispersed regions have a greater opportunity to communicate, therefore, one of the positive outcomes of IT may be its ability to bring cultures closer together.

6.3. Summary and Discussion of Regression Results

The discussion in this section is divided into two main parts. The first part focuses on the standard multiple regression results of IVs and CE orientation, while the second part focuses on the standard multiple regression results of CE orientation and measures of success. Throughout this section, reference will be made to various tables and appendices. Before proceeding with a discussion of the regression results, CE orientation will be discussed.

A factor analysis of CE orientation led to two interesting findings. First, CE is not unidimensional and second, the level of measurement of each CE dimension is complex. Previous studies (Clark and Fujimoto 1991; De Meyer 1992; Iansiti 1993a; Susman and Dean 1992) have conceptualized CE in unidimensional terms and measured CE using dichotomous variables (e.g., Iansiti 1993a). One of the central findings from this thesis is that CE is indeed multi-dimensional and that it is appropriate to think of each dimension in more than binary terms.

An examination of bivariate correlations (Table XXV) provided partial evidence

for the hypothesis that the dimensions of CE are related. For example, early manufacturing involvement in product design must be matched by: (1) changes at the interface (i.e., information exchange) between engineering/R&D and manufacturing ($r = 0.37$, $p < 0.05$); (2) changes in information tolerance ($r = 0.28$, $p < 0.10$); and (3) changes in attitudes ($r = 0.29$, $p < 0.10$). Following is a discussion of the regression results.

As indicated in Table XX, bivariate correlations between IVs and the interface/information exchange dimension of CE yielded seven significant relationships: (1) a positive relationship between job rotation and the interface/information exchange dimension of CE; (2) a positive relationship between group based rewards and evaluations and the interface/information exchange dimension of CE; (3) a positive relationship between a participative project leader leadership style and the interface/information exchange dimension of CE; (4) a positive relationship between project-based organizational structures (e.g., project matrix) and the interface/information exchange dimension of CE; (5) a positive relationship between high levels of both electronic and traditional media and the interface/information exchange dimension of CE; (6) a positive relationship between high levels of both productivity enhancement and organizational integration tools and the interface/information exchange dimension of CE; and (7) a negative relationship between time-zone differences and the interface/information exchange dimension of CE. Appendices 25 and 26 were examined to determine significant relationships

between communication technologies and tools and the interface/information exchange dimension of CE.

An examination of bivariate correlations between access to individual communication technologies and tools and the interface/information exchange dimension of CE revealed six significant relationships. Access to voice mail, GDSS, CAD, CAM, PDES, and ISO 9000 standards were all positively related to the interface/information exchange dimension of CE. In addition, Appendix 26 revealed a significant negative relationship between frequency of use of electronic mail and the interface/information exchange dimension of CE. This latter finding was surprising and suggests that daily or near daily use of e-mail may hinder information exchange between upstream and downstream functions.

Regressing the independent variables on the interface/information exchange dimension of CE yielded three significant relationships - a participative project leader leadership style, project-based organizational structures, and high levels of both productivity enhancement and organizational integration tools were positively related to the interface/information exchange dimension of CE. Taken together, the above results indicate that integrative mechanisms, coordinating mechanisms, enabling technologies and tools, and equal time-zones are helpful in promoting information exchange and managing interface changes between engineering/R&D and manufacturing.

Bivariate correlations indicated that four significant relationships emerged with respect to the overlapping problem-solving dimension of CE: (1) a positive relationship

between educational level differences and overlapping problem-solving; (2) a positive relationship between group based rewards and evaluations and overlapping problem-solving; (3) a positive relationship between deployment of productivity enhancement and organizational integration tools and overlapping problem-solving; and (4) a negative relationship between cognitive differences and overlapping problem solving.

The positive relationship between educational level differences and overlapping problem-solving suggests that problem-solving breadth (i.e., having access to diverse knowledge bases) is conducive to early manufacturing involvement in product design. The negative relationship between cognitive differences and overlapping problem-solving suggests that increasing engineering/R&D's capacity for intuitive-preceptive thinking is required in order for manufacturing to be actively involved in the "fluid" stages of product design.

As indicated in Appendix 25, there were three significant relationships between access to communication technologies and tools and overlapping problem-solving. Access to CAE, IGES, and PDES were all positively related to overlapping problem-solving. In addition, frequency of use of videoconferencing was positively related to overlapping problem-solving and frequency of use of ISO 9000 standards was negatively related to overlapping problem-solving. This latter result seems to indicate that reliance on standards and procedures to manage reciprocal interdependence does not lead to early manufacturing involvement.

Of the significant relationships discussed above, only four entered the regression

equation: (1) group based rewards and evaluations was positively related to overlapping problem-solving; (2) high levels of both productivity enhancement and organizational integration tools was positively related to overlapping problem-solving; (3) cognitive differences on the intuitive-preceptive dimension was negatively related to overlapping problem-solving; and (4) time-zone differences was negatively related to overlapping problem-solving. Therefore, to promote overlapping problem-solving, it appears that focusing on the four areas identified above is an important consideration.

Table XX indicated three significant relationships between IVs and the information tolerance dimension of CE: (1) a positive relationship between differences in organizational position and the information tolerance dimension of CE; (2) a negative relationship between a participative project leader leadership style and the information tolerance dimension of CE; and (3) a positive relationship between cultural differences and the information tolerance dimension of CE. This last result is interesting since it suggests that differences in personal interaction style (i.e., having one function be highly aggressive and assertive) is conducive to tolerance of uncertain and ambiguous information. To determine the significant relationships between communication technologies and tools, Appendices 25 and 26 were examined.

Bivariate correlations between individual communication technologies and tools and the information tolerance dimension of CE yielded two significant results: (1) access to QFD was positively related to the information tolerance dimension of CE and (2) access to PDES was positively related to the information tolerance dimension of

CE. These results suggest that organizational integration tools play an important role in promoting information tolerance in CE. Furthermore, frequency of use of GDSS was positively and significantly related to the information tolerance dimension of CE.

According to Table XXIII (Model 3 regression results), four variables were significantly related to the information tolerance dimension of CE. Differences in organizational position, a "heavy weight" project leader leadership style, group based rewards and evaluation, and high levels of both productivity enhancement and organizational integration tools were all positively related to the information tolerance dimension of CE. Taken together, the results suggest that organizational design variables (i.e., IT and group rewards and evaluation) along with variables to force engineering specialists to deal with uncertain and ambiguous information are relevant for the information tolerance dimension of CE.

As indicated in Table XX, three variables were significantly related to CE attitudes: (1) a positive relationship between group based evaluations and rewards and CE attitudes; (2) a positive relationship between a participative project leader leadership style and CE attitudes; and (3) a positive relationship between deployment of both productivity enhancement and organizational integration tools and CE attitudes. These results provided partial evidence to support the hypothesis that integrative and coordinating mechanisms are among the most important determinants of CE attitudes.

An examination of bivariate correlations (Appendix 25) revealed five significant relationships. Access to voice mail, face-to-face communication, the telephone, CAD,

and IGES were all positively related to CE attitudes.

Regressing the IVs on the attitudes dimension of CE yielded two significant relationships - group based evaluations and rewards was positively related to CE attitudes and high levels of both productivity enhancement and organizational integration tools was positively related to CE attitudes.

Before discussing the second part of this section, the lack of a statistically significant relationship between top management support and CE is discussed.

Several researchers (Hayes, Wheelwright and Clark 1988; Taft and Barclay 1993) have identified top management support as an important factor contributing towards project success. However, empirical studies (Ruusinko, 1992; Zirger and Maidique 1990) are at odds as to whether the relationship exists. In this thesis, top management support was expected to influence project success through its impact on CE orientation. Although bivariate correlations (Table XX) provided directional support for the relationship, the lack of a statistically significant relationship must be interpreted with caution. It is quite likely that top management support is extremely important during the implementation phase of a project and less important once the project is up and running.

An examination of bivariate correlations (Table XXV) provided partial evidence for the hypothesis that the dimensions of CE are related to tasks success. The two significant relationships are: (1) a positive relationship between information tolerance and task success and (2) a positive relationship between CE attitudes and task success.

An interesting finding was that early manufacturing involvement in product design was not significantly related to task success. These results suggest that achieving the CE promises of reduced product cost, project budget, and lead time is a function both of a heightened tolerance by engineering/R&D and manufacturing towards dealing with uncertain and ambiguous information and of positive attitudes among upstream and downstream functions - the typical "do not release now" attitude of engineering/R&D and "wait and see" attitude of manufacturing are clearly detrimental for task success.

Regressing the dimensions of CE on task success yielded a single significant relationship - tolerance towards uncertain and ambiguous information was positively related to task success. In summary, the results suggest that the performance goals identified above were influenced, in large part, by both engineering/R&D and manufacturing's ability to tolerate less complete and less clear information.

Bivariate correlations indicated that two significant relationships emerged with respect to process success (i.e., cooperation and satisfaction): (1) a positive relationship between the interface/information exchange dimension of CE and process success and (2) a positive relationship between CE attitudes and process success. The regression results (Table XXVI) indicate that only the interface/information exchange dimension of CE was positively and significantly related to the process outcomes of cooperation and satisfaction. Clearly the results suggest that, from the perspective of engineering specialists involved in NPD, effective management of the engineering/R&D and manufacturing interface is important.

Chapter 7

CONCLUSION

Implications for Managers

Designing and developing new products involves the execution of a collective set of efforts. Previous studies (e.g., Clark and Fujimoto 1991; De Meyer 1992) have shown that concurrent engineering (CE) is effective for structuring new product development (NPD) tasks. The focus of this thesis has been to better define CE, to understand the relevant factors that support and impede CE, and to provide managers with prescriptions on how to improve the product development process.

Recommendations to practitioners in product development are summarized below.

- ▶ Look at product development from an informational point of view in which customer needs are captured, translated, and converted into physical products. In other words, information should be the key concept linking both the design system and the production system.
- ▶ Designing and developing new products for manufacture is difficult. It is simply not enough to have only cross functional representation on teams and some simultaneous product and process design in order to achieve product, project, and process performance.
- ▶ Use the CE approach for structuring new product development tasks; CE is effective for high performance development projects.

- ▶ Achieving product cost, project budget, and project lead time goals requires that early manufacturing involvement in product design be matched by: (i) changes at the interface (i.e., information exchange) between engineering/R&D and manufacturing; (ii) changes in information tolerance among the functions; and (iii) changes in attitudes (among the functions) towards incomplete and uncertain information.
 - ▶ CE is an elaborate information exchange mechanism which is not facilitated by only a single critical factor - organizational structure, management processes, and communication related information technologies. Emphasizing team based rewards and evaluations and investing in information technology tools (i.e., both productivity enhancement and organizational integration) seem to be the most important considerations when organizing for effective product development.
 - ▶ Top management must actively support CE during the implementation stage of a development project. When the project is up and running, top management support seems to be less relevant for CE.
 - ▶ Tolerance of uncertain and ambiguous information is difficult for upstream engineering/R&D and downstream manufacturing personnel. An autocratic project leader leadership style seems appropriate to drive such behaviour.
 - ▶ Lack of co-location of upstream engineering/R&D and downstream manufacturing functions at the same site does not seem to inhibit CE.
- Deployment of communication related information technologies provides

geographically disbursed team members with increased opportunities for interaction.

► Use the measures of CE developed in this thesis as a diagnostic tool to evaluate the amount of CE currently in practice and to identify the specific dimensions on which improvements need to be made.

► The selection criteria of upstream engineering/R&D and downstream manufacturing personnel for CE teams should include cognitive styles. The measures of cognitive styles developed in this thesis can be used to identify upstream and downstream personnel having similar cognitive styles.

Alternatively, the cognitive styles measures can provide valuable information for training programs designed to prepare individuals for CE.

Directions for Future Research

As indicated in Figure 2, this thesis has focused on one part of the larger conceptual model that was developed. An obvious direction for future research should be to include and analyze the relevant variables omitted from this study (i.e., test hypotheses H6 to H9). For example, the moderating effect of the CE dimensions on the relationship between task difficulty and project outcomes needs to be examined in addition to the relationship between media, task, and performance.

Another direction for future research should be to analyze the learning curve effect of CE within and across various industries. In other words, how do experienced

and relatively new users of CE compare on the various dimensions when controlling for project characteristics.

The finding from this study that CE is multi-dimensional is relatively new. Future research should centre on corroborating or rejecting the dimensional conceptualization of CE. Moreover, the applicability of this conceptualization in various industries needs to be tested.

Additional research is also needed to support the hypothesis that engineering/R&D and manufacturing are cognitively and culturally different. Although the hypothesis of no difference was not rejected in this study, more research is needed to confirm this finding.

Two more exciting avenues for future research should be: (i) to examine the role of suppliers and customers in distributed product development and (ii) to examine the transition from CE - where team members are co-located at the same site - to global CE in various industries.

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APPENDICES

GLOBAL CONCURRENT ENGINEERING SURVEY FOR ENGINEERING/R&D AND MANUFACTURING REPS

PART 1: PROJECT INFORMATION

- 1.1 Briefly describe the product, sub-assembly or component which is/was developed by the team in which you were a participant.

- 1.2 Using the examples below as a yardstick how would you rate the scale of the project?

An Automobile or a PBX are large scale systems

An Engine or a Call Processing device are major subsystems

An Exhaust system or a Card are subsystems

A Muffler or a Printed Circuit Board are components

component		subsystem		system
1	2	3	4	5

- 1.3 Using the scale below, please rate the project on each of the following issues.

	very low		medium		very high
a. Importance of this project to corporate management.	1	2	3	4	5
b. Pressure to achieve high quality targets.	1	2	3	4	5
c. Technical difficulty of the development task.	1	2	3	4	5
d. Importance of the project's key customer/s to the corporation.	1	2	3	4	5
e. Pressure to reduce product cost in this project.	1	2	3	4	5
f. Pressure for reduction in time to market or project lead time.	1	2	3	4	5
g. Project priority in the corporation.	1	2	3	4	5
h. Amount of new technology in the project.	1	2	3	4	5
i. Cost of the development effort relative to other projects.	1	2	3	4	5

1.4 How many different types of expertise (e.g., technical, marketing) are/were necessary to complete the project?

1 2 3 4 5 6 7+

1.5 For this question please read the following descriptions and Check (✓) the one that most accurately describes the product which has been developed.

☐ **a** The product is/was based on an entirely new concept.

☐ **b.** The product is/was the first in its family (i.e., it resulted in a new product/component platform).

☐ **c.** The product results/resulted in the creation of a new line of products within an existing product family.

☐ **d.** The product incorporates/incorporated major modifications, in relation to an earlier product in its line.

☐ **e.** The product incorporates/incorporated minor modifications, in relation to an earlier product in its line.

1.6 Use the scale below to answer the following questions.

"To what extent ... "	not at all		to some extent		to a very great extent
a. ... is/was the manufacturing process equipment, used to fabricate and assemble the product, fully-proven and tested?	1	2	3	4	5
b. ... are/were the materials used in making the product standard and well-known?	1	2	3	4	5
c. ... are/were the methods (e.g., surface mount technology) used to fabricate and assemble the product new to the firm?	1	2	3	4	5
d. ... are/were the technologies embodied in the product tested and mature?	1	2	3	4	5

☛ Please turn over

PART 2: CONSTRAINTS

For questions 2.1 through 2.4, you are asked to depict the spatial arrangement of project team members and to record specific information on the world map below.

- 2.1 Use the world map to indicate where individuals, from engineering/R&D, manufacturing (i.e., manufacturing engineering), and another function (e.g., marketing), responsible for making key decisions during the project are/were located.
- 2.2a Please indicate on the world map the name of the country and town/city in which key individuals from the three functions identified are/were located during the project. Place this information directly above the names of the respective functions.
- 2.2b Please circle the names of those functions located at the same site.
- 2.3 On the map below, use lines to connect the locations of the three functions. Then, please indicate on the lines the time-zone differences (in hours) among the three functions identified.
- 2.4 Please identify on the lines connecting the locations on the map below, the means of transportation that best represents the distance between the respective functions identified. Use the following labels:
F = flying distance R = driving distance W = walking distance

- 2.5 What is/was the travel budget for this project?
Budget: (in USA dollars)_____ (or in other currency):_____
- 2.6 During the entire project, what is/was the estimated number of trips between ...
- a. ...engineering/R&D and manufacturing. _____ Trips
- b. ...engineering/R&D and the third function identified (eg., marketing). _____ Trips
- c. ...manufacturing and the third function identified (e.g., marketing). _____ Trips
- 2.7 Is/Was the travel budget for the project sufficient?
25% of
what is/was
necessary	50% of
what is/was
necessary	75% of
what is/was
necessary	100% of
what is/was
necessary	25% more
than necessary
1	2	3	4	5

PART 3: COGNITIVE STYLES

3.1 Please answer the following using the scale provided.

"When solving problems, I ... "	strongly disagree		neutral		strongly agree
a. ... look for a method and make a plan for solving the problem.	1	2	3	4	5
b. ... keep the overall problem continuously in mind.	1	2	3	4	5
c. ... discard alternatives quickly.	1	2	3	4	5
d. ... rely on un verbalized cues, even hunches.	1	2	3	4	5
e. ... define the specific constraints of the problem early in the process.	1	2	3	4	5
f. ... jump from one step in analysis or search to another, and back again.	1	2	3	4	5
g. ... am very conscious of my approach.	1	2	3	4	5
h. ... explore and abandon alternatives very quickly.	1	2	3	4	5

➡ Please turn over

"When solving problems, I ... "	strongly disagree		neutral		strongly agree
i. ... move through a process of increasing refinement of analysis.	1	2	3	4	5
j. ... consider a number of alternatives and options simultaneously.	1	2	3	4	5

"When analyzing data, I ... "	strongly disagree		neutral		strongly agree
a. ... insist on a complete examination of the data before deriving conclusions.	1	2	3	4	5
b. ... look for cues.	1	2	3	4	5
c. ... focus on details to learn about specifics of the bigger picture.	1	2	3	4	5
d. ... focus on relationships between the data to get a feel of the bigger picture.	1	2	3	4	5
e. ... suspend judgement and avoid preconceptions.	1	2	3	4	5
f. ... jump from one section of the data set to another, building on a set of explanatory precepts.	1	2	3	4	5

PART 4: PRODUCT DEVELOPMENT METHODS

4.1 Using the scale below, indicate your degree of agreement with the following statements.

	strongly disagree		neutral		strongly agree
a. The project leader encourages/encouraged the team to make critical product design and development decisions.	1	2	3	4	5
b. The project leader encourages/encouraged the team to implement critical product design and development decisions.	1	2	3	4	5
c. The project leader makes/made the team responsible for resolving internal conflicts.	1	2	3	4	5

	strongly disagree		neutral		strongly agree
d. The project leader encourages/encouraged the team to resolve problems with the rest of the organization.	1	2	3	4	5

- 4.2** Please indicate on the scale below the amount of problem-solving overlap between engineering/R&D and manufacturing that most accurately describes the way in which product and process design tasks are/were carried out in your project.

No overlap at all	25% overlap	50% overlap	75% overlap	100% overlap
1	2	3	4	5

- 4.3** Use the scale below to answer the following questions about the project when engineering/R&D and manufacturing are/were concurrently engaged in their tasks.

"How frequently do/did you have to ... "	never		sometimes		all the time
a. ... revise product or process design decisions?	1	2	3	4	5
b. ... change the schedule?	1	2	3	4	5
c. ... change resource allocations?	1	2	3	4	5
d. ... deal with conflicts?	1	2	3	4	5
e. ... respond to emergencies or crises?	1	2	3	4	5

- 4.4** Use the scale below to answer the following questions about your experiences during the project when engineering/R&D and manufacturing are/were concurrently engaged in their tasks.

"During the project, to what extent do/did you ... "	not at all		to some extent		to a very great extent
a. ... apply solutions used in previous projects to solve problems?	1	2	3	4	5
b. ... rely on judgement & intuition for solutions to problems?	1	2	3	4	5
c. ... rely on your formal (i.e., university or professional) training to solve problems?	1	2	3	4	5

"During the project, to what extent do/did you ..."	not at all		to some extent		to a very great extent
d. ... develop new solutions to solve problems?	1	2	3	4	5
e. ... rely on procedures and methods to solve problems?	1	2	3	4	5

4.5 Use the scale below to answer the following questions. Note: "counterpart" refers to engineering/R&D or manufacturing.

"When engineering/R&D and manufacturing; <u>first</u> engaged in concurrent problem-solving, to what extent ..."	not at all		to some extent		to a very great extent
a. ... was there a shared understanding between you and your counterpart on product and process specifications?	1	2	3	4	5
b. ... were the tasks your counterpart was required to perform clear to you?	1	2	3	4	5
c. ... was your counterpart able to communicate his or her concerns to you?	1	2	3	4	5
d. ... were you able to get specific answers from your counterpart on product and process design issues?	1	2	3	4	5
e. ... was your counterpart clear about the tasks you were required to perform?	1	2	3	4	5
f. ... did you and your counterpart share a common vocabulary?	1	2	3	4	5

4.6 Use the scale below to estimate how complete was the product/process design at the various stages of manufacturing involvement.

"How complete was the product design when ..."	0% complete	25%	50% complete	75%	100% complete
a. ... manufacturing became actively involved in product design?	1	2	3	4	5
b. ... manufacturing provided feedback for the first time?	1	2	3	4	5

"How complete was the product design when ... "

	0% complete	25%	50% complete	75%	100% complete
--	----------------	-----	-----------------	-----	------------------

c. ... manufacturing made formal cost estimates? 1 2 3 4 5

d. ... manufacturing started making commitments to purchase materials, tools, and equipment? 1 2 3 4 5

e. How complete was the process design when engineering/R&D ended their active involvement in the project? 1 2 3 4 5

4.7 Using the following scale, indicate your degree of agreement with the following statements.

strongly disagree		neutral		strongly agree
----------------------	--	---------	--	-------------------

a. As the product design evolves/evolved, this information is/was made readily available to manufacturing. 1 2 3 4 5

b. As the process design evolves/evolved, this information is/was made readily available to engineering/R&D. 1 2 3 4 5

c. Communication between engineering/R&D and manufacturing during the project is/was 2-way. 1 2 3 4 5

4.8 How often do/did engineering/R&D and manufacturing communicate between themselves?

once a month		once a week		at least once a day
1	2	3	4	5

4.9 Use the scale below to answer the following questions.

"How willing are/were... "

	not willing at all		moderately willing		extremely willing
--	-----------------------	--	-----------------------	--	----------------------

a. ... engineering/R&D to share incomplete and uncertain information with manufacturing? 1 2 3 4 5

b. ... manufacturing to share incomplete and uncertain information with engineering/R&D? 1 2 3 4 5

"How willing are/were... "	not willing at all		moderately willing		extremely willing
c. ... engineering/R&D to revise decisions based on incomplete and uncertain information from manufacturing?	1	2	3	4	5
d. ... manufacturing to revise decisions based on incomplete and uncertain information from engineering/R&D?	1	2	3	4	5
e. ... engineering/R&D to incorporate ambiguous information from manufacturing when making product design decisions?	1	2	3	4	5
f. ... manufacturing to incorporate ambiguous information from engineering/R&D when making process design decisions?	1	2	3	4	5

4.10a Please list three examples of problems you have encountered during the project in dealing with incomplete and ambiguous information.

(1) _____

(2) _____

(3) _____

4.10b Then, select any one (circle its number) and describe the problem and how (or if) it was resolved.

➡ Please turn over

PART 5: INTEGRATIVE MECHANISMS

5.1 Using the scale below, please indicate your degree of agreement with the following statements.

"During the project, ... "	strongly disagree		neutral		strongly agree
a. ... senior management overtly communicates/communicated their support for the project to project team members.	1	2	3	4	5
b. ... senior management overtly communicates/communicated their support for the project to the rest of the company or business unit.	1	2	3	4	5
c. ... senior management frequently communicates/communicated their support for the project to project team members.	1	2	3	4	5
d. ... senior management frequently communicates/communicated their support for the project to the rest of the company or business unit.	1	2	3	4	5

5.2a The project development budget allocated by senior management is/was?

25% of what is/was necessary	50% of what is/was necessary	75% of what is/was necessary	100% of what is/was necessary	25% more than necessary
1	2	3	4	5

5.2b The development time allocated for the project is/was?

25% of what is/was necessary	50% of what is/was necessary	75% of what is/was necessary	100% of what is/was necessary	25% more than necessary
1	2	3	4	5

5.3 Compare yourself to your counterpart (engineering/R&D or manufacturing) on the following dimensions and circle the appropriate number.

	much lower		same		much higher
a. my educational level is	1	2	3	4	5

	much lower		same		much higher	
b. my working environment is (e.g., office furniture)	1	2	3	4	5	
c. my experience in this company is	1	2	3	4	5	
d. my organizational position is	1	2	3	4	5	

5.4 Use the scale below to rate the relative influence of the project leader (PL) and functional managers (FM) on the following issues:

PL/FM	20%/80% Mainly FM	40%/60%	50%/50% Equal Influence	60%/40%	80%/20% Mainly PL
	1	2	3	4	5
a. Selecting project team members.	1	2	3	4	5
b. Setting schedules.	1	2	3	4	5
c. Making budget re-allocation decisions.	1	2	3	4	5
d. Controlling costs.	1	2	3	4	5
e. Directing work flow activities.	1	2	3	4	5
f. Deciding what needed to be accomplished.	1	2	3	4	5
g. Conducting performance evaluations.	1	2	3	4	5
h. Defining the reward system.	1	2	3	4	5
i. Ensuring project completion.	1	2	3	4	5
j. Making technological decisions.	1	2	3	4	5
k. Making decisions about tools and methods.	1	2	3	4	5

☛ Please turn over

5.5a What proportion of team members' evaluation is/was based on group outcomes/performance?

	0%	20%	40%	50%	60%	80%	100%
(Circle) ➡	1	2	3	4	5	6	7

5.5b What proportion of team members' rewards are/were based on group outcomes/performance?

	0%	20%	40%	50%	60%	80%	100%
(Circle) ➡	1	2	3	4	5	6	7

5.6 Using the scale below, indicate your degree of agreement with the following statements.

	strongly disagree		neutral		strongly agree
"During the project, ... "					
a. ... I am/was reporting simultaneously to the project leader and my functional manager.	1	2	3	4	5
b. ... the role of the project leader is/was mainly to plan activities and coordinate the work across functions.	1	2	3	4	5
c. ... the role of functional managers is/was that of an advisor.	1	2	3	4	5
d. ... the project leader has/had responsibility for project completion.	1	2	3	4	5

➡ Please turn over

PART 6: COMMUNICATION TECHNOLOGIES & TOOLS

For questions 6.1 through 6.3, please use the table below to answer the questions.

6.1 Please Check (✓) in the ACCESS column in the table below all the media and tools which are/were accessible to you during the project.

6.2 Please use the following scale to estimate how frequently you use/used the various media and tools that you have/had access to during the project and place the number in the FREQUENCY column below.

once a month		once a week		at least once a day
1	2	3	4	5

6.3 For questions 6.3a and 6.3b please use the following scale to evaluate the media and tools you use/used during the project.

extremely poor		moderate		excellent
1	2	3	4	5

"How would you rate the media and tools in the table below in terms of ... "

6.3a ... providing quick feedback? Place the number in column FEEDBACK.

6.3b ... clarifying a misunderstanding? Place the number in column CLARIFY.

Question number:	6.1 <u>ACCESS</u>	6.2 <u>FREQUENCY</u>	6.3a <u>FEEDBACK</u>	6.3b <u>CLARIFY</u>
(a) electronic mail	_____	_____	_____	_____
(b) voice mail	_____	_____	_____	_____
(c) facsimile machine	_____	_____	_____	_____
(d) conference call	_____	_____	_____	_____
(e) videoconferencing	_____	_____	_____	_____
(f) group decision support sys.	_____	_____	_____	_____
(g) groupware	_____	_____	_____	_____
(h) face-to-face	_____	_____	_____	_____
(i) telephone	_____	_____	_____	_____
(j) mailed documents	_____	_____	_____	_____
(k) CAD	_____	_____	_____	_____
(l) CAE	_____	_____	_____	_____
(m) CAM	_____	_____	_____	_____
(n) CIM Software	_____	_____	_____	_____
(o) electronic data interchange	_____	_____	_____	_____
(p) quality function deployment	_____	_____	_____	_____
(q) IGES (Initial Graphic Exchange Specification)	_____	_____	_____	_____
(r) PDES (Product Definition Exchange Specification)	_____	_____	_____	_____
(s) ISO 9000 Standards	_____	_____	_____	_____
(t) Other - Please Specify	_____	_____	_____	_____

6.4 Using the scale below, how would you rate the effectiveness of the indicated media and tools for the various tasks during the project.

not effective
at all
1

2

moderately
effective
3

4

extremely
effective
5

	group decision support system	video- conference	e-mail	fax	face-to- face	integrated CAD/CAE /CAM
a. transfer business information	_____	_____	_____	_____	_____	_____
b. transfer technical information	_____	_____	_____	_____	_____	_____
c. exchange time- sensitive information	_____	_____	_____	_____	_____	_____
d. make critical product/process design & development decisions	_____	_____	_____	_____	_____	_____
e. convey preliminary information	_____	_____	_____	_____	_____	_____
f. bargain & negotiate (e.g., persuade your counterpart to revise a decision, resolve conflicts)	_____	_____	_____	_____	_____	_____
g. coordination (e.g., plan activities, set schedules, assign tasks)	_____	_____	_____	_____	_____	_____
h. innovation- oriented (e.g., generate ideas, suggest changes or introduction of new features)	_____	_____	_____	_____	_____	_____

PART 7: CULTURE

In this part of the questionnaire we are interested in measuring various dimensions of cultural attitudes. Your responses to the following statements will be extremely useful for important research questions. Please note that there are no right or wrong responses.

7.1 Using the following scale, indicate your degree of agreement with the following statements about culture.

	strongly disagree		neutral		strongly agree
a. Inequality in society should be minimized.	1	2	3	4	5
b. Time is free.	1	2	3	4	5
c. In society, everybody is supposed to take care of himself/herself and his/her immediate family.	1	2	3	4	5
d. Performance is what counts.	1	2	3	4	5
e. There should be a tendency to persevere towards long term results.	1	2	3	4	5
f. Superiors are ordinary people like me.	1	2	3	4	5
g. The authorities are there to serve the citizens.	1	2	3	4	5
h. Everybody has a right to a private life and opinion.	1	2	3	4	5
i. Money and material things are important.	1	2	3	4	5
j. Reciprocation of greetings, favours, and gifts should be consciously de-emphasized.	1	2	3	4	5
k. All should have equal rights.	1	2	3	4	5
l. Hard work, as such, is not a virtue.	1	2	3	4	5
m. There should be emotional independence of the individual from his/her organization.	1	2	3	4	5
n. One admires the successful achiever.	1	2	3	4	5

➡ Please turn over

	strongly disagree		neutral		strongly agree
o. Social relations should be conducted in such a way that everybody's face (i.e., sense of dignity, self-respect and prestige) is preserved.	1	2	3	4	5
p. Use of power should be legitimate.	1	2	3	4	5
q. Uncertainty is inherent in life and each day is taken as it comes.	1	2	3	4	5
r. Emphasis should be on individual initiatives and achievement.	1	2	3	4	5
s. Men should dominate in society.	1	2	3	4	5
t. One should not spend more money than necessary.	1	2	3	4	5

PART 8: PROJECT OUTCOMES/RESULTS

8.1 Please rate the relative importance of achieving each of the following project goals. More important goals should have a higher percentage; the total sum should equal 100%.

a. product cost	____%
b. overall product quality	____%
c. project budget	____%
d. overall development lead time	____%
	100% Total

8.2 How successful is/was the project in meeting the following goals? Use the scales below.

	below plan		met	exceeded plan			
	-50%	-25%	plan	+25%	+ 50%	+75%	+100%
a. product cost	1	2	3	4	5	6	7
	below target		met	above target			
	-50%	-25%	target	+25%	+ 50%	+75%	+100%
b. overall product quality	1	2	3	4	5	6	7

	below budget		met budget	exceeded budget			
	-50%	-25%		+25%	+ 50%	+75%	+100%
c. project budget	1	2	3	4	5	6	7
	below schedule		met plan	above schedule			
	-50%	-25%		+25%	+ 50%	+75%	+100%
d. overall development lead time	1	2	3	4	5	6	7

8.3 Using the scale below, indicate your degree of agreement with the following statements.

	strongly disagree		neutral		strongly agree
a. The team is/was good at resolving internal conflicts and disagreements.	1	2	3	4	5
b. I enjoy/enjoyed working with this team.	1	2	3	4	5
c. The members of this team work/worked well together.	1	2	3	4	5
d. The level of stress felt by team members is/was low.	1	2	3	4	5
e. There is/was a high level of trust amongst team members.	1	2	3	4	5
f. In the future, if given the opportunity, I would like to participate in a similar project.	1	2	3	4	5

➡ Please turn over

PART 9: PERSONAL BACKGROUND INFORMATION

Your answers to the following questions will be strictly confidential.

- 9.1 What is your current position?
Job Title: _____
Functional or Product Area: _____
- 9.2 What is the position from which you joined the project team (Check (✓) one) ?
____ a. Individual contributor
____ b. Technical specialist
____ c. Project team leader
____ d. Product or program manager
____ e. Technical/functional manager
____ f. Administrative position
____ g. Other (please specify) _____
- 9.3 What is the functional area from which you joined the project team (Check (✓) one)?
____ a. Research, advanced development
____ b. Product design, hardware or software
____ c. Product engineering, test or QA
____ d. Manufacturing operations
____ e. Process development
____ f. Sales or marketing
____ g. Administration (finance, personnel, etc.)
____ h. Other (please specify) _____
- 9.4 Age: _____ years
- 9.5 Are you: Male? _____ or Female? _____

9.6 Total years of experience in the industry: _____ years

9.7 Years of work experience in various functional areas:

Design/Engineering/R&D: _____ years

Manufacturing/Production: _____ years

Marketing or Sales: _____ years

Administration: _____ years

Other - please specify
_____ years

We thank you for completing this questionnaire. Your assistance in this research project is very much appreciated.

Appendix 2:
Composition of Variables in the Model

Attribute	Variable	Data used From Survey
Project Characteristics	- project scale (5-point)	1.1 1.2
	- project scope	1.4
	- product novelty (ordinal)	1.5 (a, b, c, d, e)
	- process/product technology	
	- process tech (5-point)	1.6 (a, b, c)
	- product tech (5-point)	1.6 (d)
Task Difficulty	- variety (5-point)	4.3 (a, b, c, d, e)
	- analyzability	
	- analyz (5-point)	4.4 (a, c, e)
	- unanalyz (5-point)	4.4 (b, d)
	- equivocality (5-point)	4.5 (a, b, c, d, e, f)
Project Outcomes/ Results	- project success (7-point)	8.1 (a, b, c, d) 8.2 (a, b, c, d)
	- cooperation (5-point)	8.3 (a, c, e)
	- satisfaction (5-point)	8.3 (b, d, f)

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Attribute	Variable	Data used From Survey
Integrative Mechanisms	- status parity (5-point)	5.3 (a, b, c, d)
	- job rotation	9.7
	- group based rewards and evaluations	
	- evaluation (7-point)	5.5 (a)
	- reward (7-point)	5.5 (b)
	- co-location	2.2 (b)
	- project structure (5-point) (5-point)	5.4 (a through k) 5.6 (a, b, c, d)
	- leadership style (5-point)	4.1 (a, b, c, d)
	- top management support	
	- endorsement (5-point)	5.1 (a, b, c, d)
	- resources (5-point)	2.7, 5.2 (a, b)
Communication Technology & Tools	- access	6.1
	- frequency of use (5-point)	6.2
	- richness	
	- feedback (5-point)	6.3 (a)
	- clarify (5-point)	6.3 (b)
	- effectiveness (5-point)	6.4 (a through h)

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Attribute	Variable	Data used From Survey
Cognitive Styles	- systematic (5-point)	3.1 (a, c, e, g, i)
	- intuitive (5-point)	3.1 (b, d, f, h, j)
	- receptive (5-point)	3.1 (a, c, e)
	- preceptive (5-point)	3.1 (b, d, f)
Culture	- small power distance (5-point)	7.1 (a, f, k, p)
	- weak uncertainty avoidance (5-point)	7.1 (b, g, l, q)
	- individualism (5-point)	7.1 (c, h, m, r)
	- masculinity (5-point)	7.1 (d, i, n, s)
	- confucian (5-point)	7.1 (e, j, o, t)
Barriers	- distance	2.1, 2.2 (a), 2.4
	- time-zone	2.3
CE Orientation	- behaviour (5-point) (5-point)	4.7 (a, b) 4.9 (a, b, c, d, e, f) 4.10 (a, b)
	- overlap (5-point) (5-point)	4.2 4.6 (a, b, c, d, e)
	- direction of commu on (5-point)	4.7 (c)
	- frequency of info transmission (5-point)	4.8

Appendix 3:
Profile of Companies By Country

Country	# of Companies	Company Name
Australia	2	D, J
Canada	2	F, L
Denmark	1	K
England	2	B, I
Finland	2	M, N
U.S.	5	A, C, E, G, H

Appendix 4:
Sample of Project Descriptions By Industry

Industry	Project Description
Automobile	<ul style="list-style-type: none">- sealing components for a 2.5L 4 valve V6 engine- hydraulic valve actuation system
Chemicals	<ul style="list-style-type: none">- integrated brack mounted system for coal blasting- overcoated plastic tubing used in non-electric delay detonators
Computers	<ul style="list-style-type: none">- circuit card assembly for display workstations- large scale shipboard computer
Electronics	<ul style="list-style-type: none">- plug-in interface module- microwave radio
Shipbuilding	<ul style="list-style-type: none">- web-fabrication line- panel and section line
Telecom.	<ul style="list-style-type: none">- hand held cellular phone- data network switch

Appendix 5:
Differences in Mean Scores Between
Engineering/R&D and Manufacturing (N = 86)

Item	Eng./R&D	Mfg.	t-value	p
prodcost - 8.2a*	2.47	2.46	0.04	0.97
quality - 8.2b*	3.49	3.41	0.44	0.66
budget - 8.2c*	2.19	2.31	-0.78	0.44
leadtime - 8.2d*	2.23	2.23	0.02	0.99
teameval - 5.5a	3.68	3.92	-0.65	0.52
tmreward - 5.5b	3.08	3.79	-1.86	0.07
selecttm - 5.4a	2.72	2.26	1.62	0.11
setsched - 5.4b	3.13	3.18	-0.18	0.85
makebud - 5.4c	2.98	3.05	-0.25	0.80
ctrlcost - 5.4d	3.57	3.36	0.84	0.41
workflow - 5.4e	3.38	3.28	0.40	0.69
accompli - 5.4f	3.47	3.36	0.51	0.61
perfeval - 5.4g	2.64	2.69	-0.22	0.83
defrward - 5.4h	2.45	2.59	-0.53	0.60
projcomp - 5.4i	3.70	3.51	0.86	0.39
maketech - 5.4j	3.40	3.38	0.08	0.94

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Appendix 5: (continued)

Item	Eng./R&D	Mfg.	t-value	p
maketool - 5.4k	3.21	2.82	1.46	0.15
rolefm - 5.6c	3.00	3.46	-1.86	0.07
resppl - 5.6d	4.06	3.92	0.68	0.50
resconf - 4.1c	3.34	3.44	-0.45	0.66
resprob - 4.1d	3.43	3.41	0.08	0.94
overttm - 5.1a	2.98	3.15	-0.83	0.41
overtbu - 5.1b	3.04	3.33	-1.42	0.16
frequ - 5.1c	2.89	2.77	0.58	0.56
frequ - 5.1d	3.17	3.08	0.49	0.63
prdinio - 4.7a	4.02	3.64	1.76	0.08
prcinfo - 4.7b	3.83	3.67	0.75	0.46
r_dshare - 4.9a	3.40	3.67	-1.27	0.21
mfshare - 4.9b	3.15	3.92	-4.39	0.00**
r_drev - 4.9c	2.79	2.67	0.63	0.53
mfrev - 4.9d	2.66	2.87	-1.04	0.30
r_dincrp - 4.9e	2.15	2.38	-1.17	0.25
mfincrp - 4.9f	2.30	2.49	-0.92	0.36

(continued on next page)

Appendix 5: (continued)

Item	Eng./R&D	Mfg.	t-value	p
overlap - 4.2	3.00	2.97	0.12	0.90
comm2way - 4.7c	3.94	4.15	-1.12	0.27
oftencom - 4.8	3.68	3.87	-0.83	0.41

Notes: *items were re-coded.

** $p < 0.05$; Levene's Test was used to test for equal variances.

Appendix 6:
Factor Analysis of Project Characteristics

Item	Factor 1	Factor 2	Factor 3	Communality
scale_1	0.02	0.94	-0.02	0.88
scope_1	0.07	-0.01	0.95	0.92
novelt_1	0.53	-0.31	-0.26	0.45
mfgpro_1	0.78	-0.00	0.29	0.70
matstn_1	0.76	0.27	-0.05	0.65
metodn_1	0.83	-0.14	0.00	0.70
techte_1	0.78	0.02	0.05	0.60
% variance explained	39.6	15.7	14.5	
Eigenvalue	2.77	1.10	1.02	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.73

Appendix 7:
Inter-Item Pearson Correlations
for Newness

Item	Corrected Item-Total Correlation	1	2	3	4	5
1. novelt_1	0.41	-				
2. mfgpro_1	0.62	0.28	-			
3. matstn_1	0.61	0.34	0.52	-		
4. metodn_1	0.56	0.27	0.59	0.41	-	
5. techte_1	0.65	0.43	0.47	0.58	0.46	-

Notes: Cronbach alpha = 0.79; N = 50.

Appendix 8:
Factor Analysis of Task Uncertainty

Item	Factor 1	Factor 2	Communality
revise_1	0.65	-0.04	0.43
schedu_1	0.73	0.10	0.55
confli_1	0.82	-0.03	0.67
crises_1	0.78	0.08	0.61
method_1	0.36	0.77	0.72
previo_1	-0.23	0.84	0.76
% variance explained	40.8	21.6	
Eigenvalue	2.45	1.30	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.69.

Appendix 9:
Factor Analysis of Task Equivocality

Item	Factor 1	Communality
shareu_1	0.74	0.54
taskcl_1	0.69	0.47
countc_1	0.81	0.66
specif_1	0.79	0.63
countc_2	0.84	0.70
vocabl_1	0.64	0.41
% variance explained	57.1	
Eigenvalue	3.42	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.82.

Appendix 10:
Inter-Item Pearson Correlations
for Task Equivocality

Item	Corrected Item-Total Correlation	1	2	3	4	5	6
1. shareu_1	0.61	-					
2. taskcl_1	0.55	0.50	-				
3. countc_1	0.69	0.53	0.50	-			
4. specif_1	0.68	0.40	0.47	0.54	-		
5. countc_2	0.72	0.56	0.40	0.69	0.63	-	
6. vocabl_1	0.50	0.36	0.30	0.37	0.53	0.44	-

Notes: Cronbach alpha = 0.84; N = 47.

Appendix 11:
Factor Analysis of
Concurrent Engineering Orientation

Item	Factor 1	Factor 2	Factor 3	Factor 4	Communality
prdif_1	0.77	-0.01	0.20	0.24	0.69
prcinf_1	0.84	-0.06	0.02	0.10	0.72
r_dsha_1	0.19	0.12	-0.11	0.88	0.84
mfshar_1	0.34	0.06	0.10	0.85	0.85
r_drev_1	0.23	-0.18	0.83	-0.08	0.78
mfrev_1	0.07	0.13	0.86	-0.06	0.77
r_dinc_1	-0.16	0.48	0.50	0.39	0.65
mfincr_1	-0.32	0.42	0.61	0.36	0.79
overla_1	0.46	0.15	0.01	0.31	0.32
mfinvo_1	0.51	0.66	0.07	-0.09	0.71
mffeed_1	0.35	0.63	-0.09	0.22	0.58
mfcost_1	0.02	0.81	0.03	0.14	0.67
mfpurc_1	-0.05	0.69	0.10	-0.00	0.49
r_dend_1	0.65	0.33	-0.18	0.08	0.57

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Appendix 11: (continued)

Item	Factor 1	Factor 2	Factor 3	Factor 4	Communality
comm2w_1	0.77	0.02	0.05	0.04	0.60
oftenc_1	0.72	0.07	0.01	0.10	0.54
% variance explained	28.7	16.9	11.5	8.9	
Eigenvalue	4.60	2.71	1.84	1.43	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.61

Appendix 12:
Inter-Item Pearson Correlations
for CEOPS Measure

Item	Corrected Item-Total Correlation	1	2	3	4
1. mfinvo_1	0.62	-			
2. mffeed_1	0.62	0.64	-		
3. mfcost_1	0.61	0.49	0.48	-	
4. mfpurc_1	0.42	0.29	0.29	0.47	-

Notes: Cronbach alpha = 0.76; N = 50.

Appendix 13:
Inter-Item Pearson Correlations
for CEINFTOL Measure

Item	Corrected Item-Total Correlation	1	2	3	4
1. r_drev_1	0.46	-			
2. mfrev_1	0.59	0.65	-		
3. r_dinc_1	0.53	0.27	0.27	-	
4. mfincr_1	0.63	0.21	0.49	0.71	-

Notes: Cronbach alpha = 0.75; N = 47.

Appendix 14:
Inter-Item Pearson Correlations
for LEADER

Item	Corrected Item-Total Correlation	1	2	3
1. makede_1	0.49	-		
2. rescon_1	0.46	0.36	-	
3. respro_1	0.56	0.48	0.44	-

Notes: Cronbach alpha = 0.69; N = 47.

Appendix 15:
Factor Analysis of
Top Management Support

Item	Factor 1	Communality
overtt_1	0.76	0.58
overtb_1	0.81	0.65
freqtm_1	0.75	0.56
freqbu_1	0.88	0.78
% variance explained	64.2	
Eigenvalue	2.57	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.52

Appendix 16:
Factor Analysis of
Organizational Structure

Item	Factor 1	Factor 2	Communality
report_1	-0.07	0.85	0.72
rolepl_1	-0.25	-0.62	0.45
rolefm_1	0.77	0.35	0.71
resppl_1	0.89	-0.08	0.80
% variance explained	41.4	25.8	
Eigenvalue	1.66	1.03	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.54

Appendix 17:
Factor Analysis of
Influence Issues

Item	Factor 1	Factor 2	Factor 3	Communality
select_1	0.14	0.76	0.18	0.63
setsch_1	0.70	0.25	-0.37	0.68
makebu_1	0.63	0.31	-0.55	0.79
ctrlco_1	0.75	0.10	-0.02	0.57
workfl_1	0.36	0.27	0.63	0.60
accomp_1	0.52	0.48	0.04	0.50
perfev_1	0.24	0.75	0.11	0.63
defrwa_1	-0.01	0.84	-0.08	0.71
projco_1	0.79	-0.00	0.28	0.70
makete_1	-0.02	0.08	0.75	0.57
maketo_1	-0.14	0.03	0.86	0.77
% variance explained	31.9	21.3	11.8	
Eigenvalue	3.50	2.34	1.30	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.72.

Appendix 18:
Inter-Item Pearson Correlations
for STSALPRO

Item	Corrected Item-Total Correlation	1	2	3
1. select_1	0.51	-		
2. perfev_1	0.56	0.42	-	
3. defrwa_1	0.60	0.47	0.54	-

Notes: Cronbach alpha = 0.73; N = 47.

Appendix 19:
Factor Analysis of Cognitive Styles

Item	Factor 1	Factor 2	Communality
plansolv	0.74	-0.01	0.55
cnstearl	0.48	-0.30	0.32
conscius	0.55	-0.10	0.32
complete	0.73	-0.24	0.60
suspend	0.62	0.24	0.45
hunches	-0.20	0.54	0.34
onestep	-0.37	0.61	0.50
cues	0.02	0.76	0.59
jump	0.15	0.82	0.70
% variance explained	28.9	19.4	
Eigenvalue	2.60	1.74	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.61.

Appendix 20:
Factor Analysis of Culture

Item	Factor 1	Factor 2	Communality
perfcnts	0.81	0.06	0.66
money	0.68	-0.27	0.54
success	0.86	0.01	0.73
reciproc	-0.06	0.82	0.67
saveface	-0.03	0.78	0.61
% variance explained	38.4	25.8	
Eigenvalue	1.92	1.29	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.56.

Appendix 21:
Factor Analysis of Success

Item	Factor 1	Factor 2	Communality
prodco_1	0.11	0.86	0.76
budget_1	0.17	0.75	0.60
leadti_1	-0.06	0.85	0.72
teamgo_1	0.76	0.07	0.58
workwe_1	0.85	0.17	0.75
hightr_1	0.75	0.00	0.56
enjoy_1	0.80	0.16	0.67
stresl_1	0.52	0.08	0.28
likepa_1	0.67	-0.06	0.45
% variance explained	38.2	21.3	
Eigenvalue	3.44	1.92	

Note: Kaiser-Meyer-Olkin Measure of Sampling Adequacy = 0.74.

Appendix 22:
Statistics of Communication Technologies & Tools (N = 47)

Item	# Access	% Access
1. emilac_1	36	76.6
2. vmilac_1	34	72.3
3. faxacc_1	47	100.0
4. ccalac_1	42	89.4
5. vcnfac_1	25	53.2
6. gdssac_1	23	48.9
7. ftfacc_1	46	97.9
8. phonac_1	46	97.9
9. cadacc_1	42	89.4
10. caeacc_1	24	51.1
11. camacc_1	21	44.7
12. ediacc_1	27	57.4
13. qfdacc_1	24	51.1
14. igesac_1	20	42.6
15. pdesac_1	8	17.0
16. isoacc_1	22	46.8

Appendix 23:
Discriminant Analysis for Engineering/R&D and
Manufacturing Based on Cognitive Styles

Discriminating Variables	Unstandardized Discriminant Function Coefficients
plansolv	0.07
discalt	-0.00
cnstearl	0.43
conscius	-0.74
refine	0.80
probcont	-0.06
hunches	-0.38
onestep	0.24
abandon	0.48
simult	-0.08
complete	0.09
details	0.40
suspend	-0.08
cues	-0.08
relation	-0.30
jump	-0.67

Notes: group1 (eng/r&d) function score = 0.44; group2 (mfg) function score = -0.53.

Appendix 24:
Discriminant Analysis for Engineering/R&D and
Manufacturing Based on Culture

Discriminating Variables	Unstandardized Discriminant Function Coefficients
inequal	-0.37
ordinary	-0.00
eqtright	0.00
pwrlegit	0.35
timefree	0.04
servctzn	0.54
hardwork	0.11
uncertok	0.07
takecare	-0.24
private	0.63
emotion	-0.02
individl	0.42
perfcnts	0.03
money	-0.50
success	0.15
mendom	0.00

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Appendix 24: (continued)

Discriminating Variables	Unstandardized Discriminant Function Coefficients
longterm	0.22
reciproc	-0.30
saveface	0.29
notspend	-0.11

Notes: group1 (eng/r&d) function score = 0.48; group2 (mfg) function score = -0.58.

Appendix 25:
Pearson Correlations Between Individual Indicators of
Access and CE Orientation (*N* = 47)

Item	CE Orientation			
	ceintdim	ceops	ceinftol	ceatitd
1. emilac_1	0.03	0.17	0.16	-0.06
2. vmilac_1	0.41***	0.13	0.05	0.33**
3. faxacc_1	----	----	----	----
4. ccalac_1	0.13	-0.06	-0.14	0.11
5. vcnfac_1	-0.12	-0.09	0.22 ^a	-0.18
6. gdssac_1	0.35**	-0.03	-0.01	0.09
7. ftfacc_1	0.20	0.12	0.10	0.31**
8. phonac_1	0.20	0.12	0.10	0.31**
9. cadacc_1	0.33**	0.21	0.06	0.29**
10. caeacc_1	0.07	0.25 ^a	0.07	0.05
11. camacc_1	0.32**	0.14	0.19	0.21
12. ediac_1	0.08	0.01	-0.07	0.05
13. qfdacc_1	0.22 ^a	0.23 ^a	0.30**	0.21 ^a
14. igesac_1	0.12	0.29**	-0.02	0.33**

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Appendix 25: (continued)

Item	CE Orientation			
	ceintdim	ceops	ceinftol	ceatitd
15. pdesac_1	0.34**	0.32**	0.38***	0.20
16. isoacc_1	0.25*	0.05	0.16	0.04

Notes: *p < 0.10.

**p < 0.05.

***p < 0.01.

*marginally insignificant at p < 0.10.

"----" means correlations could not be computed because of zero variance.

Appendix 26:
Pearson Correlations Between Individual Indicators of
 Frequency of Use and CE Orientation^b

Item	CE Orientation			
	ceintdim	ceops	ceinftol	ceatitd
1. emilfr_1	-0.36**	-0.02	0.00	-0.22
2. vmilfr_1	-0.18	0.05	-0.04	-0.16
3. faxfre_1	-0.09	-0.13	-0.02	0.08
4. ccalfre_1	0.10	-0.05	0.01	0.08
5. vcnffr_1	0.02	0.34*	0.31*	0.11
6. gdssfr_1	0.13	0.35*	0.45**	0.17
7. fr_face	-0.05	0.15	-0.09	-0.02
8. fr_phone	0.04	0.19	0.11	0.32**
9. cadfre_1	-0.05	0.04	-0.11	-0.13
10. caefre_1	-0.09	0.07	0.18	-0.07
11. camfre_1	0.03	0.11	-0.25	0.14
12. edifre_1	-0.09	0.01	0.05	0.07
13. qdfre_1	0.24	0.41	0.40	0.07
14. igesfr_1	0.33	0.23	0.25	0.17

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Appendix 26: (continued)

Item	CE Orientation			
	ceintdim	ceops	ceinfltol	ceatitd
15. pdesfr_1	0.04	-0.14	0.51	0.47
16. isofre_1	0.00	-0.45**	0.13	0.10

Notes: *p < 0.10.

**p < 0.05.

*marginally insignificant at p < 0.10.

^bN varies throughout.

Appendix 27:
Glossary of Main Variables

Variable	Description
CEINTDIM	Information exchange and interface dimension of CE orientation
CEOPS	Overlapping problem-solving dimension of CE orientation
CEINFTOL	Information tolerance dimension of CE orientation
CEATITD	Attitudes dimension of CE orientation
CBUDLT	Task measure of success
COOPSAT	Process measure of success
EDLEVEL	Equality between functions on educational level
WORKENV	Equality between functions on working environment
EXPLEVEL	Equality between functions on experience level
ORGPOSIT	Equality between functions on organizational position
JOBROTN	Total number of years of upstream/downstream rotation
EVALREWD	Group based rewards and evaluations
LEADER	Participative project leader leadership style
MGMTSUP	Top management support (in terms of endorsements)
PRJSTRUC	Project matrix organizational structure
ADMORG	Relative influence (project leader/functional manager) on administrative and organizational issues

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Appendix 27: (continued)

Variable	Description
STSALPRO	Relative influence (project leader/functional manager) on selecting team members, salaries, and promotions
TECHTOOL	Relative influence (project leader/functional manager) on technological decisions
INDXMEDI	Level of electronic and traditional media deployed
INDXTOOL	Level of productivity enhancement and organizational integration tools deployed
DFSYSREC	Difference between engineering/R&D and manufacturing on the systematic-receptive cognitive style
DFINTPRE	Difference between engineering/R&D and manufacturing on the intuitive-preceptive cognitive style
DFMASCUL	Difference between engineering/R&D and manufacturing on the aggressive/assertive dimension of culture
DISTANCE	Distance between engineering/R&D and manufacturing
TIMEZONE	Timezone difference between engineering/R&D and manufacturing

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