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**Skills, Knowledge and Training
of
Design and Manufacturing Personnel
in Concurrent Engineering Teams**

by

KARL J. GHIARA, B. Tech. (Mech. Engg.)

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of**

Master of Management Studies

Department of Business

**Carleton University
Ottawa, Ontario**

July 9

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**SKILLS, KNOWLEDGE AND TRAINING OF DESIGN AND
MANUFACTURING PERSONNEL IN CONCURRENT ENGINEERING TEAMS**

submitted by Karl J. Ghiara, B. Eng. (Hons.)
in partial fulfilment of the requirements for
the degree of Master of Management Studies

Thesis Supervisor

Chair, Department of School of Business

Carleton University
August 31, 1993

*Mum and dad,
this thesis is dedicated to both of you*

ABSTRACT

This research investigated the skills, knowledge and training of design and manufacturing personnel that belonged to concurrent engineering teams. The findings show that there was a difference in the skills and knowledge present in manufacturing personnel that belonged to successful and less-than-successful project teams, strengthening the importance for early involvement of Manufacturing in the NPD process. Also, skills and knowledge that are present were contrasted with the skills and knowledge that should be present with the help of a self-developed assessment tool. The results indicated that personnel felt the need to further develop their skills and knowledge so that they could maximize their contribution in their respective teams. When manufacturing (design) personnel's perceptions of the skills and knowledge present in design (manufacturing) were compared the results indicated that there was a lack of mutual understanding as to the skills and knowledge prevalent in the other department. Important factors like timing of training and cross-functional exposure were also studied and were found to have an influence on project success. Essentially what was concluded from this study was that before firms implement concurrent engineering, they should first analyze their organization emphasizing that concurrent engineering is a "people" issue and then focus on segments that need further development prior to the implementation of concurrent engineering. Consequently, these same firms can reap the maximum potential benefits concurrent engineering has to offer.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my thesis advisor, Professor D. Gerwin, and thesis committee members Professor D. Compeau and Professor C. Hobbs for their guidance, instruction and encouragement during this study. I would also like to thank personnel from Lumonics Inc., Gandalf Data Ltd., Digital Equipment of Canada, Mitel and Dy4 Systems for their contribution during the data collection process. Special thanks to the managers of the same five firms that contributed comments and suggestions during the critical discussion of the research.

Financial support was provided in part by the Research Program in Managing Technological Change in Manufacturing.

Georgia, Conrad, Wilma and Wynton, thank you for providing me a home away from home.

Finally, I owe a great debt to my parents, sister and brother-in-law who have been a refuge in times of stress and helped me in more ways than can be listed.

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"The dominant theme in concurrent engineering is to eliminate over-the-wall transactions.It's best carried out by a multi-functional product development team. Product design, production capability, field support capability and quality are developed together in one system, developed in one activity with decisions made in one trade-off space."

Don Clausing¹

1.0 INTRODUCTION

Most North American firms have recognized that the 1990's call for some new philosophy of working. In order to excel in the ever-changing environment, traditional factors like high quality, low costs and product differentiation are not sufficient for these companies to gain a leading edge over other firms. They have to simultaneously look after issues pertaining to speed of product introduction as well as manufacturing flexibility (Smith & Reinertsen 1991; Bower & Hout 1988; Dertouzos et. al. 1989).

There is a general unanimity among researchers that the traditional, linear way of doing things is the main obstacle to enhancing the environment in manufacturing firms. The 80/20 rule that has been cited in the literature gives us a clearer picture of the necessity for firms to change their method of working. This rule essentially implies that in the development of a product, 80% of manufacturing costs are committed to the first 20% of the development process (Downey 1969). This calls for a revamping of the prevailing relationship that exists between Design and Manufacturing. Presently firms are more concerned with improving their manufacturing operations, thereby neglecting the improvement of engineering design (Dixon and Duffey 1990). Management has failed

¹ Don Clausing, professor at Massachusetts Institute of Technology in a speech at a recent conference on Design for Manufacturability. Source: Mayer, John. "Concurrent engineering lures designers over the wall," Computer Design/News Edition, January 14, 1991, pp.19-23.

to exploit strategies that will facilitate the introduction of products at a faster rate.

It is a general belief in industry that one of the best ways to reduce the new product development cycle is by stressing upstream-downstream links with the implementation of new methods and approaches that include concurrent engineering, Design for Manufacturability, Early Manufacturing Involvement and Cross-functional teams. Stalk and Hout (1990) mention the use of cross-functional teams for the acceleration of new product development. Researchers at the Massachusetts Institute of Technology (Dertouzos et al. 1989) concluded in their study that better coordination of Manufacturing and Design through multidisciplinary teamwork is the only way in which the declining Manufacturing industrial scenario can be revived in North America. Dean and Susman (1989) mention that cross-functional teams are an important step towards integrating Manufacturing with Design. In order to reap the benefits of cross-functional team working, firms are adopting newer management techniques. They are looking for new approaches that provide a uniform direction for the different functional groups (Hayes, Wheelright & Clark 1988). The drawbacks of the sequential process of new product development have forced firms to look at the innovation process in a different perspective. The traditional linear model of development of a product is slowly being replaced as more and more companies realize the benefits of newer strategies.

This research focuses on one of the strategies called **Simultaneous Engineering** or as some researchers call it, **Concurrent Engineering** (Whitney 1988). This philosophy is also referred to as **Parallel Engineering** (Ettlie 1990), **Overlapping Approach** (Hayes, Wheelright and Clark 1988; Stoll 1990; Takeuchi and Nonaka 1986), **Design Integration**

(Stoll 1990) and the **Z curve phenomenon** (Kharbanda 1991). This management technique calls for multidisciplinary teams, where different departments work in an integrated manner, from the concept stage of new product development. Several researchers have touched upon this issue and have stressed the benefits of concurrent engineering for manufacturing firms (Carter and Baker : 1992). Enhancing technical productivity, increasing quality, decreasing engineering change orders, and decreasing product development time are some of the advantages of concurrent engineering cited in the literature. As mentioned earlier, there is an increasing degree of awareness in manufacturing practice that one of the ways to improve Manufacturing in the coming decade is with the help of collaborative and cooperative multi-functional teams (Edmondson and Wheelwright 1989). It has been observed that cooperative functioning of these teams suffers from too little mutual understanding. New product development teams are usually composed of personnel that have varying degrees of experience as well as qualifications. Also team personnel may have little or no knowledge of the work of their colleagues from other departments. The greater the diversity of disciplinary skills in a team, the greater the potential for conflict to arise among team members. This is a major deterring factor in efficient, intelligent decision making in the early stages of new product development. Unfortunately, little research exists on the influence of skills and knowledge of design and manufacturing personnel on concurrent engineering project success. Further, there is a general lack of knowledge on the effect of variables like timing of training and parallel departmental experience on project success. Through preliminary meetings with design and manufacturing personnel the researcher arrived at

certain research questions that were considered important in the five firms included in the study, and to an extent in the literature reviewed. The importance of training of team members and cross-training in each other's tasks is an important focus of this thesis. This report details an exploratory study of an investigation of the type of skills and knowledge within Manufacturing and Design, in firms that have implemented strategies that facilitate the concept of concurrent engineering. A probe into the skills and knowledge that are possessed by the concerned personnel and those that should be possessed by the same personnel is included in this study. The researcher also attempts to study if the skills and knowledge inherent in Design and Manufacturing have an influence on project success. In order to do this a number of successful and less-than-successful teams that belonged to five high technology firms in the Ottawa region were studied to assess whether skills and knowledge had an effect on project success. Project success was investigated at both the micro level as well as the macro level. At the micro level, respondent satisfaction was used as a measure of project success. At the macro level, six items of project success were used that included five measures of perceived benefits of concurrent engineering and one measure that evaluated the extent of successful implementation of the concurrent engineering approach within projects, as perceived by the respondents.

Another notable contribution of this study is an investigation of whether there was a difference in the respondents' perceptions of the skills and knowledge present in other departments. This was done primarily to investigate if there was a lack of understanding of the skills prevalent in both design and manufacturing personnel.

The growing awareness of issues related to training prompted the researcher to

investigate the suitability of different training techniques as perceived by team personnel. The effect of timing of training and parallel departmental exposure on project success was also investigated to study their importance and usefulness in the development of training programs.

The purpose of this research was to provide personnel involved in training development programs with a more in depth view as to what issues they should emphasize on while developing and implementing training programs.

2.0 LITERATURE REVIEW

The literature review discusses six major areas that are considered pertinent to this study. This approach to the review of the literature helps in analyzing the existing viewpoints held by researchers on the proposed researchable issues. They are:

1. Skills and Knowledge Definitions;
2. A brief description of the traditional model of new product development;
3. An account of the transition from Design to Manufacturing emphasizing obstacles that inhibit integration of Design with Manufacturing; and integrating factors which companies use to aid synthesis of Design with Manufacturing;
4. A description of the importance of concurrent/simultaneous engineering;
5. Activities performed by Design and Manufacturing Personnel in concurrent engineering teams -- skills and knowledge needed in concurrent teams; and
6. Training techniques that are used to impart skills and knowledge to team personnel.

2.1 Skills and Knowledge

The skill base of an organization is one of the first considerations in analyzing the benefits of new technologies (Adler 1989). The main concern is whether the personnel in the organization have the necessary proficiency to properly sustain the implementation and application of the new technology. Adler (1989) goes on to propose that the deployment of the skills within the organization depends a great deal on the type of

strategy used to integrate Manufacturing with Design. He also mentions that a departments skill and knowledge can be acquired through training and learning, making it an extremely important and feasible alternative to changing the culture of an organization in order to promote the effectiveness of project teams.

Fleishman (1984), defines **skill** as the level of proficiency on a specific task or group of tasks. Skills are further broken down into two classes:

1. **Content Skills** which are sometimes referred to as task skills or job skills include all those skills and technical capabilities that are essential to be present in members in order that the job be carried out successfully (Wellins, Byham & Wilson 1991). Weiss (1990), defines "task" as a driver of group dynamics consisting of work related activities and goal-oriented activities.
2. **Process skills** on the other hand deal more with issues pertaining to interpersonal, team interaction and communication capabilities (Weiss 1990).

The term **knowledge** is being used here in a very broad sense. It includes different aspects of the product development process like background knowledge of the working of Manufacturing and Design departments, new management techniques like quality function deployment, product function analysis, design for manufacturing and so on. If design and manufacturing personnel have the knowledge of a particular technology, function or management technique, it does not necessarily imply that they possess the skill in the same. As a tool, knowledge without skill is of little importance and use to the designer (Cain 1969) as well as manufacturing personnel. Therefore, both these characteristics, skills and knowledge, were included in this study.

2.2 Sequential Model in New Product Development

There is no dearth of literature describing the activities involved in the development of new products (Cain 1969; Holt 1983; Cooper and Kleinschmidt 1985; Cooper 1986). A number of researchers have come up with new product development models depicting the different activities performed in the development process (Saren 1984). In order to give an account of the activities involved in the development of new products, a brief description of the sequential process of new product introduction will first be cited.

In the traditional development of a product, the innovation process is broken down into a series of sequential stages in each of which some specific activity is performed (Figure 1). Functional departments are identified within these different stages and each department is accountable for its specific activity. Takeuchi and Nonaka (1986), likened the old sequential approach to that of a relay race where one group of functional professionals passes the baton on to the next group. Firms that operate in this traditional manner essentially have no cross-functional teams working on a project. Each functional department operates at a specific stage or phase in the new product development (NPD) cycle and performs a certain activity with little or no collaborative work from other departments. In order to provide a basis for the description of the various activities performed in the new product introduction process, the activity innovation model used by Baker and McTavish (1976) is adopted and refined. The innovation process is broken down into a sequence of six stages (Figure 1): they are i) idea generation; ii) screening; iii) commercial evaluation; iv) technical development; v) testing; and vi)

Figure 1

THE TRADITIONAL SEQUENTIAL APPROACH

commercialization. In reality, this sequential approach to the development of new products is very time consuming. It results in late involvement of the different functional personnel that traditionally get involved downstream in the development process. Firms that work under this traditional manner of operation have an over-the-wall relationship between Manufacturing and Design engineers, who are treated with far more importance, feel that they have completed their job once the design is completed and **"thrown over to manufacturing"**. In such a scenario, manufacturing has no other alternative but to struggle and build the product even if it is beyond their means. Design as well as other functional departments do not take into account the constraints of Manufacturing, and this leads to conflict between the different departments. This results in the lengthening of the development cycle due to delays in development of the product and it has been seen that quite often companies lose market opportunity due to these delays. A bottleneck in one of the phases may result in a delay or even abandonment of a particular development process (Takeuchi and Nonaka 1986). Also, this traditional approach, involving top-down decision making in a step-wise manner, results in a very slow and risky process of adoption of advanced manufacturing technologies (Hayes and Jaikumar 1988; Lee 1991) as it leaves little room for integration. Lack of organizational integration (Lee 1991) and inappropriate technical problem solving approaches are some of the impediments cited in the literature. The main problem with this approach however is that firms that work in this manner are unable to reap the benefits enjoyed by multi-disciplinary teams.

The next section will highlight some of the obstacles that prevent Manufacturing from integrating with Design and thereby help in analyzing which aspects of knowledge

and skills would be required by personnel in these groups to do away with these hindrances.

2.3 Design and Manufacturing Interface

2.3.1 Transition from Design to Manufacturing

High-tech industries continuously face increasing competitiveness as well as complexity. The competitive nature of these high-tech industries continuously calls for more efficient technology development that will reduce the time for the transition of the development of a product from its design stage to its volume manufacturing stage. In order to remain competitive, firms are realizing that this transition has to be changed from the traditional sequential approach to one that defines a seamless evolution. It has been observed that the maximum integration between Design and Manufacturing takes place in the development phase of the new product development life-cycle. The Manufacturing and Design interface is perceived as a key part of the innovation process. However, firms that have initiated strategies to integrate these two departments have found that this interfacing is not simple. Conflict between R&D and process engineering is an inherent weakness in the development of new products (Clark and Fujimoto 1991). Ginn and Rubenstein (1986) show in their study that severe turbulence and conflict tend to arise at the Manufacturing/R&D interface.

Nevins, Whitney and De Fazio (1989), state that engineering and institutional limitations inhibit the smooth interfacing of the two departments. Engineering limitations are caused due to the fact that certain decisions can be made only after others have been

carried out. Institutional limitations deal with issues like habits of workers, training of workers, lack of experience in working in cross-functional teams and presence of a large development team.

2.3.2 Barriers to Smooth Transition from Development to Production

Lawrence and Lorsch (1967), studied the organizational problems associated with differentiation of different sub-systems in organizations. They define differentiation as the difference in the structural attributes and patterns of cognitive and normative orientations of team members belonging to the different functional departments. Ensuing is a list of barriers to cooperation between the two concerned functional departments, namely product design and manufacturing.

Late involvement of Manufacturing

It is essential that the different functional departments (e.g., Production) be involved early in order to be significantly influential in the development of a product (Carlsson 1991; Gupta and Wilemon 1990). This is a key consideration as it is one of the main reasons why product development delays occur.

Barriers due to different cultural settings and goals of the different departments

Personnel from different functional departments have separate goal orientations in making decisions relevant to product and process innovations (Carlsson 1991; Clark and Fujimoto 1991; Hottenstein 1988; Lawrence and Lorsch 1967). Designers work under a scenario that focuses on new product development and product performance. This slows down production rates initially. On the other hand, manufacturing personnel look for

plant efficiency and production with optimum use of the plant equipment and resources. The attainment of one goal hinders the attainment of the other making the two objectives incompatible.

Geographical separation of departments resulting in lack of communication

Sometimes the design department and manufacturing department are located in two separate buildings (Ettlie & Reifeis 1986) or at times in two different cities (Dean and Susman 1989; Carlsson 1991). This naturally leads to communication problems between the two departments and has proved to be a major deterrent in interfacing the working of the two departments. Most often Design is blamed for the poor interfacing of Manufacturing with Design (Hottenstein 1988). This can be attributed to the fact that the designers' area of focus is far more limited as compared to other departments and, hence, they lack knowledge of what happens in the other functional disciplines (Carlsson 1991). However, this is not always true since it may happen that Manufacturing may express its process capabilities in an inefficient manner to Design. This lack of communication and conflict resolution can have detrimental effects on the development of new products.

Lack of common database systems

A shared common database system does not usually exist in firms that work in the traditional manner. Design and Manufacturing personnel are not aware of and knowledgeable of information sharing mechanisms and are inept in skills and knowledge pertaining to computer support initiatives. This may result in a non-uniform numbering system leading to duplication of parts. Also, designers may design parts that already exist resulting in proliferation of parts (Hottenstein 1988).

Clark and Fujimoto (1991) mention that apart from multiple objectives, companies are faced with numerous constraints and uncertainties about market reaction, resulting in conflict between the two departments.

Having mentioned some of the interfacing problems between Design and Manufacturing, it would be appropriate to mention some of the strategies which companies use to facilitate the coordinated working of the two departments.

2.3.3 Integrating Factors Companies Use to Aid Coordination of Design with Manufacturing

As a result of differentiation the need for integration is introduced in organizations. Galbraith (1973) differentiates the integrating mechanisms into those at the organizational level and lateral processes. Integrating mechanisms at the organizational level include integration by rules and procedures, by targets and by using higher levels in the organizational structure. Lateral processes include cross-functional teams, matrix design, direct contact, liaison roles and task forces.

A number of researchers have elicited methods used to integrate Manufacturing with Design (Ettlie 1990; Carlsson 1990; Dean and Susman 1989; Hottenstein 1988). Important to all the approaches used by firms to integrate the two departments is the essential element of structural change. In a study carried out by Ettlie (1990) on firms that have adopted strategies to facilitate integration of Design with Manufacturing, a list of five integrating actions which firms adopt was discussed:

Members of cross-functional teams are trained for Design For Manufacturing (DFM)

In order to close the gap between Design and Manufacturing, companies like Hewlett-Packard have very successfully introduced training programs where members of cross-functional teams are taught DFM techniques (Mayer 1991). In this approach, the different functional departments are educated on issues of manufacturing and CAD/CAM integration.

There is a manufacturing sign-off on design reviews

In this approach, manufacturing is given the power to veto any design if it is not manufacturable (Dean and Susman 1989; Hottenstein 1988). With such an approach, it is rare that a design will be scrapped downstream in the development process, due to manufacturability reasons.

The next two strategies involve cross-training of team personnel by temporary or permanent transfer of personnel from one functional department to another.

Job rotation is encouraged between functional departments

In this approach, the training of personnel in multiple functions is encouraged. This strategy, which is based on interfacing with the help of organizational relationships, attempts to reduce some of the cultural differences that exist between Design and Manufacturing (Hottenstein 1988). It is a process that induces professionals to cherish multiple viewpoints that arise in the development of a product. Carlsson (1991), mentions the importance of job rotation as a "soft approach" integration mechanism that should be encouraged along with teamwork in firms that wish to operate in an integrated fashion.

Permanent change of manufacturing personnel to R&D and vice versa

In this approach, personnel from either department are moved to the other department on a permanent basis. This proves beneficial to the organization because decisions are now made by people who know the constraints on both departments. Design personnel who have had prior experience in Manufacturing are able to carry out their responsibilities keeping in mind the working constraints and issues faced by Manufacturing. This helps in ironing out issues that traditionally would have been focused on downstream in the product development process.

Change in organizational structure for closer coordination. Use of cross-functional teams, integrators and product-process design departments

These are steps away from the traditional approach. These approaches, apart from the integrator approach, help in planning for the manufacturing process before the design of a product is complete.

Lawrence and Lorsch (1967) mention the emergence of cross-functional coordinating teams as organizations get more differentiated and thereby need greater integration. This strategy demands that team members possess excellent interpersonal skills and facilitates close cooperation of the different functional departments that participate in the development of a product. The frequent interaction involved allows people from the various departments to educate one and other, thus providing an opportunity for team members to enhance their skills and knowledge.

In the integrator approach, manufacturing personnel do not face the additional burden of learning a design or activities performed by designers. At the same time,

designers do not have to be more knowledgeable in manufacturing (Dean and Susman 1989). The integrator, who serves as a liaison between designers and manufacturing personnel, must be knowledgeable in both sets of activities to look after producibility issues.

The product-process department approach is one that involves a radical change in the structure of an organization (Dean and Susman 1989). It creates a department that is responsible for both product as well as manufacturing process. This approach facilitates the concurrent engineering philosophy of working as it encourages interpersonal communication as well as sharing of technical knowledge.

Some additional strategies which companies use to integrate the two functional departments are interfacing via technology, interfacing via parts simplification programs and interfacing via supraorganizational efforts (Hottenstein 1988).

Interfacing via technology

Promoting use of CAD, CAM, AI, common databases etc. are some of the components of this strategy. As an example to describe this strategy, CAD/CAM integration is cited. The use of CAD/CAM integration provides a technical foundation on which Design(Manufacturing) can integrate in an efficient manner (Carlsson 1991).

Interfacing via parts simplification

Some examples of this strategy are the use of a uniform parts numbering system, modular designs, standardized parts etc. (Hottenstein 1988). With the help of this strategy, project team members can simplify the design, fabrication and use of the product.

Interfacing via supraorganizational efforts

This integrating mechanism seeks to integrate Manufacturing with Design through the creation of new organizational structures. Manufacturing is given the opportunity to play a more significant role in corporate strategy. Components of this strategy are: improving the status of manufacturing, changing corporate culture, and creating manufacturing R&D units (Hottenstein 1988). These corporate or division level organization units are responsible for testing and debugging manufacturing processes and systems before moving them to the manufacturing shop floor.

Interfacing via technology and interfacing via parts simplification are discussed in detail later in the literature review explaining the generic elements of concurrent engineering.

2.4 Concurrent Engineering

Imai, Takeuchi and Nonaka (1985) illustrate three approaches to the development of products. The first one being the sequential approach just described followed by the overlapping approach that essentially is of two forms. The first form encourages the overlapping of functions that are involved in adjacent phases. For example, interfacing marketing with design. The second form of the overlapping approach involves concurrent engineering.

Concurrent engineering can be defined as a cross-functional, cooperative team-solution process that systematically looks after the parallel development of products and their related manufacturing processes with the help of computer support initiatives and

formal analytical methods, taking into consideration functionality, reliability, producibility and marketability of a product from the onset of the product development process².

There is a growing emphasis on making important decisions earlier in the development of a product (Wilemon and Gupta 1990; Dixon and Duficy 1990; Carlsson 1990). As can be seen in Table 2.1, the cost incurred in design decisions is only a small portion of the total cost spent in the development of a product from its concept to commercialization. However, once the design engineering phase has been passed, around 80% of the total costs for the product development have been committed. This is reiterated in Table 2.2 (ref. Port, O. 1990), which depicts the increasing cost of engineering changes as one goes down the product development process. If an engineering change is made to a product during its design phase, i.e. upstream in the development process, it would cost the development project for a typical electronics product a thousand dollars. On the other hand, one engineering change would cost the development project ten million dollars if it is made during the final production phase of the product development process. These findings indicate that management should not be insensitive to the important criteria that are traditionally regarded downstream in the new product development process. As far as possible, issues involved in the development of a new product, i.e. from concept to commercialization, should be considered in the early developmental stages. In a concurrent engineering scenario (Figure 2), development activities should be worked upon in parallel. Design and Manufacturing personnel should

² Definitions and suggestions made by different researchers (Winner et. al. 1988; Lu 1990; Jones 1990; Bruschi and McKinnis 1991) have contributed to the development of the definition.

Table 2.1
Design Decisions

	PERCENT OF TOTAL	CUMMULATIVE COSTS
PHASE	INCURRED	COMMITTED
Conception	3% - 5%	40% - 60%
Design Engineering	5% - 8%	60% - 80%
Testing	8% - 10%	80% - 90%
Process Planning	10% - 15%	90% - 95%
Production	15% - 100%	95% - 100%

Source: Data - Computer-Aided Manufacturing International Inc.

Table 2.2
Traditional Approach

TIME OF DESIGN CHANGE	COST*
During Design	1,000
During Design Testing	10,000
During Process Planning	100,000
During Test Production	1,000,000
During Final Production	10,000,000

* Typical cost for each change made during the development of a major electronics product

Source: Dataquest Inc.

Figure 2

CONCURRENT ENGINEERING PRODUCT DEVELOPMENT

Source: Adapted from Lu 's(1990) model.

have skills in and knowledge of each others tasks and activities. This creates an environment where competing concerns are shared and knowledge is integrated before the final result is reached (Lu 1990). It is only recently that firms that work in the traditional manner have realised that they need designs that will anticipate manufacturing and assembly. Concurrent engineering eliminates design-flow bottlenecks by encouraging multiple steps of the design process to occur in parallel (Gunn 1990). For example, the manufacturing engineering activities, which involve preliminary process planning and design, could commence as soon as the preliminary design information is made available and need not wait for the final stage where the drawings are officially released. Simultaneously, the initial manufacturability evaluation in process design can be fed back to the product design activities. In other words, if the manufacturing engineers are involved in the design stage from the beginning, their constraints and criteria can be taken into account as important decisions are being made. To support this new organizational change, the new product development team members must possess different characteristics than those used in the traditional manner of working. The team personnel must work in an environment that encourages cooperative and collaborative working relationships with members of the different functional groups on the product development team. Personnel should have either the skills or knowledge of formal analytical methods and Design for Manufacture Tools. Marketing, Design, Quality, Service etc. along with Manufacturing personnel all need to work simultaneously towards achieving a common goal. In Figure 3, which details a more complete picture of the concurrent engineering environment, the dashed line arrows represent the transition from one phase to the ensuing phase. The

Figure 3

CONCURRENT MODEL OF DEVELOPMENT OF A PRODUCT

Source: Adapted from Bush and Frohman (1991).

double-headed arrows represent learning through the transfer of knowledge and expertise into and out of the basin of knowledge of the innovative team. This will ensure the development of a highly manufacturable product.

2.4.1 Traditional vs. Concurrent Engineering

Clark and Fujimoto (1991) developed a framework to explain the integration of all engineering activities including testing, design review, process design, drawing release, tool making and manufacturing sign-off which they term as elements of a problem solving cycle. They explain five dimensions of interface between the design of a part and the development of a process for manufacturing it (Figure 4). The figure depicts the extent of these five dimensions across a spectrum consisting of the sequential approach and the concurrent approach at the two extremes. The first dimension determines the nature of the integration between functions and deals with the timing of the upstream-downstream activities (i.e., whether the activities are in sequence or overlap). Firms that are in the transition from the sequential to the concurrent approach fall between these two polar opposites of the spectrum. The same figure shows important differences observed in the two approaches. The right hand side of the spectrum, which depicts the concurrent working philosophy, depicts the need for rich, intense communication skills whereas the sequential approach calls for more limited communication skills. This explains the second dimension. The third dimension deals with the frequency with which the information is transmitted. In the sequential approach, the information is transmitted in batches as compared to the "frequent information-sharing" enjoyed in the simultaneous approach.

Figure 4

DIMENSIONS OF INTERFACE WITH REGARD TO THE TWO APPROACHES

Source: Clark and Fujimoto (1991), Chapter 8.

The direction of communication i.e., whether it is unilateral or one that consists of feedbacks (bilateral) is the fourth dimension. Mention is also made of the difference in the timing of information flow during the development process which is the fifth interface dimension. In the sequential approach, information is released late in comparison to the simultaneous approach where there is early release of information. It can be inferred from the same figure that firms can proceed from the sequential approach to the concurrent approach by increasing the frequency of information transmission, focusing on the integration of skills and knowledge required by team members and overlapping of the different functional departments (Hayes, Wheelright and Clark 1988).

Although concurrent engineering is proving to be an extremely useful philosophy of working, it is difficult to implement. Fear of "blame placing" is one of the reasons. Designers may be apprehensive in parting with design information early on in the development of a product. If, at a later date, they decide to alter the design, they may be accused by the downstream groups of failure to design right the first time.

2.5 Activities Performed in Concurrent Teams

Having explained concurrent engineering, this section will first try to outline the need for an in depth awareness of the skills and knowledge required by the personnel concerned, following which an inventory of concurrent engineering activities and formal methods used for design and manufacturing support will be discussed. Focus will be placed on the specific type of activities performed by design and manufacturing people.

2.5.1 Need for Knowledge and Interdisciplinary Skills

The philosophy of concurrent engineering demands the development of new technical as well as interpersonal skills (Dean and Susman 1989). Eppinger et. al. (1990) mentioned the need for engineering and management interdisciplinary skills in design professionals belonging to product development teams. They further suggested that the activity of designing products requires basic skills in marketing, engineering analysis, process technology, manufacturing management, organizational behaviour and industrial design. They also stated that these skills need to be augmented by process skills involving synthesis and organization. According to Thamhain (1990), a major difficulty in product development is constructing a unified multi-functional group that would support the implementation of the original product plan. This is due to the fact that the team may consist of members that possess different needs, knowledge, backgrounds and skills. Although, these individuals may be very highly skilled in their respective fields of specialization, their inadequacies with regard to other specialized areas may result in poor functioning of the team. This reflects the growing need for teams to be comprised of personnel that are able to pool their knowledge and skill thereby strengthening the depth of knowledge within the innovative team. Wilemon and Meyers (1988) mention the dearth of knowledge on the different skills needed at the various stages of the technological development process and the need for a study in this specific area. Several other researchers have observed the necessity for diverse skills and capabilities in team members and team leaders across organizational interfaces but fail to make mention of the important skills (Takeuchi and Nonaka 1986; Edmondson and Wheelwright 1989).

Clark and Fujimoto (1991) stress the importance of skills, attitudes and managerial philosophy when a particular approach involving integration of different functional personnel is considered but again fail to come up with a comprehensive list of skills required. Moreover, no attempt has been made to empirically relate skills and knowledge prevalent in design and manufacturing personnel with concurrent engineering project success.

2.5.2 Generic Elements of Concurrent Engineering

Design and manufacturing are two of the key players in the introduction of new products and therefore this research is limited to an analysis of skills and knowledge of personnel belonging to the two departments. In order to provide a framework to highlight the activities carried out by concurrent engineering teams, the generic elements of concurrent engineering teams classified by Winner et. al (1988) will be adopted. This list of activities highlight the need for additional skills and knowledge to be prevalent in Design and Manufacturing personnel belonging to concurrent teams.

- I] Use of computer-based support initiatives like CAD/CAM to support design integration through shared databases and product and process models;
- II] Use of various formal, analytical methods to optimize a product design and its manufacturing and support processes; and
- III] The use of cross-functional or multi-functional teams to integrate design of a product and its manufacturing and support functions.

Content skills and knowledge were derived from the first two generic elements while on the other hand process skills and knowledge were obtained from the third generic element. It would be prudent to mention at this point that team personnel may or may not be responsible for actual performance of the activities that are mentioned in the next section. Nevertheless, knowledge of these activities is assumed to be of general importance so that these people may carry out their task of managing the product development process in a proper fashion. The need for process skills is greater amplified due to a mixture of disciplines in teams.

D) Computer-based Support Initiatives

To promote concurrent engineering, software support and automation are playing major roles in bringing information and knowledge to both designer and manufacturing engineer. As was found in the obstacles that inhibit integration of Design with Manufacturing, lack of a common database system was cited in firms that operated in the traditional manner. In the concurrent engineering scenario, the use of a common database system provides a mechanism by which common data can be shared by the different team members thereby aiding in the concurrent design of the product and manufacturing process. The amount of data that can be included in the database to define a design can be endless (Decastro and Hoogerhuis 1991). Personnel may now be faced with the task of defining the scope of the data required in order to meet design objectives. Based on industry standards, in order to integrate the close functioning of different departments, software tools, databases, hardware platforms and networking have to be integrated into

a uniform framework (Brusch and Mckinnis 1991). Team personnel should have knowledge of the prevailing engineering environment network, and skills in updating these networks whenever new design information has been accepted by the development team.

Mention is also made of the usefulness of "mechanical computer-aided engineering systems" (MCAE)³ which are basically design tools that help the managers to predict reliability, manufacturing costs and manufacturability. In the traditional manner of working, these three issues are incorrectly dealt with towards the latter end of the development process which is counter to the concurrent way of working which emphasizes the early recognition of the same issues. As mentioned earlier, expert systems and artificial intelligence are some of the ways firms interface Design with Manufacturing (Hottenstein 1988). Expert systems can be used to project likely manufacturing costs as well as check for the manufacturability of a product. This emphasizes the need for the personnel of the two departments to be familiar with, as well as skilled in, these systems if they are to work simultaneously. Lu (1990) indicates that one of the new important tasks that manufacturing personnel have to deal with is to provide design personnel with manufacturability analyses with the use of expert tools. In other words, the designers should be notified of the manufacturability of certain parts and components included in the design of a product. This technique is usually applicable when processing capabilities are known and manufacturing resources are pre-organized.

³ Philippe Villers, who is the president of Cognition Inc., a developer of MCAE systems, gives a brief description of MCAE systems under the heading, "Designing for Predictability: New MCAE Tools", which appears in Daniel Whitney's article titled "Manufacturing by Design," Harvard Business Review, July-August, 1988.

II) Formal methods including product process integration tools used by Concurrent Teams -- Content Skills and Knowledge

Team members must have the skill and knowledge of each other's tasks and functions in order to perform the activities, involving various techniques, that are carried out by "concurrent teams." Concurrent engineering can be viewed as a process carried out by a team of "knowledge sources"⁴ with different but overlapping expertise (Lu 1990). This section will be devoted to activities, involving formal methods, performed by concurrent teams which rely on content or job skills and knowledge that will provide manufacturing people, including manufacturing engineers, better visibility of the design process and at the same time designers with better knowledge of the constraints and working of the manufacturing department. It is important to mention here that certain product design methods, for eg. value engineering, are considered. These activities are found to be inherent in concurrent engineering teams as well.

Customer Requirements-- Quality Function Deployment (QFD)

The ideal of Quality Function Deployment is closely related to the philosophy of concurrent engineering. This has been defined by Stoll (1990) and Hauser and Clausing (1988), as a new technique that provides for the interpretation of needs of the users into technical information using a formal correlation matrix. QFD requires that cross-functional teams consider customer requirements at the early phases of the design of a product and then translate these requirements into engineering objectives that are

⁴Stephen C.-Y. Lu defines "knowledge sources" as the product development participants in his article titled "Knowledge processing for concurrent engineering", Robotics and Computer-Integrated Manufacturing, Vol. 7, No. 3/4, 1990.

maintained throughout the design process (Decastro and Hoogerhuis 1991). Firms that are able to translate users' needs into technical information will survive the fierce competitive battles they face in the 1990s. Therefore, knowledge of customer requirements as well as skills in using techniques to translate customer requirements are two attributes that need to be considered.

Statistical Process Control

Nevins, Whitney and De Fazio (1989), include statistical process control in their list of activities carried out by concurrent design teams. This technique involves the application of powerful statistical tools that will help team members understand and improve their manufacturing processes. Stoll (1990) defines statistical process control as a design for manufacturing tool comprising statistical monitoring and control techniques to obtain the desired quality of the final product. This activity involves the knowledge of: process tolerances (functional and tooling) and variances, and control charts that indicate an out-of-control condition so as to reduce the probability of incompatibility between the assembly method and the product design.

Design for Assembly

The DFA technology developed by G. Boothroyd and P. Dewhurst offers significant benefits, including decreased costs and increased quality (Boothroyd and Dewhurst 1987). This tool involves the designing of a product keeping in mind how it will be assembled (Stoll 1986). Knowledge of group technology methods along with decisions and rules to be made while designing new products are encompassed under this technique. The skill and knowledge in establishing priorities and time sequences for

assembly work used by concurrent design teams are included in this category of skills.

Modular Design

Modular design reduces the possibility of diversity as it allows the design of a customized product with the help of standard components (Stoll 1986). Modular design is a process that calls for the ability to break down the product and manufacturing process into smaller modules. Each module is then controlled by the production team separately after which all the modules are combined together to form the overall product. Importance of the knowledge and skill of this activity is highlighted in Nevins, Whitney and De Fazio's (1989) list of concurrent design activities.

Value Engineering

Value engineering has been defined as a powerful tool and technique used to analyze the merit of a product, system or service and to provide the necessary functions at the lowest cost (ASTME 1967). Although value engineering usually occurs after the product design has been completed, certain activities carried out in this technique seem to fit under the concurrent engineering philosophy. Its basic aim is to reduce manufacturing costs through proper choice of materials and production methods (Whitney 1988). The activity is usually carried out by a informal group that includes design, manufacturing, procurement and sales personnel (Cain 1969). First, the design of the product is challenged checking for simpler standardized designs that will reduce costs following which the manufacturing process is analyzed for possible cost-saving refinements (Stoll 1986). The following are two salient characteristics or techniques used in value engineering analysis.

Standardization of key designs

This implies the identification of designs of a part or sub-assemblies that can be used in the development of another product. The need for knowledge and skill in this particular activity was derived from the literature review. It was also supported at the meetings held with the companies.

Knowledge of available materials for the manufacture of a product

It may occur that a new material could be used for the manufacture of a particular product that may either increase the ease of manufacture, decrease the cost of manufacturing or both. Most often, the manufacturing personnel should have a good knowledge about the effect of different materials on machining and other processing operations (ASTME 1967).

Product Function Analysis

Product function analysis is an important activity which calls for important content knowledge and skills. Although this term may not be well understood in industry it basically implies the knowledge of a very important communal skill for both the departments. It emphasizes the necessity for team members to know exactly how the product is supposed to function in relation to the production methods before important design decisions are made (Whitney 1988; Nevins, Whitney and De Fazio 1989). With the help of software, designers and manufacturing engineers are able to model and design robust and high quality products with their choice of the best production method chosen from an array of manufacturing processes.

Decision Rationale

Lu (1990) defines decision rationale as a recollection of previous product designs and manufacturing process designs, and is represented in the form of design plans and design constraints." Knowledge of such records help the designer and manufacturing engineer in tracing design decision-making processes, rationales, assumptions and interdependencies carried over from the design of other products, thereby aiding in the design of new products. With the help of decision rationale records, designers and manufacturing personnel can express and justify their future decisions.

Logistics-- Distribution and Supplier Relationships

At the preliminary meetings, certain logistic issues pertaining to distribution as well as supplier knowledge were mentioned. Whitney, Nevins and De Fazio (1989) mention about design for logistics as an approach that is used to increase the awareness of designers about issues pertaining to purchasing and stocking. There are two issues that are discussed here. Namely, distribution methods and supplier relationships.

Distribution Methods

Concern was expressed about design and manufacturing's lack of knowledge of the distribution system adopted once the product was ready for the market. At the preliminary meetings with companies, cases were cited where the design of a product had to be scrapped due to problems inherent in the delivery methods used.

Supplier Relationships

This issue is traditionally addressed late in the development process. However, in the concurrent engineering scenario, knowledge of suppliers is regarded as an important

upstream function in the development of a product (Mayer 1991). Cross-functional teams that include representatives from design and manufacturing should be responsible for the evaluation and selection of component suppliers. In order to do this, cross-functional team members should be familiar with supplier assessment processes and identification of supplier performance requirements. More and more companies are looking to reduce the number of suppliers thereby targeting a closer relationship between the suppliers and the design and manufacturing departments. This encourages a better knowledge of logistic support functions that include reliability and maintainability of the suppliers. If a supplier cannot meet all the requirements, the team approaches a new supplier for the same commodity.

III Cross-Functional Teams

The inventories of process skills and knowledge required by the different team members cited in the literature are extremely vast. Consequently, only those process skills and knowledge considered pertinent to concurrent teams that link the upstream phases with the downstream phases were included in this study. In order to explain some of the process skills and knowledge, the third generic element of concurrent engineering will be discussed.

The formation of cross-functional teams plays an important role in projects that follow the concurrent engineering philosophy (Dean and Susman 1989; Thryft 1991; Mayer 1991; Decastro and Hoogerhuis 1991). Whitney and Nevins (1989), consider the team approach as one of the most useful tools to facilitate integration of Design and

Manufacturing. The team concept encourages personnel from the different departments to educate one another, thus contributing to better working in the future. The decisions carried out are interdependent and therefore companies have to rely on teams consisting of a pool of specialists with expertise in various disciplines. Fairhead (1991) mentions that there is a fair degree of overlap between members of interdisciplinary teams which enhances cooperation and collaboration. This team approach advocates the identification of problems early in the development process thereby enhancing the eradication of bottlenecks that slow down the process. This cross-functional team working calls for certain process skills and knowledge that will be included in the ensuing section.

Tushman and Nadler (1986) describe some of the formal and informal organizational approaches and strategies that firms should follow in order to integrate the different functional departments and thereby remain innovative. They stress the importance of communication, conflict resolution, and problem solving.

Communication skills and knowledge

Early communication among different personnel in concurrent engineering teams is an essential pre-requisite (Lu 1990). A concurrent engineering scenario requires that the different teams and team members work and share information in an integrated product development environment (Carter 1992). Therefore, being part of a team, members are forced to possess good communication skills in order to accomplish early evaluations that prevent costly iterations, fast execution for interactive decision making as well as attract and retain high calibre personnel, reduce dysfunctional conflict and induce active participation (Thamhain 1990). According to the same researcher, lower

level managers and team leaders must possess the expertise to set and communicate clear objectives to their team members.

Knowledge of imperatives for action

Ginn and Rubenstein (1986) conclude that conflict between the two departments can be overcome with the help of superordinate goals and common imperatives for action. Similarly, Wilemon and Meyers (1989), concluded in their study, that the most common reason for inefficient team learning is the failure to establish and maintain clear corporate objectives resulting in pressures and conflict within the team. From these two studies, it seems that knowledge for setting imperatives for action, is an important process skill that both Design and Manufacturing personnel should possess if teams are to function in a smooth manner. Thamhain (1990) mentions that team members should be able to communicate the project objectives to all concerned personnel and at the same time possess the ability to build up a favourable image for new product development activities (i.e. high priority, interesting work and potential professional rewards etc.).

Conflict Resolution and Problem Solving Skills

As indicated by Ginn (1983), interpersonal interactions between Design and Manufacturing have led to serious conflict. This conflict arises due to the fact that the different functional departments work under different goal scenarios (Tushman and Nadler 1986). According to Ginn and Rubenstein (1986), conflict between the two departments can also be attributed to manufacturing complexities, uncertainty of product outcomes, exercises of power, and different imperatives for action. Manufacturing as well as Design personnel should possess the necessary skills to overcome conflicts. Conflict resolution

plays an important role in team problem solving and in order that new product development activities be carried out in an adaptable manner, the concurrent engineering scenario demands more problem solving and conflict resolution skills. Also, Varney (1989) mentions that in order to resolve conflict, three essential skills are necessary. They are: diagnosis or problem identification, initiation and listening.

Problem identification

This skill involves the ability of an individual to identify common as well as contrasting points of view of personnel included in teams.

Initiation

This skill calls for team members to bring into the open the topic of disagreement.

Listening:

This is a facilitative skill enabling team personnel to spend time and effort on identifying essential information and attending to what the other team members have to say.

Empathetic Problem Solving

Varney (1989), describes empathy as the ability of team members to understand how another person in the team feels and reacts to certain problems and situations. To explain the above statement consider the following example. Manufacturing can take an empathetic view in the development of a product if it takes into consideration the constraints faced by the Design team. This can be done if Manufacturing takes the role of Design, and consequently learns the constraints and issues faced by design personnel.

Anticipation of Problems

This process skill facilitates the cooperative working of the cross- functional teams. Nevins, Whitney and De Fazio (1989), mention anticipation of assembly and fabrication methods and problems as an important skill in the development of a product in concurrent design teams. Design (manufacturing) should be familiar with and anticipate the constraints and problems faced by manufacturing (design).

Leading and Staffing

Thamhain (1990) mentions some recommendations on the management of project-oriented teams. Members should have the ability to lead and drive the involvement of personnel at all organizational levels and be skilled in staffing their on teams.

2.6 Training

In order to make concurrent engineering work, training of team members should be emphasized. Due to the new organizational structures and added task responsibilities, team members need to be trained so that they can develop and enhance their task/content as well as process skills and knowledge. Training and development is done to improve the skills and knowledge already possessed, and also to train personnel in new tasks and activities that have been introduced within their project environments. Personnel must be taught skills like communication and team problem solving which will help them perform more effectively in concurrent teams. Not only should team members be trained in these skills but they should also be cross-trained in each others task/content skills. Another important issue is timing of training. Most often training is reactive rather than

proactive (Frankel 1990), resulting in a situation where team members are trained only after the implementation of a new technology or organizational philosophy within their work environment.

Training can be defined as any organizational endeavour involving procedures employed to impart (or raise the level of) skills (Hinrichs 1976) and knowledge to team personnel. Having mentioned the need and importance of training, the next step is to try and understand the suitability and importance of various training techniques. Training may be highly formalized involving off-the-job training techniques like lectures; or training may take the form of informal instruction involving on-the-job training techniques (e.g., job rotation). The following section discusses nine training techniques that are categorized under the two training development approaches: off-the-job training and on-the-job training.

2.6.1 Off-The-Job Training

Under the general category of off-the-job training techniques designed to impart both content as well as process skills and knowledge, the techniques of lecture, audiovisual, case study and conference discussion are included.

Lecture

Most people who have had some form of formal education are aware of this technique. This technique is widely used in industry due to its simplicity (Hinrichs 1976). The same author goes on to state that although this technique does have its advantages, it should be complemented with other techniques.

Audiovisual

This technique relies on the use of visual aids like television and film. The main drawback of this technique is that the trainees are treated as a passive audience. However, it is through video and film alone that experts can impart their knowledge in specific disciplines to a large number of trainees at relatively low costs per trainee (Hinrichs 1976).

Case Study

This technique uses cases which essentially offer a description of some area of activity with which it is desired that the trainee become familiar (Hinrichs 1976). This technique is designed to impart real life situations to trainees in an off-the-job environment, and is considered as an important learning instrument.

Conference Discussion

This technique has a number of advantages over other off-the-job training techniques. First, it encourages a bilateral flow of information and knowledge and encourages the involvement of all the participants making it an extremely important technique that should be considered by concurrent teams. Second, it provides an environment that encourages the resolution of conflict on opposing issues faced by team members.

2.6.2 On-The-Job Training

In this category, job rotation, job instruction training, performance appraisal, apprenticeship training and role playing are included.

Job Rotation

Job rotation has been discussed by a number of researchers as being a useful technique for cross-training of team personnel (Carlsson 1991; Hottenstein 1988). In this technique, personnel are exposed to a number tasks and/or functional departments (Hinrichs 1976) and are given the opportunity to take responsibility and make decisions.

Job Instruction Training

Unlike the preceding technique, the job instruction method is more narrow in range. In this technique, the trainee is able to learn, over a period of time, the manner in which he/she should go about performing his/her specific tasks. Here, more emphasis is placed on the specific skills required by personnel that are directly related with the job that is assigned to them (Vaught, Hoy and Buchanan 1985). The trainee is provided feedback about his actual performance in the job setting by the trainer.

Performance Appraisals

According to Hinrichs (1976), this technique fulfils a separate training function as it provides feedback about the performance and on-the-job skills and knowledge of team members.

Apprenticeship Training

Personnel may also undergo training by the way of apprenticeships and internships. Apprentices are subjected to a quasi-environment and gain knowledge and skills as a result of the experiences he/she receives through their involvement in projects. The apprentice can then apply the same skills and knowledge to real-life issues outside the training condition (Simmons 1975).

Role Playing

In this technique, the trainee is first provided an interpretation of the role he/she has agreed to assume and then is free to develop the manner in which they feel they can carry out the responsibilities and functions of the new role (Simmons 1975). Role playing can be also done off-the-job by placing the trainees in realistic situations created specially to provide trainees an opportunity to assume the parts of specific personnel in the situation.

3.0 RESEARCH QUESTIONS AND PROPOSITIONS

In the present study, five research issues are addressed. The issues researched were derived from the literature as well as from meetings the researcher held with team personnel and managers that belonged to three of the five firms included in the study. Project success was defined in terms of the micro level (unit of analysis = respondent) as well as macro level (unit of analysis = project)⁵. At the micro level, project success was measured in terms of respondent satisfaction. At the macro level, reduction in development time, increase in overall quality, reduction in engineering change orders, reduction in manufacturing costs and cost of development were five measures of project success. Also, respondents were asked to indicate the extent of successful implementation of concurrent engineering within their project environments. This was the sixth measure of project success at the micro level.

3.1 Research Questions

RQ - 1. How do the skills and knowledge, of Design and Manufacturing personnel, relate to concurrent engineering project success?

RQ - 2. Is there a difference between the skills and knowledge possessed and the skills and knowledge that should be possessed by Design and Manufacturing personnel that belong to concurrent engineering teams?

⁵The two unit of analyses are described in greater detail in Section 4.2.3.

RQ - 3a. Is there a difference in the skills and knowledge present in Design, as indicated by Design, and as perceived by Manufacturing to be present in Design?

RQ - 3b. Is there a difference in the skills and knowledge present in Manufacturing, as indicated by Manufacturing, and as perceived by Design to be present in Manufacturing.

RQ - 4 Does a respondent's cross-functional experience in Design and Manufacturing affect project success?

RQ - 5. Does timing of training influence project success? How do Design and Manufacturing personnel rate the suitability of different training techniques?

3.2 Propositions

To reach an objective decision as to whether a proposition should be rejected or accepted with the help of collected data, the propositions are expressed in the null form. The null form is a proposition of "no effect" . The first two propositions are developed to investigate the influence of skills and knowledge on respondent satisfaction, a measure of micro level success.

#1. There is no difference in the skills and knowledge of satisfied and relatively dissatisfied Design personnel.

#2. There is no difference in the skills and knowledge of satisfied and relatively

dissatisfied Manufacturing personnel.

Proposition #3, #4, #5 and #6 investigate project success at the macro level.

- #3.** There is no difference in the skills and knowledge of **Design personnel** that were associated with projects where **implementation of the concurrent engineering approach was successful and less-than-successful.**
- #4.** There is no difference in the skills and knowledge of **Manufacturing personnel** that were associated with projects where **implementation of the concurrent engineering approach was successful and less-than-successful.**
- #5.** There is no difference in the skills and knowledge of **Design personnel** that belong to **successful and less-than-successful** project teams in terms of **product development and manufacturing success.**
- #6.** There is no difference in the skills and knowledge of **Manufacturing personnel** that belong to **successful and less-than-successful** project teams in terms of **product development and manufacturing success.**
- #7.** There is no difference between the skills and knowledge that **should be present** and that **are present** in **Design personnel.**

- #8.** There is no difference between the skills and knowledge that **should be present** and that **are present** in **Manufacturing** personnel.
- #9.** There is no difference in the skills and knowledge present in **Design** as **indicated** by **Design** and as **perceived by Manufacturing**.
- #10.** There is no difference in the skills and knowledge present in **Manufacturing** as **indicated by Manufacturing** and as **perceived by Design**.
- #11.** **Cross-functional experience** has no effect on **project success** measures at the **micro** as well as **macro** level.
- #12.** The **timing of training** has no effect on **project success** at the **micro** as well as **macro** level.
- #13.** There is no difference in the suitability of different training techniques as perceived by **Design** and **Manufacturing** personnel.

4.0 RESEARCH METHODOLOGY

A two step methodology was employed to gather the primary data required for this study. The first step consisted of preliminary meetings conducted with design and manufacturing personnel belonging to three high technology manufacturing firms in the Ottawa-Carleton region. These firms were chosen because they possessed cross-functional working of the different functional departments within their respective organizations. Another feature that was considered important in selecting these firms for the initial study was the fact that they recognised the benefits of concurrent engineering and wished to implement it on a more comprehensive basis in the near future. The firms were also interested in the findings of this research and provided every possible means to assist the researcher in developing interview schedules.

4.1 Step 1

4.1.1 Preliminary Meetings

Meetings were held with 16 managers who belonged to Design or Manufacturing sub-disciplines. A semi-structured interview format was used with each of the managers. Through this procedure, a better understanding of the potential interviewees for this study was acquired. The interactive nature of the interviews enabled the researcher to probe for further information on issues considered important in industry. The questions asked at the meetings were developed from the literature as well as from knowledge gained by the researcher after each subsequent meeting. Issues pertaining to pre-requisite skills and knowledge as well as training were discussed during these meetings. Also, an initial

questionnaire draft containing an inventory of skills and knowledge was examined. The average length of each meeting was one hour. Following this stage, the inventory of skills and knowledge was appended and modified and the questionnaire reformulated. A final draft copy of the questionnaire ready for pretesting was the culmination of this stage of the research.

4.1.2 Pretesting of the Questionnaire

Before the actual data collection phase, the questionnaire was pretested twice to identify errors in wording and questionnaire format. The researcher looked for both non-verbal feedback by observing as to how the respondents answered the questions, and verbal feedback. After carefully following some guidelines in questionnaire and scale design suggested by Davis and Cosenza (1988) and Dillman (1978) the instrument was ready for primary data collection.

4.2 Step 2 - Research Design and Strategy

The second step of the research methodology was used to address the research questions and propositions. The research design was an Ex Post Facto Design as the researcher made no attempt to manipulate the independent variables in the study. The research strategy was an exploratory study.

4.2.1 The Sample

The respondents were selected from five manufacturing firms in the Ottawa-

Carleton region. Each company has its own perception of the concurrent engineering concept and hence the researcher did not try to rigidly define concurrent engineering while identifying appropriate firms. Instead, the basic components of concurrent engineering were checked for and it was unlikely that this philosophy could have been confused with other methodologies and concepts. All projects selected involved the close cooperation between Design and Manufacturing departments and encouraged the early involvement of Manufacturing in the new product development process.

In order to select respondents from each firm, the researcher, along with a knowledgeable company liaison⁶, was able to identify personnel belonging to Design and Manufacturing who had participated in a concurrent engineering project. Another criteria was the overall success of the project. The liaison helped identify personnel belonging to both successful relatively unsuccessful concurrent engineering projects, intuitively.

In order to perform a concurrent engineering audit to check and assess if certain generic elements of concurrent engineering were prevalent in the twenty project teams, three measurement items were used. Respondents were asked to indicate 'Yes', 'No' or Don't Know as to whether #1) Design and Manufacturing engineers worked simultaneously in the design phase of new product development, #2) Activities that were traditionally performed downstream in the development process were brought forward and carried out upstream and as to whether #3) A cross-functional team was formulated that included representatives from different functional departments. A provision of 'Don't

⁶The liaison was either the company President, head of the R&D department or middle level official who was actively involved in the firms Concurrent Engineering programs.

Know' was also provided to the respondent.

4.2.2 Data Collection Method

Respondents were located with the help of another liaison belonging to each of the four firms. Appointments were made for the meetings 2-3 weeks in advance to allow for a group of respondents to be present at one single meeting. The meeting was scheduled and organized by the liaison. The purpose of the research was briefly explained and the respondents' willingness to participate in the study was sought. The respondents completed the questionnaire at the same meeting. In order to overcome certain drawbacks associated with structured questionnaires, the researcher was present at the time the questionnaire was being administered. This aided in helping the respondent to understand certain questions. Each meeting lasted for approximately one hour. If at a later stage clarification was needed on the answers provided by the respondents, either the respondent or the liaison was contacted depending on the issue in doubt.

It was not possible to administer the questionnaire in the same manner to one of the five firms as some of the respondents were inaccessible to the researcher. However, they were included in the sample as the firm showed an incredible willingness to participate in the study. Questionnaires were sent by courier to five of the ten respondents belonging to the manufacturing unit of the same firm in the US. These respondents were provided with the researcher's e-mail/address and telephone number, so they could clarify any doubts or misgivings about the questionnaire.

4.2.3 Measures

The researcher used overall project success as the important criterion variable. Two units of analysis were considered in order to investigate the research questions and propositions. When examining the effect of skills and training on the success measure at the micro level, satisfaction, the respondent was treated as the unit of analysis. In order to analyze the effect of skills and knowledge on the five measures of product development and manufacturing success, as well as extent of implementation of the concurrent engineering approach, the unit of analysis employed was the project.

4.2.3A Development of Dependent Variables

Seven measures of project success (Figure 5) were developed for this study. There was one measure at the micro level called **respondent satisfaction** and six measures at the macro level, which included **five measures of product development and manufacturing success** and one measure of **extent of successful implementation of the concurrent engineering approach**.

Satisfaction of Respondent

A five point Likert-type scale ranging from strongly disagree to strongly agree was used to assess how the respondents felt about the implementation of concurrent engineering in their work environment. The measures of satisfaction used in a study of the impact of computer-based systems (Sanders 1984) were adopted and modified by the researcher for this study. The four measures investigated issues regarding psychological growth and job satisfaction of the respondents (refer Appendix B).

Figure 5

MEASURES OF PROJECT SUCCESS

Additional indicators of success were used at the macro level and classified into two categories, namely product development and manufacturing success, and extent of successful implementation of concurrent engineering.

Measures of Product Development and Manufacturing Success

In order to investigate the association between team member skills and knowledge, and project performance, five measures of product development and manufacturing success were included in the study. The instrument required respondents to use a seven point Likert-type scale to indicate their projects' success in development and manufacture of a product in a concurrent engineering environment. The different performance items used to measure success included: 1 - the time taken in the development of a product; 2 - the number of engineering change orders encountered in the development of a product; 3 - the quality level of the product during its development; 4 - manufacturing costs; and 5 - cost of development.

These five measures of success basically reflect the perceived benefits of concurrent engineering as cited in the literature (IDA Report 1988). For each measure of success, respondents were asked to compare product development in the concurrent engineering environment to the development of a same or similar product in the traditional environment.

Successful Extent of Implementation of Concurrent Engineering

The instrument asked respondents to indicate their perceptions as to how successful the implementation of the concurrent engineering approach had been within

their project. Respondents had to indicate their views on a five point Likert-type scale ranging from very successful to very unsuccessful. Project success at the micro level is not always found to correlate with project success at the macro level and this is explained in greater detail in section 5.4.

4.2.3B Development of Independent Variables

Three Categories (A, B, and C) of Skills and Knowledge

The previously discussed inventory of skills and knowledge was categorized into three groups. The relevance of categorizing the skills and knowledge is that it offers a framework for future analysis of these skills as well as it provides insight into the specific profile of skills and knowledge needed for training development programs. This grouping was done on the basis of the literature as well as close consultation with managers before the final instrument was developed. The three groups are as follows:

'A' technical skills and knowledge that included only computer support initiatives;

'B' technical skills and knowledge that involved a specialized knowledge of a method, process procedure, or technique required of employees at all the different levels of an organization apart from category 'A'; and

'C' process skills which involved the interpersonal relationship ability of an individual.

Each respondent was requested to indicate the skills and knowledge that were present, as well as should be present in personnel belonging to their respective departments (Design and Manufacturing) who participated on the project. Respondents

had to also indicate their perceptions of the presence of the same skills and knowledge in personnel belonging to their parallel department on a specific project basis. For example, if a person is in Manufacturing, the parallel department is Design and vice-versa.

Training Techniques

Respondents were requested to indicate on a five point Likert-type scale the suitability of nine training techniques for imparting the desired skills and knowledge to team personnel working in a concurrent engineering environment. The training techniques were derived from the literature as well as the preliminary meetings held with sixteen managers.

The issue of training was further assessed using responses to two items. When asked as to whether training was provided for all team members on the tools, procedures and standards he/she should use, respondents indicated their views on a five point Likert-type scale ranging from strongly agree to strongly disagree. In order to investigate if the team members had cross-discipline knowledge, respondents were also requested to indicate on a five point Likert-type scale their degree of agreement or disagreement with the following statement: "Team members have cross-discipline awareness of tools, procedures used by other departmental team members'.

Timing of Training

During the preliminary meetings with company managers, the issue of timing of training was identified as being of considerable importance. In order to investigate the effect of timing of concurrent engineering training on the measures of project success,

provision was made in the instrument so that the respondents could indicate their answer to the following question: "When was training provided to the team members?" (1 = Before Implementation of Concurrent Engineering, 2 = During Implementation of Concurrent Engineering, and 3 = After Implementation of Concurrent Engineering).

Parallel Departmental Experience

Respondents were asked to indicate whether they had any exposure in the parallel department (i.e. if manufacturing personnel had worked in Design and vice-versa). If they indicated that they were exposed to both Design as well as Manufacturing they were requested to indicate the time they spent in both departments. If they indicated that they did not have parallel department exposure, they indicated the time they have been in their present department.

5.0 RESULTS OF THE STUDY

This segment of the thesis details the results of the study. The results are presented here in six parts: (1) results of the concurrent engineering audit, (2) sample characteristics, (3) tests for psychometric properties of the instrument, (4) correlation of the measures of project success, (5) testing of the propositions and (6) ranking of suitability of various training techniques.

5.1 Concurrent Engineering Audit

In response to the three measures used to investigate the presence of the concurrent engineering philosophy within the respondent's work environment (project), there was no conflict in the responses of different people on the same team. Eighty-four percent of the respondents indicated that Design and Manufacturing engineers worked simultaneously in the design phase of new product development. Six percent indicated a 'No' and ten percent indicated 'Don't Know'. Eighty-eight percent indicated that activities that were traditionally performed downstream in the development process were brought forward and carried out upstream. Six percent indicated a 'No' and six percent indicated 'Don't Know'. Ninety percent of the sample indicated that a cross-functional team was formulated that included personnel belonging to various functional departments as opposed to ten percent who indicated the absence of cross-functional teams. For the sake of this research the third measure was used as a control variable in order to eliminate respondents that indicated the absence of cross-functional teams.

5.2 Sample Characteristics

In this section, sample characteristics for the two units of analyses are presented.

5.2.1 Unit of Analysis : Individual Respondent

Out of the fifty respondents participating in this study, thirty of the respondents belonged to Design and twenty respondents belonged to Manufacturing. After eliminating respondents that indicated the absence of cross-functional teams within their work environment, the sample consisted of twenty-eight design personnel and seventeen manufacturing personnel.

Table 5.1 presents the classification of respondents in the different project teams. Twenty three respondents indicated that they were team members representing their respective departments and sixteen of the respondents indicated that they were project leaders. Four respondents indicated that they were working level members⁷ of their projects. Respondents also mentioned the years they had been in their respective positions. The majority of the respondents (forty) indicated that they had been in their present position for five years or less and ten respondents indicated that they had spent more than five years in their present position.

Respondents also indicated the project with which they were associated. In all there were twenty projects indicated. Five of the respondents did not disclose which project team they were affiliated with. Fourteen respondents indicated that they had experience in Design as well as in Manufacturing while thirty respondents mentioned that they had no parallel departmental exposure. Also, only a few respondents indicated

⁷If a hierarchy of teams existed, working level members were those that actually performed the Concurrent Engineering activities.

Table 5.1
Team Designation of Respondents

TEAM DESIGNATION	NUMBER OF RESPONDENTS
Team Leader	16
Team Member	23
Working Level Member	4
Did Not Disclose	2
Total	45

Table 5.2
Time When Training Provided to Respondent

TIME WHEN TRAINING PROVIDED	NUMBER OF RESPONDENTS
Before Implementation of Concurrent Engineering	3
During Implementation of Concurrent Engineering	17
After Implementation of Concurrent Engineering	10
Did Not Disclose	15
Total	45

they had received training before the implementation of concurrent engineering. The majority of the respondents (twenty-seven) indicated that they were provided training during, or after, the implementation of concurrent engineering (seventeen respondents indicated that they were given training during the implementation of concurrent engineering and ten respondents mentioned training was provided to them after concurrent engineering had been implemented within their work environment). There were fifteen missing cases that included respondents that did not receive training (See Table 5.2).

The scale used to measure whether adequate training was provided for all team members on the tools, procedures and standards he/she should use was recoded into two categories namely, 1) training was provided and 2) relatively no training was provided. Twenty three respondents indicated that they were provided with the above mentioned training while on the other hand twenty one respondents indicated that they were not provided with relatively adequate training in the tools, procedures and standards to be used by them. There was one missing case. In response to whether team members have cross-discipline awareness of tools and procedures used by other departmental team members, the scale was recoded similar to what was done for the prior scale. Twenty three respondents reported their agreement to the mentioned statement, and twenty two respondents indicated that their team members did not possess cross-discipline knowledge of tools, procedures used by other departmental team members.

5.2.2 Unit of Analysis: Project

As noted earlier, there were twenty projects reported by the fifty respondents,

indicating that some projects had more than one respondent. In order to choose a single response for each project, the team leader was selected where the project team consisted of more than one respondent. If there was no project team leader in the sample of one belonging to each remaining specific project, then the team member was selected. The sample of respondents that were associated with the twenty projects consisted of nine respondents that belonged to Design and eleven respondents that belonged to Manufacturing.

Out of the twenty respondents, seven indicated that they were team leaders, ten mentioned that they were team members and two respondents mentioned that they were working level team members. Table 5.3 presents the classification of the roles of the respondents in the different projects. There was one missing value.

At the project level unit of analysis, only six respondents reported that they had experience in Design as well as in Manufacturing. Fourteen indicated that they were not exposed to both departments.

Five respondents indicated that they were provided training during the implementation of concurrent engineering in their work environment and five mentioned that they were provided training after the implementation of concurrent engineering (Table 5.4). There were ten missing cases that included respondents that received no training.

Provision was also made in the instrument for respondents to indicate which success measures were used by their respective project team. Responses fell into three categories: time, cost and quality. The variable mentioned most frequently was time. Eleven respondents mentioned time as opposed to six respondents and four respondents

Table 5.3
Unit of Analysis Project
Team Designation of Respondents

TEAM DESIGNATION	NUMBER OF RESPONDENTS
Team Leader	7
Team Member	10
Working Level Member	2
Did Not Disclose	1
Total	20

Table 5.4
Unit of Analysis Project
Time when Training Provided to Respondent

TIME WHEN TRAINING PROVIDED	NUMBER OF RESPONDENTS
Before Implementation of Concurrent Engineering	0
During Implementation of Concurrent Engineering	5
After Implementation of Concurrent Engineering	5
Did Not Disclose	10
Total	20

for quality and cost respectively. Two respondents mentioned that project success had not yet been evaluated and one respondent indicated his ignorance as to how project success was evaluated. There was one missing case.

The five measures of product development and manufacturing success were recoded and respondents were now associated with projects that fell into two categories for each of the five measures. Responses were coded on a seven point Likert-type scale with a high score of (1, 2, or 3) for each measure indicating successful projects while a low score (4, 5, 6, or 7) suggesting less-than-successful projects. The item that measured successful implementation of concurrent engineering was recoded in a similar manner, and respondents were classified into two categories, namely, those that belonged to projects where the implementation of the concurrent engineering approach was successful and where the implementation of the concurrent engineering approach was less-than-successful. See Table 5.5A for the distribution of the respondents across the different categories and Table 5.5B for a distribution of project success across the five firms included in the study (project success measured in terms of extent of successful implementation of the concurrent engineering approach within projects).

5.3 Reliability Tests of Independent and Dependent Variables

Skills and Knowledge Categories

In order to test the psychometric properties of the instrument, a test of reliability was performed and Cronbach alpha scores were used to measure the reliabilities of the different dependent variables. The reliability test is used to measure the extent to which

Table 5.5A**Categorization of Macro Measures of Project Success**

	Number of Respondents					
	Time	ECO	Quality	Mfg. Cost	Cost of Dev.	Extent of Successful Implement.
SUCCESSFUL	10	12	15	13	12	8
LESS-THAN-SUCCESSFUL	9	7	4	6	7	12
MISSING	1	1	1	1	1	0
TOTAL	20	20	20	20	20	20

Table 5.5B**Categorization of Project Success (Successful Implementation of the Concurrent Engineering Approach) Across Firms**

FIRM	NUMBER OF PROJECTS	
	SUCCESSFUL	LESS-THAN-SUCCESSFUL
A	2	4
B	0	1
C	1	1
D	3	5
E	2	1
TOTAL	8	12

a measuring procedure is consistent on repeated trials. As mentioned earlier, the inventory of skills and knowledge was categorized into three groups. Reliability tests were performed within each skill and knowledge category, for the skills and knowledge that are present as well as should be present. Cronbach alpha scores for all but one of the independent variable fell in the range of .75 to .9, well above the acceptable limit (see Table 5.6).

Satisfaction

The four measures of satisfaction were first recoded so that their scales would be reversed and be in conjunction with the other measures of project success. Reliability of the satisfaction scale was assessed using Cronbach alpha. The value .7967 was well above the traditional benchmark of 0.7. The mean of the four measures was computed to arrive at one measure of satisfaction (SATIS). Respondents were classified as satisfied and relatively dissatisfied. In order to achieve this classification, the median of 2.00 was used as the cut-off point which resulted in twenty three (51%) satisfied respondents and twenty two (49%) relatively dissatisfied respondents.

Product Development and Manufacturing Success

The same test was done to assess consistency in the measures of product development and manufacturing success indicated by the twenty respondents which provided a low Cronbach alpha score (see Table 5.6). This tendency towards inconsistency found in measures of the same phenomena restricted the grouping of the five measures under one common success variable and each measure was treated separately.

Table 5.6

Reliability Tests for Variables

VARIABLES	Cronbach α Score
Computer Support Initiatives Skill & Knowledge 'A' is present	.6009
Computer Support Initiatives Skill & Knowledge 'A' should be present	.7559
Formal Analytical Methods Skill & Knowledge 'B' is present	.7983
Formal Analytical Methods Skill & Knowledge 'B' should be present	.8320
Process Skill & Knowledge 'C' is present	.8641
Process Skill & Knowledge 'C' should be present	.8941
Satisfaction	.7967
Product Development and Manufacturing Success	.5452

5.4 Correlation Of The Measures of Success

Individual satisfaction which is at the micro level, and the six success measures at the macro level were found to be independent of each other. The Spearman Rank Order Correlation was calculated to investigate the degree of relationship between the seven measures of project success. No correlation was found to exist between the variable Satis (individual perceived satisfaction) and the other six measures of project success. This supports the theory discussed by Sanders (1984) that there is no guarantee that an increase in success at the micro level would also result in an increase in success at the macro level, and vice-versa. Also as seen in Table 5.7, successful implementation of concurrent engineering is found to be correlated with four of the five measures of product development and manufacturing success, namely, Engineering Change Order, Quality, Manufacturing Cost and Cost of Development.

On the other hand, it was found that time and successful implementation of concurrent engineering were not correlated. A possible reason for this is that the time measured in this study is only the time of development and not the overall time (time of development plus time of manufacturing ramp-up). The time taken during the initial phases of the product development life-cycle is usually longer than for the traditional sequential approach due to the extensive deliberations. As one goes down the product development life-cycle, the time taken to ramp-up production is presumably less than for the sequential approach as most of the manufacturing constraints and issues have been ironed out earlier on during the development phase. It is important to mention that each respondent was asked to indicate the success measures by comparing product development

Table 5.7

Spearman Correlation of Measures of Project Success

Items	Mean	Std. Dev.	Items Spearman Correlation Coefficients					
			Extent	Satis	Time	ECO	Quality	Mfg. Cost
Extent	2.51	.982						
Satis	2.180	.643	.2331					
Time	3.146	1.53	.1734	-.233				
ECO	3.404	1.455	.4296*	.096	.0239			
Quality	4.979	1.139	.3548*	.132	.0017	.4663**		
Mfg. Cost	3.196	1.108	.5847**	.1597	-.093	.3464*	.3494*	
Cost of Dev.	3.467	1.236	.3587*	-.003	.5341**	.1841	.2696	.2857

* SIGNIF .LE. .01

** SIGNIF .LE. .001

in the concurrent engineering approach to product development in the traditional approach. If the overall time (development time + ramp-up time) had been measured rather than the development time, probably, it would be regarded as less than the overall time taken in the traditional approach for projects where the implementation of concurrent engineering was considered a success, thereby depicting some positive correlation between the two variables. As this is regarded as one of the significant benefits of concurrent engineering, it would be interesting to observe whether there is an association between the overall time (time of development + ramp-up time) and extent of successful implementation of concurrent engineering.

5.5 Testing the Propositions

Since ordinal data was collected for the variables being studied, non parametric tests like the Wilcoxon-Mann-Whitney test, Wilcoxon Signed Rank test, Kendall Rank-Order Correlation test and the Kruskal Wallis test were used to test the propositions. In most cases the Wilcoxon-Mann-Whitney test is used as it is considered as one of the most powerful non-parametric tests used in the analysis of ordinal data and considered an alternative to the parametric t test used in parametric methods (Siegel and Castellan 1988). This test essentially investigates as to whether the two independent populations have been drawn from the same population. For the sake of this research, observed probability scores less than the level of significance of .05 were considered significant and led to a rejection of the null propositions.

Satisfied and Relatively Dissatisfied Respondents (#1, and #2)

In order to test if skills and knowledge in Design and Manufacturing personnel had an effect on micro project success (Propositions #1, and #2), Satisfaction was considered as the dependent variable. The Mann-Whitney test was employed and the probability scores were found to be higher than the previously set level of significance of $\alpha = .05$ (see Table 5.8) preventing the rejection of Proposition #1 and #2. Apparently the satisfaction of the respondents depends on other factors like perhaps the amount and kind of benefits they received rather than on the possession and transfer of content and process skills.

Extent of Successful Implementation of Concurrent Engineering Approach (#3 & #4)

The presence of skills and knowledge in Design personnel had no influence on the extent of successful implementation of concurrent engineering; and Proposition #3 could not be refuted as indicated in Table 5.9. However, Proposition #4 is refuted. Essentially it can be inferred that the skills and knowledge of manufacturing personnel that belong to teams where the implementation of concurrent engineering was successful differ from the skills and knowledge of manufacturing personnel that belong to teams where the implementation of concurrent engineering was less-than-successful. Manufacturing personnel that were part of successful project teams were more equipped with skills and knowledge in comparison to Manufacturing personnel that belonged to less-than-successful projects. A reasonable explanation for this inference is that in the case where the implementation is less-than-successful, sufficient emphasis was not placed

Table 5.8

Skills and Knowledge with Micro-Level Success Measure

Skill and Knowledge	Category: Are Present	Probability Scores
DESIGN	Computer Support Initiatives	.1160
	Formal Analytical Methods	.9632
	Process Skills and Knowledge	.9631
MANUFACTURING	Computer Support Initiatives	.3992
	Formal Analytical Methods	.3043
	Process Skills and Knowledge	.3273

* SIGNIF. LE. .05

Table 5.9
Skills and Knowledge with Macro-Level Success Measures

	Skill and Knowledge Category are present	EXT of Succ. Impl.	Time	ECO	Qual.	Mfg. Cost	Cost of Dev.
DESIGN	Computer Support Initiatives	.5480	.2396	.4972	.6567	.8831	.2396
	Formal Analytical Methods	.4623	.7715	.5024	.8262	1.000	.8845
	Process Skills & Knowledge	1.000	.3836	.8668	.6606	.2454	.7715
MANUFACTURING	Computer Support Initiatives	.0309*	.5970	.0445*	.2044	.2903	.7293
	Formal Analytical Methods	.0183*	.9163	.0356*	.0855	.1890	.6465
	Process Skills and Knowledge	.0416*	.2933	.0157*	.0855	.0356*	.5664

* SIGNIF .LE. .05

in the early involvement of manufacturing in the development of a product. Consequently, one can speculate that these same personnel were not given adequate training in the skills and knowledge that would typically be present in manufacturing personnel that belonged to teams where the implementation of concurrent engineering was successful.

Successful and less-than-successful projects in terms of product development and manufacturing success (#5 and #6)

In comparing projects where product development and manufacturing was successful and less-than-successful, the five measures of success were investigated separately and the Mann-Whitney test generated significance scores for each of the five measures. The researcher found no difference in the skills and knowledge present in design personnel that belonged to successful and less-than-successful projects for the five measures of project success (Proposition #5). However, the same was not observed with Manufacturing. When investigating project success in terms of reduction in engineering change orders, the probability scores for each of the three skill categories present in Manufacturing was less than the significance level of .05, thereby, rejecting Proposition #6. On further investigating the presence of the specific skills inherent in manufacturing personnel, the researcher observed that the presence of the skills and knowledge included in the three categories, namely, computer support initiative skills, formal analytical skills and process skills were greater in manufacturing personnel that belonged to successful teams than in manufacturing personnel that belonged to less-than-successful teams. When

investigating project success in terms of reduction of manufacturing costs, a small probability score for process skills and knowledge was observed. Further investigation of the specific process skills and knowledge indicated that successful team personnel were more equipped with communication skills, conflict resolution and problem solving skills, empathetic problem solving skills, anticipatory skills and team building skills.

Skills & Knowledge are present versus Skills & Knowledge that should be present (#7 and #8)

In order to test Proposition #7 and #8, the Wilcoxon Matched-Pairs Signed-Rank test was employed. As can be seen from Table 5.10, the probability scores for all the tests are smaller than the significance level of $\alpha = .05$ resulting in a rejection of the two propositions. This result suggests that the skills and knowledge that are present differ significantly from the perceived skills and knowledge that should be present in design and manufacturing personnel. Also as observed in the mean values in Table 5.11, it can be deduced that the skills and knowledge that are present are considerably less than the skills and knowledge that should be present as perceived by the respondents. The respondents felt that they needed to further develop the skills and knowledge they possessed in order to maximize their contribution to their respective project teams. Only three respondents were provided training before the implementation of concurrent engineering and therefore had the opportunity to develop the new skills and knowledge that were required of them. On the other hand, a majority of the respondents (nineteen) were provided training during the implementation of concurrent engineering and twelve were provided training after the

Table 5.10**Skills and Knowledge - Are Present and Should Be Present****Wilcoxon Matched Pairs**

DEPARTMENT	COMPUTER SUPPORT INITIATIVES	FORMAL ANALYTICAL METHODS	PROCESS SKILL. AND KNOWLEDGE
	A	B	C
Design	.000*	.000*	.000*
Manufacturing	.0002*	.0002*	.0001*

* SIGNIF .LE. .05

Table 5.11**Mean Values of Skills and Knowledge**

SKILLS & KNOWLEDGE	DESIGN		MANUFACTURING	
	Are	Should	Are	Should
Computer Support Initiatives	1.417	2.030	1.174	1.663
Formal Analytical Methods	1.698	2.159	1.385	1.745
Process Skills and Knowledge	1.876	2.390	1.575	1.880

implementation of concurrent engineering within their project environments. Consequently, these respondents were probably not able to fully develop their technical and process skills causing a contrast in the skills and knowledge they possessed and felt they should possess.

Skills and Knowledge that are present - A Comparison of Perceptions of Design and Manufacturing (#9 & #10)

In order to test Proposition #9 and #10, the Mann-Whitney test was employed. When examining whether there was any difference in the presence of skills and knowledge in Design, as indicated by design personnel, and as perceived by Manufacturing, probability scores of .0064 and .0474 were observed when investigating the presence of skills in computer support initiatives and formal analytical methods respectively. As can be seen from the mean ranks reported in Table 5.12, manufacturing personnel perceived that designers were more equipped with skills and knowledge in the two categories than what the designers actually reported were present in personnel belonging to their department within their concurrent engineering project environment. When examining whether there was any difference in the presence of skills and knowledge in Manufacturing, as indicated by manufacturing personnel, and as perceived by design personnel, a probability score less than the significance level was observed when investigating the presence of computer support initiative skills and process skills (probability scores of .0205 and .0096 respectively). When design personnel were asked to indicate their perceptions of the skills and knowledge present in Manufacturing, the

Table 5.12

**Difference in Skills and Knowledge Taking Into
Account Perceptions of Design and Manufacturing**

	SKILL & KNOWLEDGE ARE PRESENT	PERCEPTION OF (Mean Rank)		PROBABILITY SCORES
		DESIGN	MFG.	
DESIGN	Computer Support Initiatives	18.88	29.79	.0064*
	Formal Analytical Methods	19.98	27.97	.0474*
	Process Skills & Knowledge	22.04	24.59	.5263
MANUFACTURING	Computer Support Initiatives	19.50	28.76	.0205*
	Formal Analytical Methods	20.34	27.38	.0807
	Process Skills and Knowledge	19.05	29.50	.0096*

* SIGNIF .LE. .05

mean ranks computed were less than the mean ranks when manufacturing personnel indicated the skills and knowledge existing in Manufacturing. This demonstrates that either manufacturing personnel are possibly over-estimating the skills and knowledge they possess or that design personnel are not altogether aware of the skills and knowledge prevalent in Manufacturing. A reason for this could be the fact that Manufacturing is not effectively involved in the early stages of the development cycle, thus, resulting in an unawareness in the Design department of the skills and knowledge inherent in Manufacturing. This depicts a lack of communication skills between the two departments, late involvement of Manufacturing and a lack of interactive working and sharing of knowledge between the two departments.

Cross-functional Experience and Project Success (#11)

The Mann-Whitney test was adopted to investigate the effect of parallel departmental experience on the measures of project success. The researcher performed the test for personnel belonging to Design and then for personnel belonging to Manufacturing. At the macro level, the measures of project success were tested using the project as the unit of analysis. Probability scores were observed to be higher than $\alpha = .05$ for each of the tests involving the measures of project success when the test was performed for personnel currently employed in Manufacturing (see Table 5.13). When the test was carried out involving personnel currently employed in Design, parallel departmental experience was found to affect project success. This was the case when project success was measured in terms of engineering change orders and Quality (see

Table 5.13). At the micro level, parallel departmental experience was found to have no effect on satisfaction of design and manufacturing respondents.

Timing of Training and Project Success (#12)

The Mann-Whitney test was used to investigate Proposition #12, and probability scores above the preset significance level of $\alpha = .05$ were observed for all but one of the tests. Since multiple statistical tests are being conducted (seven tests in all), the significance level must be adjusted to account for the inflated experiment wise type 1 error rate resulting from a type 1 error rate of .05 for each of the tests. However, for the sake of this research, a liberal significance level of .05 has been used to test Proposition #12. Timing of training was found to influence project success when measured in terms of development time (probability .0413). At the micro level, the time of training did not have any overbearing effect on satisfaction as can be seen from the high probability scores in Table 5.14.

5.6 The Suitability of Training Techniques

Vaught, Hoy and Buchanan (1985) stated that the method of training was not likely to have any overbearing effect on the attitude change or extent of satisfaction in a person. In order to investigate how responds rate the suitability of different training techniques, the Kendall Rank-Order Correlation Coefficient Test was employed. The same test was used to calculate the mean ranks for each training technique over all the cases. A low probability score was observed which helps refute the null proposition

Table 5.13**Cross-Functional Experience and Project Success**

ITEMS	PARALLEL EXPERIENCE	Probability Scores
	DESIGN	MANUFACTURING
Satis	.6577	.4963
Extent	.2386	.808
Time	.7518	.807
ECO	.0336*	.8023
Quality	.0398*	.9004
Manufacturing Cost	.3688	.1370
Cost of Development	.2155	.3013

* SIGNIF .LE. .05

(Note: For Satis the unit of analysis is the respondent. For Extent, Time, ECO, Quality, Manufacturing Cost and Cost of Development the unit of analysis is the project.)

Table 5.14
Effect of Timing of Training on Measures of Project Success

ITEMS	TIMING OF TRAINING Probability Scores
Satis	.6966
Extent	.2328
Time	.0413*
ECO	.8266
Quality	.1659
Manufacturing Cost	.3290
Cost of Development	.9107

* SIGNIF .LE. .05

which stated that there is no difference in the suitability of the different training techniques as perceived by Design and Manufacturing personnel. In ranking the suitability of the nine training techniques, it was evident that the respondents were more in favour of training techniques that encouraged bilateral communication between the trainee and the trainer (for eg. apprentice training, job rotation and job instruction), than those techniques that focused on a unilateral mode of training (for eg. the lecture and audiovisual techniques). Table 5.15 indicates the ranking of the suitability of the nine training techniques.

Table 5.15
Ranking of Suitability of Training Techniques

TRAINING TECHNIQUE	RANK*	MEAN RANK
Apprenticeship Training	1	6.0
Job Instruction Training	2	5.98
Job Rotation	3	5.76
Case Study	3	5.67
Conference Discussion	5	5.55
Performance Appraisal	6	5.05
Audiovisual	7	4.6
Lecture Technique	8	3.93
Role Playing	9	2.48

* Ranking of suitability of the training techniques as perceived by the respondents.

2 of / de 2

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

6.0 CONCLUSIONS AND FUTURE RESEARCH IMPLICATIONS

This research confirmed that there is a need for design and manufacturing personnel to further develop the skills and knowledge they possess in order to work effectively in concurrent engineering teams. The skills and knowledge included in the three categories were checked for individually and the researcher found that in all the cases, the respondents indicated that they needed to further develop their skills and knowledge. The questionnaires showed that although the respondents possessed the skills and knowledge, there was an overwhelming need to further enhance the level of the same skills and knowledge, implying a greater need for training in the same. Present engineering undergraduate and graduate programs should stretch their curricula to include such areas like change management and teamwork so that engineers are more equipped with skills and knowledge that will help them contribute more efficiently in a concurrent engineering environment. As is evident from this study, firms are realizing that they lack engineers and managers that are able to constructively work in a multi-functional environment. Lake (1992) discusses some recommendations as to how engineering programs need to be altered to include a graduate degree in manufacturing engineering that will provide engineering graduates with the necessary skills and knowledge required to work efficiently following the principles of concurrent engineering. Companies on the other hand should play an active part in helping develop engineering programs in universities. Present academic programs should first be evaluated with the help of a needs analysis of the present engineering community. Engineering programs should then be modified to effectively reflect the engineering community. An industrial advisory

board comprising of manufacturing firms should be given the authority to play an important role in university curriculum design. This will help encourage the philosophy of concurrent engineering, and industry will be provided with graduates who have had some form of formal training in process as well as content skills before they join a firm. As for individuals who are already part of a workforce, they should be provided with training before the implementation of the concurrent engineering approach within their project. This way they will be knowledgeable at all times during the new product development process to what is expected of them in terms of skills, knowledge and competencies.

A valuable contribution that is rendered from this study is the researcher's attempts to develop dependent variables that will offer greater insights into understanding the effect of implementation of concurrent engineering in project teams. Researchers suggest that cycle time should be considered as the important metric to assess concurrent engineering rather than cost and quality, as it can be used to drive improvements in both (Stalk and Hout 1991). However, in this research, five performance criteria at the macro level were used that included performance measures that have been regarded as being benefits of concurrent engineering (Carter and Baker 1992). Time of development was positively correlated with cost of development, while on the other hand, reduction in the number of change orders was positively related to improvement in quality and decrease in manufacturing costs. The successful implementation of the concurrent engineering approach as perceived by the respondents, was positively correlated with all the measures of success at the macro level except time of development. Time was addressed as

development time in this study. If overall time or innovation cycle time was considered rather than just time of development, one could speculate that there would have been some positive correlation between the two measures, namely overall time and extent of successful implementation of concurrent engineering.

Satisfaction of the design and manufacturing personnel do not solely depend on the skill and knowledge sets of personnel. The purpose of this study was to investigate only one aspect of user satisfaction, which in this case relate to personal benefits. In order to study the issue of project success at the micro level in greater detail, if additional criteria other than skills and knowledge are investigated, it would provide a stronger base in order to gain insights and learn as to which criteria should be considered important in order to ensure that team members remain satisfied in their respective work environments. Some criteria the researcher proposes that should be investigated are lower level needs such as job security and economic benefits.

Comparison of projects that were successful and less-than-successful in terms of implementation of the concurrent engineering approach revealed that, in the case of Manufacturing, there was a difference between the skills and knowledge present in manufacturing personnel. The issue of early involvement of Manufacturing is of considerable importance in discussing this phenomena and it would be prudent to mention its effect. The extent of early manufacturing involvement could not be measured in this study and needs to be employed in future research with the help of an exhaustive concurrent engineering audit. One can speculate that in cases where the implementation of the concurrent engineering approach was successful, the early involvement of

Manufacturing was greater than in cases where implementation was regarded as being less-than-successful. The observed difference in the skill sets could possibly be due to the fact that the personnel belonging to the successful teams may have been more equipped with additional skills and knowledge due to their earlier involvement in the development process.

When considering project success in terms of reduction of Engineering Change Orders and Manufacturing Costs, the presence of skills and knowledge in Manufacturing did have an influence on project success. When investigating the effect of skills and knowledge on reduction in Engineering Change Orders, manufacturing personnel belonging to successful projects turned out to be better equipped with the three computer support initiative skills and all the process skills as compared to manufacturing personnel that were part of less-than-successful projects. This inference brings into light a very important issue. Presence of computer support initiative skills and process skills influence project success and should be emphasized in project environments. This finding also supports the literature that if firms emphasize the importance of equipping their personnel with skills and knowledge included in the generic elements of concurrent engineering, namely computer support initiatives, formal analytical methods and process skills, they will be able to reap the rewards concurrent engineering has to offer. However, there was no difference in the skills and knowledge of design and manufacturing personnel that belonged to projects that were successful and less-than-successful when considering product development and manufacturing success in terms of time of development, improvement in quality, and cost of development.

In order to further understand and stress the importance of teams that possessed personnel that had some cross-training, the researcher observed that cross-training/parallel department experience in design personnel had an effect on project success. This indicated that designers, who had prior experience in Manufacturing, were associated with projects that were successful. In comparison, design personnel who had no prior experience in manufacturing were associated with less-than-successful projects. However, for manufacturing personnel, prior experience in design did not have an effect on project success. It would be prudent to mention that the research only investigated the experience a team member had with Design and Manufacturing and not with other subdisciplines like Finance and Marketing. It would be beneficial as well as interesting to investigate if the same results are observed if experience in sub-disciplines other than the two discussed in the research are considered. Also, it may provide some useful findings to training program developers who are specifically interested in the development of an inventory of skills and knowledge that could be included in on-the-job training and other training programs.

Before going on to further pursue the implications of this study, it is important to note its limitations. First, due to the non-random sample, the results that have been drawn from this study have limited generalizability. Second, one should be cautioned that individual perceptions of project success are not the best indicators for evaluation (Larson and Gobeli 1989). The results that are documented in this research should be considered exploratory and further amplified using objective indicators of project performance. Projects which meet or exceed the sales, profit and strategic goals set forth could be used

to differentiate a successful project from a less-than-successful project. Nevertheless, the results do provide some benefits to the five firms that participated in this research. Also, the same framework could be used in studying the same research questions investigated on a larger scale i.e. with a larger sample. Further, the exploratory nature of this study and the nature of the data limit the conclusions that can be inferred from the data analyses. It would be prudent to mention that due to a small sample size, the researcher was unable to control for certain variables that could have emerged as a function of the independent variable thereby helping the explanation of the influence of the independent variable on the dependent variables. One of the control variables that could be used is the phase of implementation of concurrent engineering. Nonetheless, potential research ideas have emerged which may offer valuable contribution to this area of research.

The method of categorization of skills and knowledge may not be the best indicator of project success. Research involving other methods of skill and knowledge categorization adopting the same research framework and methodology would surely offer invaluable contribution to the literature on concurrent engineering.

Timing of training was found to influence project success when measured in terms of time of development. Time of development measures success upstream in the product development and manufacture process and therefore timing of training was found to influence project performance in the early stages of development. One can speculate that personnel who were trained before or during the implementation of concurrent engineering were better equipped with skills and knowledge consequently resulting in better project performance in terms of time of development, as compared to personnel that

were provided training after the implementation of concurrent engineering. Personnel who received training after the implementation of concurrent engineering, may not have possessed the requisite skills required of them to perform successfully. This throws light on the importance of training in the early stages of the product development process. An important aspect in the acceptance of a new project by potential team members is the transfer of additional skills and knowledge to the concerned members through pertinent training development programs. These same programs must be carefully planned and employed and should be provided to the team participants well before the project goes underway. Most often, project training is reactive rather than proactive. This sometimes results in a last minute effort to salvage a project by trying to remedy certain problem situations by providing training to the selected team members to perform their function effectively. It has been reported that quite often projects have failed due to improper training programs (Frankel 1990).

On the other hand, timing of training did not affect project success when success was measured with the other six macro measures. Therefore, the researcher recommends this issue be given more importance. Quality of training could also be used along with the timing of training in order to answer the question of the influence of timing of training on project success. To a certain extent, the researcher found that communication between Design and Manufacturing did suffer from obstacles as was evident while investigating the perceptions of the skills and knowledge prevalent in the two departments. Ginn and Rubenstein (1986) state that fundamental differences in goal orientations hinder close cooperation between Design and Manufacturing. Traditional

functionally-dominated structures lead to an environment where designers and manufacturing engineers both believe themselves to be more superior than the other department. This difference in cultural settings and lack of interactive working results in either department underestimating or overestimating the capabilities and expertise of their parallel department. In this study, we observed that Design underestimated the skills and knowledge prevalent in Manufacturing. One could also conjecture that Manufacturing may have overestimated the skills and knowledge they actually possessed. At the same time, the researcher observed that Manufacturing overestimated the computer support initiatives as well as process skills and knowledge capability of Design. This lack of mutual understanding of the capabilities of the two departments is an important obstacle that can be eliminated through the use of a broad organizational goal rather than the use of localized functional goals.

Training can be provided through in-plant class training, on-the-job training or external sources. As mentioned by one of the managers at the preliminary meetings, training can be provided by either outside consultants or by supervisors and in-house training coordinators through a company wide internal program. Training and development programs should be designed in such a way that apart from providing sound training techniques, they should also include aspects of member welfare like job performance reward packages, job security and quality of life. A basic element of concurrent engineering, which is bilateral communication, is reflected in the way in which the respondents indicated the suitability of the nine techniques included in this study. Firms should place more emphasis on techniques like job rotation and job instruction

training which encourage interactive communication between the trainee and trainer.

The concept of early involvement of Manufacturing in the development process has not been incorporated on a comprehensive basis in the five firms and this calls for a greater emphasis on the integration of the two departments with the help of concrete training programs. A more indepth analysis is proposed by the researcher, in order to understand the philosophy of working within each of the five firms. Skill assessments should be carried out to first identify those respondents that need to undergo training in order to develop on their process as well as content skills. This should be done before the implementation of concurrent engineering so that people are aware of the doctrines of the new organizational philosophy before they get totally involved. The questionnaire that has been developed for this research can be modified to offer a more exhaustive inventory of relevant skills and knowledge. The same research methodology can then be employed in order to investigate the presence or absence of certain skills as well as to indicate the perception of the respondents and to relate the presence of skills to project success. The additional performance criteria mentioned earlier should be included in order to provide a more indepth analysis.

The findings of the study suggest several other streams of potential research. Some of the more significant questions are:

- 1) What kinds of training techniques are best suited to impart each of the different skill and knowledge categories to team participants?**

It would be particularly beneficial to training and development specialists if they

were provided some kind of guidance in the form of empirical research as to which training techniques are suitable for imparting the different categories of skills and knowledge mentioned. Also, if satisfaction of the respondents who underwent training could be measured, it may be interesting to learn if there is a direct link between training received and respondent satisfaction.

2) How does the skill base get augmented during the different phases of implementation of concurrent engineering?

This study has a limitation in that it did not take into account the different phases of implementation of concurrent engineering. Since concurrent engineering is a continuous improvement process, skills and knowledge of team personnel need to be continuously upgraded as newer technologies and DFM technologies are introduced in organizations. Case studies of ideal concurrent engineering projects that have faced similar issues would provide training and development specialists a useful benchmarking tool on how projects should look after skill and knowledge enhancements of team members at the different stages of implementation of concurrent engineering.

3) What are the dependent variables that can be developed in order to gain further insights on skills and training of team members that belong to concurrent engineering teams?

The researcher looked at only seven performance criteria. Some additional measures that the researcher suggests for future research are: overall time (development

+ ramp-up time), conflict resolution, worker involvement in concurrent teams, profitability, adaptation to change, and market performance. Concurrent engineering has a direct effort on market performance. As new product concepts emerge, the concurrent engineering team can place all its efforts on focusing on the intended function and performance aspects of a product (e.g. function of new product) rather than spend time and resources in the development of design and tooling components that are already standardized for manufacturability (e.g. tooling components like gears etc. can be standardized for manufacturability and be used in future product development ventures). These same products can be effectively phased out after exploiting the market.

4) How do the inventory of skills and knowledge present in Design differ from the skills and knowledge present in Manufacturing?

If the above issue is investigated, it will provide added useful information to project management specialists on the skill gaps present in Design and Manufacturing personnel. It will also provide information on the expertise present in either department that could be capitalized upon in the design and manufacture of a product.

Lastly, I would like to reiterate that concurrent engineering is an important organizational team philosophy that requires project members to understand and be knowledgeable of the basics of the product development process. In order to stay competitive, firms have to stress the importance of making good up-front decisions so that these decisions do not have a detrimental effect downstream in the product development cycle. In order to do this, each team member should be encouraged to cherish multiple

viewpoints. This can be achieved only if team members are trained to possess multidisciplinary skills and knowledge. As one team manager indicated, "Ideally, design and manufacturing personnel should have either the knowledge or the skills to perform activities that are performed by both the departments. This would enhance the integration of the two departments resulting in less time spent in either department trying to explain their tasks."

Integration of Design with Manufacturing evidently does need more emphasis within firms included in this study. The lack of understanding of the skills and knowledge present in design and manufacturing personnel show the presence of a lack of communication between the two departments. Communication is a must if firms want to reap the benefits of concurrent engineering. Manufacturing personnel should further strengthen their presence by playing a more decisive role in the development process. Also, Early involvement of manufacturing should primarily be the responsibility of the manufacturing department (Gerwin 1993). As was evident in the results, manufacturing personnel have to establish their credibility by enhancing their skills and knowledge in order to successfully contribute to their respective teams.

Also, the research was able to empirically state that there was a need to further enhance the skill level of design and manufacturing personnel that belonged to the five firms that participated in this study. This throws light on the importance of training of the same individuals in new techniques and tasks included in project teams. With the help of bilateral-feedback training mechanisms, team members should be educated in skills and knowledge common to both departments. The result should be a team,

equipped with personnel that possess a wide variety of skills and knowledge, that is in a continuous state of improvement keeping in pace with the latest techniques, activities and skills present in the manufacturing environment. Simultaneously, or rather concurrently, concurrent engineering propagators should keep in mind that this organizational philosophy is a 'people' issue first before becoming a technology issue.

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APPENDIX A
Skills, Knowledge and Training Questionnaire

Carleton University

Ottawa, Canada K1S 5B6

Welcome to the "Concurrent Engineering : Skills, Knowledge and Training " study.

Please answer all the questions in the questionnaire. If you have any doubts with regard to a particular question you can direct them to the interviewer. Remember there are no right or wrong answers.

Also note that annonymity and confidentiality of the respondent will be respected.

Thank you for your time and consideration.

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A) This section of the questionnaire asks you general questions regarding the Concurrent Engineering environment you worked within, in the development of a new product. For each of the following questions, please circle your appropriate response. Remember there are no right or wrong answers. For the sake of this research, you are requested to **select a project** from most recent projects that have been carried out by the firm within a Concurrent Engineering environment. Also, you are requested to consider projects which involved the development of a new product and not one that involved an incremental innovation of a previous product.

0. Please give the name of this project.

1. To which functional department do you belong? (CIRCLE NUMBER)

1 DESIGN

2 MANUFACTURING

Sub discipline _____

2. What is your designation? (CIRCLE NUMBER)

1 TEAM LEADER

2 TEAM MEMBER

3 WORKING LEVEL TEAM MEMBER (IF A HIERARCHY OF
TEAMS EXISTS)

3. How many years have you been in this present position with this department?

4. Have you ever worked in the parallel¹ department? (CIRCLE NUMBER)

1 YES

2 NO

If yes, how many years did you spend there?

¹ For example if you are in Manufacturing, the parallel area is Design.

Please answer the following questions to the best of your ability. If you do not know the answer, circle "DONT KNOW". If you feel the answer is sometimes yes and sometimes no, circle the answer that is true more than 50% of the time.

5.	a.	DESIGN AND MANUFACTURING ENGINEERS
WORKED SIMULTANEOUSLY IN THE DESIGN
PHASE OF NEW PRODUCT DEVELOPMENT.	Y	N	DONT KNOW
	b.	ACTIVITIES THAT WERE TRADITIONALLY
PERFORMED DOWNSTREAM IN THE DEVELOPMENT
PROCESS WERE BROUGHT FORWARD AND
CARRIED OUT UPSTREAM.	Y	N	DONT KNOW
	c.	A CROSS-FUNCTIONAL TEAM WAS
FORMULATED THAT INCLUDED REPRESENT-
-ITIVES FROM DESIGN, MANUFACTURING
AS WELL AS PERSONNEL BELONGING TO
OTHER FUNCTIONAL DEPARTMENTS.	Y	N	DONT KNOW

(IF YES) Who was on this team? Please indicate only titles and not names.

6. Circle the choice that best describes how the team leader was selected.

- 1 NATURAL EMERGENCE OF MOST
KNOWLEDGEABLE TEAM MEMBERS
AT THE DIFFERENT PHASES OF
THE PROGRAM.
- 2 PERMANENT TEAM LEADERS WERE APPOINTED
BY THE MANAGEMENT.
- 3 OTHER--PLEASE SPECIFY.

7.a How was project success evaluated?

7.b In your opinion, how successful has the implementation of Concurrent Engineering been?
(CIRCLE NUMBER)

VERY SUCCESSFUL		NEITHER SUCCESSFUL NOR UNSUCCESSFUL		VERY UNSUCCESSFUL
1	2	3	4	5

7.c For each of the following factors, please compare product development in the Concurrent Engineering environment to the traditional environment (CIRCLE NUMBER).

Under Concurrent Engineering.....

	DECREASED GREATLY					INCREASED GREATLY
.....The time taken in the development of a new product.....	1	2	3	4	5	6 7

	DECREASED GREATLY					INCREASED GREATLY
.....The number of engineering change orders (ECO) has.....	1	2	3	4	5	6 7

	DECREASED GREATLY					INCREASED GREATLY
.....The overall quality of the product has.....	1	2	3	4	5	6 7

	DECREASED GREATLY					INCREASED GREATLY
.....The manufacturing costs have.....	1	2	3	4	5	6 7

	DECREASED GREATLY					INCREASED GREATLY
.....The cost of development has.....	1	2	3	4	5	6 7

7.d The following statements express opinions that some people may have about Concurrent Engineering. For each of the following items please indicate the extent to which you agree or disagree with the opinion being expressed. (CIRCLE NUMBER).

1. I personally benefitted from the Concurrent Engineering philosophy of working.	STRONGLY DISAGREE 1	2	NEUTRAL 3	4	STRONGLY AGREE 5
2. I have become more valuable in the organization after the initiation of Concurrent Engineering.	STRONGLY DISAGREE 1	2	NEUTRAL 3	4	STRONGLY AGREE 5
3. I have come to rely on the overall Concurrent Engineering environment of working to maximize my contribution.	STRONGLY DISAGREE 1	2	NEUTRAL 3	4	STRONGLY AGREE 5
4. All in all I think Concurrent Engineering is an important organizational philosophy for this organization.	STRONGLY DISAGREE 1	2	NEUTRAL 3	4	STRONGLY AGREE 5

8. a In your opinion, how suitable is each of the following training techniques for imparting the typical skills you believe are required to work in a Concurrent Engineering scenario? (CIRCLE NUMBER). Any questions concerning the meaning of the different techniques should be directed to the interviewer.

	VERY UNSUITABLE			VERY SUITABLE		DONT KNOW
<u>In-plant classes on technical topics:</u>						
The lecture technique.....	1	2	3	4	5	DK
Audiovisual technique.....	1	2	3	4	5	DK
Case study technique.....	1	2	3	4	5	DK
Conference discussion technique.....	1	2	3	4	5	DK
<u>On-the-job training programs:</u>						
Job rotation.....	1	2	3	4	5	DK
Job instruction training.....	1	2	3	4	5	DK
Performance appraisal.....	1	2	3	4	5	DK
Apprentice training.....	1	2	3	4	5	DK

Role Playing..... 1 2 3 4 5 DK

8.b Please indicate the extent to which you agree or disagree with the following statements. (CIRCLE NUMBER)

	STRONGLY DISAGREE				STRONGLY AGREE
	1	2	3	4	5

1. Adequate training was provided for all individuals on the tools, procedures and standards he/she should use.

	STRONGLY AGREE				STRONGLY DISAGREE
	1	2	3	4	5

2. Team members have adequate cross-discipline awareness of procedures, tools etc., used by other departmental members.

8. c Are there any team effectiveness training² techniques that include the involvement of customers and third party vendors? (CIRCLE NUMBER).

1 YES

2 NO

If YES, what were the techniques of training employed?

8. d What training did you personally receive after Concurrent Engineering was implemented and how do you rate its effect on your performance and its use in practice? (CIRCLE APPROPRIATE NUMBER).

<u>Training Program</u>	<u>No Bad Effect</u>	<u>Beneficial</u>	<u>Very Beneficial</u>
1 _____	1	2	3
2 _____	1	2	3
3 _____	1	2	3
4 _____	1	2	3

² Effectiveness training includes issues concerning problem solving, goal setting, creative thinking and cross-discipline awareness.

8. e When was training provided to the team members? (CIRCLE NUMBER)

- 1 BEFORE IMPLEMENTATION OF CONCURRENT ENGINEERING
- 2 DURING IMPLEMENTATION OF CONCURRENT ENGINEERING
- 3 AFTER IMPLEMENTATION OF CONCURRENT ENGINEERING

8. f Please indicate as to who provides the training.

8. g What training, if any, would make you more effective now?

8. h What training do personnel belonging to the parallel department need?

B)

This part of the questionnaire contains a listing of skills and knowledge considered important to facilitate the integration of Design and Manufacturing personnel and perform activities that are inherent to Concurrent Engineering teams. Skills and knowledge that should be present as well as those that are present in the concerned individuals are requested for in this section.

For each of the following skills and knowledge please rate:

A ::: Your area's representative

B ::: Parallel area's representative

C ::: Team leaders

Rate each of the respective skills and knowledge as being:

Very					Very
Low					High
1	2	3	4	5	

CONTENT SKILLS AND KNOWLEDGE

<u>Computer Support Initiatives</u>	<u>SKILLS AND KNOWLEDGE THAT</u>											
	<u>Are present</u>					<u>Should be present</u>						
		VERY LOW				VERY HIGH		VERY LOW		VERY HIGH		
Defining extent of information required for databases.	Your rep	1	2	3	4	5		1	2	3	4	5
	Parallel rep	1	2	3	4	5		1	2	3	4	5
	Team Leader	1	2	3	4	5		1	2	3	4	5
Presenting engineering environment network that helps in integration of databases, software tools and platforms.	Your rep	1	2	3	4	5		1	2	3	4	5
	Parallel rep	1	2	3	4	5		1	2	3	4	5
	Team Leader	1	2	3	4	5		1	2	3	4	5
Using expert system tools that help managers predict reliability, manufacturing costs and manufacturability	Your rep	1	2	3	4	5		1	2	3	4	5
	Parallel rep	1	2	3	4	5		1	2	3	4	5
	Team Leader	1	2	3	4	5		1	2	3	4	5
Interpretation of needs of the user into technical information throughout the design process (QFD).	Your rep	1	2	3	4	5		1	2	3	4	5
	Parallel rep	1	2	3	4	5		1	2	3	4	5
	Team Leader	1	2	3	4	5		1	2	3	4	5

Other:Content skills**SKILLS AND KNOWLEDGE THAT****Are present****Should be present**VERY
LOWVERY
HIGHVERY
LOWVERY
HIGH

Statistical monitoring and controlling techniques to get desired quality of product eg. use of control charts.

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

Assembly scheduling--Establishing priorities and time sequences for assembly work.

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

Breaking down of products and processes into modules which can be controlled individually.

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

Identifying designs of a part or sub-component that can be used in the development of another product.

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

Working in an environment that includes the use of CAD/CAM integration.

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

Selecting appropriate materials that will help increase the ease of manufacture and/or decrease the cost of manufacture.

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

Understanding the function of products in relation to the available production methods

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

Tracing design decision making processes, rationale, assumptions, interdependency of previous designs

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

Distribution and delivery methods used once the design is ready for the customer.

Your rep 1 2 3 4 5
Parallel rep 1 2 3 4 5
Team Leader 1 2 3 4 5

1 2 3 4 5
1 2 3 4 5
1 2 3 4 5

SKILLS AND KNOWLEDGE THAT **Are present**

Should be present

		VERY LOW					VERY HIGH					VERY LOW					VERY HIGH				
Building relationships with suppliers of raw materials and sub-components.	Your rep	1	2	3	4	5						1	2	3	4	5					
	Parallel rep	1	2	3	4	5						1	2	3	4	5					
	Team Leader	1	2	3	4	5						1	2	3	4	5					

PROCESS SKILLS **& KNOWLEDGE:**

Communication:

Encouraging communication between team members that include personnel from different departments.

Your rep	1	2	3	4	5						1	2	3	4	5
Parallel rep	1	2	3	4	5						1	2	3	4	5
Team Leader	1	2	3	4	5						1	2	3	4	5

Setting and communicating goals for action.

Your rep	1	2	3	4	5						1	2	3	4	5
Parallel rep	1	2	3	4	5						1	2	3	4	5
Team Leader	1	2	3	4	5						1	2	3	4	5

Building up a favourable image for product development activities (e.g., high priority)

Your rep	1	2	3	4	5						1	2	3	4	5
Parallel rep	1	2	3	4	5						1	2	3	4	5
Team Leader	1	2	3	4	5						1	2	3	4	5

Problem Solving and **Conflict Resolution:**

Identifying common as well as contrasting points of view of personnel included in teams.

Your rep	1	2	3	4	5						1	2	3	4	5
Parallel rep	1	2	3	4	5						1	2	3	4	5
Team Leader	1	2	3	4	5						1	2	3	4	5

Bringing into open the topic of disagreement.

Your rep	1	2	3	4	5						1	2	3	4	5
Parallel rep	1	2	3	4	5						1	2	3	4	5
Team Leader	1	2	3	4	5						1	2	3	4	5

Listening to what the team members have to say.

Your rep	1	2	3	4	5						1	2	3	4	5
Parallel rep	1	2	3	4	5						1	2	3	4	5
Team Leader	1	2	3	4	5						1	2	3	4	5

Empathetic **Problem-solving**

Enabling concerned personnel to understand how another person, belonging to the other departments, feels and reacts to certain problem situations.

Your rep	1	2	3	4	5						1	2	3	4	5
Parallel rep	1	2	3	4	5						1	2	3	4	5
Team Leader	1	2	3	4	5						1	2	3	4	5

Other: Process Skills

Anticipating problems in design and production.

Encouraging the involvement of all team personnel.

Staffing of new product development teams

Planning of layout of teams within the organization to address needs of organizational design, groupings of related functional departments and structuring of command and control.

Capital budgeting to address needs of organizational design, groupings of related functional departments and structuring of command and control.

Setting and communicating plan of action e.g. Use of PERT, CPM.

SKILLS AND KNOWLEDGE THAT

Are present

VERY
LOW

VERY
HIGH

Should be present

VERY
LOW

VERY
HIGH

Your rep

Parallel rep

Team Leader

Your rep

Parallel rep

Team Leader

Your rep

Parallel rep

Team Leader

Your rep

Parallel rep

Team Leader

Your rep

Parallel rep

Team Leader

Your rep

Parallel rep

Team Leader

1 2 3 4 5

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APPENDIX B

Measures of Satisfaction

1. I personally benefitted from the Concurrent Engineering philosophy of working.
 2. I have become more valuable in the organization after the initiation of Concurrent Engineering.
 3. I have come to rely on the overall Concurrent Engineering environment of working to maximize my contribution.
 4. All in all I think Concurrent Engineering is an important organizational philosophy for this organization.
-

END

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FIN