New mathematical model for assessment of concurrent engineering.

Guoli Jian
University of Windsor

New Mathematical Model For Assessment of Concurrent Engineering

By

Guoli Jian

A Thesis
Submitted to the Faculty of Graduate Studies and Research
through Industrial Engineering
in Partial Fulfillment of the Requirements for
the Degree of Master of Applied Science
at the University of Windsor

Windsor, Ontario, Canada

2006

Your file Votre référence
ISBN: 978-0-494-17047-2
Our file Notre référence
ISBN: 978-0-494-17047-2

1043448

ABSTRACT

Recently, global competition has led to shorter product life cycles and increased technological sophistication. Products are becoming more complex due to rapid technological developments and increasing consumer demands for lower costs, greater variety, and greater performance. At the same time the proliferation of new technologies is rendering products obsolete at an increasingly rapid pace. These market and technology trends lead to the emerging of concurrent engineering.

This thesis firstly will give a definition and briefly introduction of concurrent engineering, including its fundamentals, and the benefits of concurrent engineering, it's difficulties and caveats. After that this thesis will introduce an implementation method for concurrent engineering.

This thesis will focus on concurrent engineering assessment model; the purposes of concurrent engineering assessment model are providing information about your current state of affairs. It describes how things are done now and how well they are being done. Firstly, two existing assessment models will be introduced. The existing assessment models are focused on the present situation; they only assess the present situation, they do not assess the past situation, and the future situation; most of these models look like a questionnaire, the assessment is highly subjective and not very accurate. This thesis will focus on constructing a mathematical assessment model, making the assessment much more objective and accurate.

All in all, the major contribution of this thesis research is the constructing of the mathematical assessment model. This new model describes the history and the future of company, assessing the company's performance, exposing practical problems and identifying potential improvements.

ACKNOWLEDGEMENTS

I would like to acknowledge and appreciate Dr. Leo Oriet, for his supervision, dedication, and suggestions that were of definitive value in the development and termination of this project.

I would also like to acknowledge the members of my committee, Dr. Mohammed Fazle Baki, and Dr. Guoqing Zhang, for their valuable suggestions and refereeing.

Additionally, my sincere thanks to Ms. Hui Meng, Ms. Helen Zhang and Ms. Caiyun Wang for their help in the information given during my research on this thesis.

Also to Ms. Jacquie Mummery and Mr. Ram Barakat for their assistance and moral support.

Finally, I wish to express my gratitude to my wife Dr. Lihong Guo, and my son Haozhe Jian for their unconditional solidarity and for all that they have done in these years in order to achieve our goals. In appreciation, it is to them that I dedicate my work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I. INTRODUCTION

1.1 The definition of Concurrent Engineering

The principles of concurrent engineering have been around for a long time, and were discussed as early as the beginning of the twentieth century. However, concurrent engineering has grown to become a dominant product development management approach only in the past two decades. As science and technology develop very fast, and as the competition in the local market, or even globally, becomes increasingly keener, the traditional method of product design and development has become unsuitable. Therefore, concurrent engineering with its promise to shorten the product development process, to increase product quality, to decrease product cost and to improve services (including the satisfactory extent of clients' needs, post-sale services and escalation of post-sale products) is capturing manufacturers' attention. So far, a good many enterprises, especially large firms, have tried putting concurrent engineering into elementary practice, and have benefited well from it.

The concept of concurrent engineering implies the almost simultaneous design of new and revised products, their development, and their preparation for volume production to reduce time to market. There have been many definitions of concurrent engineering, but all of them emphasize the importance of co-coordinating and integrating design engineering activities in order to move away from a practice evocatively described as "over-the-wall engineering"

Pennell and Winner defined concurrent engineering as: Concurrent Engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception to disposal, including quality, cost, schedule, and user requirements. (Pennell and Winner, 1989)

Concurrent Engineering is a systematic approach to creating a product design that considers all elements of the product life cycle from conception through disposal...concurrent engineering defines simultaneously the product, its manufacturing processes, and all other required life-cycle processes, such as logistic support. Concurrent engineering is not the arbitrary elimination of a phase of the existing, sequential, feed-forward engineering process, but rather the co-design of all desired downstream characteristics during upstream phases to produce a more robust design that is tolerant of manufacturing and use variation, at less cost than sequential design. (CALS, 1991.)

Concurrent Engineering is a systematic approach to integrated product development that emphasizes the response to customer expectations. It embodies team values of cooperation, trust, and sharing in such manner that decision making proceeds with large intervals of parallel working by all life-cycle perspectives early in the process, synchronized by comparatively brief exchanges to produce consensus. (Cleetus & Ashley, 1992.)

Another concurrent engineering definition is: Concurrent Engineering is, a systematic approach to integrated development of a product and its related processes, that emphasizes response to customer expectations and embodies team values of cooperation, trust, and sharing in such a manner that decision making proceeds with large intervals of parallel working by all life-cycle perspectives, synchronized by comparatively brief exchanges to produce consensus. [3]

SIMPLY stated, concurrent engineering is the incorporation of downstream factors and concerns into the upstream phase of product development. This should lead to a shorter product development time, better product quality, and lower manufacturing costs. It is concerned with the availability of information to all members involved in the design of a product. Its basic concern is to make available all relevant information to a member involved in the design process before the design task is begun. The ability (of the design member) to act on the information as soon as it becomes available is yet another important dimension of CE. Unfortunately, for most engineering tasks all relevant information required by a specific task cannot be made available at the start of that task. Therefore, concurrent engineering requires the maximization of such information and the ability to share and communicate useful information on a timely basis. [1]

1.2 Background

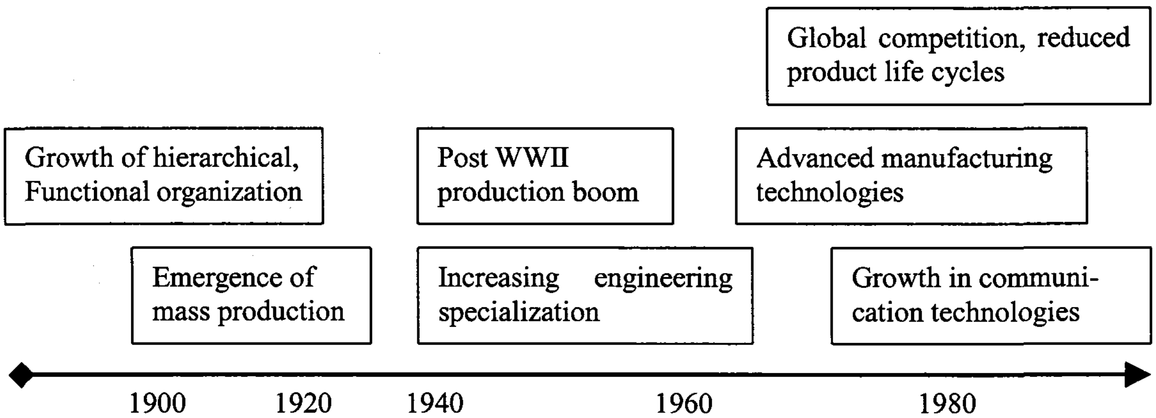

Figure 1. Timeline of major events in the development and adoption of CE

Figure 1 illustrates the development and growth of Concurrent Engineering in the twentieth century. The understanding principles of concurrent engineering have been around for a long time, and were discussed as early as the beginning of the twentieth century (Smith, 1997). However concurrent engineering has grown to become a dominant product development management approach only in the past two decades. Smith (1997) suggests several reasons for this growth. First, the need for concurrent engineering increased because engineering training became intensely specialized, emphasizing engineering science over engineering practice. Second, the advent of useful information and communication and technologies has enabled and lowered the cost of implementing concurrent engineering. Third, changes in the competitive environment have increased the importance of reducing product development lead time and improving product quality.

While the fundamentals of concurrent engineering are not new, there has a marked growth in the score of concurrent engineering. According to Nevins and Whitney (1989), early concurrent engineering approaches focused only on identifying part fabrication issues early in the product development process. Over the years, this focus was expanded to include assembly issues and groups of parts in design decision, until finally all production and product support processes were addressed. For example, the U.S. Department of Defense emphasizes "cradle-to-grave" considerations in concurrent engineering programs with the primary objective of coordinating decisions between different engineering functions. Market-oriented advocates of concurrent engineering also stress the need for integrating the "voice of the customer" and marketing strategies into design decisions, emphasizing information exchange between marketing and R&D personnel. Others suggest an even broader view of concurrent engineering which addresses environmental and societal cost issues (Alting, 1993).

Performance goals associated with concurrent engineering have grown as well. Early concurrent engineering developments were aimed at improving quality or minimizing product acquisition costs, while more recent programs have emphasized reductions in product development time. The result of this growth in concurrent engineering concepts is a more holistic, strategic view of concurrent engineering. [4]

1.3 Concurrent engineering and other manufacturing initiatives

Industry is inundated these days with new initiatives clamoring for attention. Let us consider the following list:

- Concurrent Engineering

- Just-In-Time (JIT)
- Total Quality Management (TQM)
- Lean Manufacturing
- Agile Manufacturing
- Business Process Reengineering
- Continuous Improvement
- Kaizen
- Downsizing

There are several ways to view these kinds of initiatives.

- Program of the month. An executive learns about a new initiative and gets very excited about it. People are trained and start to try to implement it, but before they get a chance to gain the benefits, the executive is already off on the next initiative and the cycle starts all over. The main product of this kind of situation is high income for consultants combined with low moral and high cynicism for people in the company.
- Fundamentalist religion. The executive treats the initiative like a new religion, and any book written by the initiative's spokesperson like a set of fundamental truths which must be adhered to without question. The main reason for taking this approach seems to be a desire to achieve "the answer" without a lot of thought or work. The result is an inflexible application of the initiative without consideration for the unique conditions at the company – usually leading to no gain, since the initiative is applied with no real understanding of its intent, limitations, or necessary modification.
- Use what works for you and move on. The executive takes the time to really understand the principles behind the initiative and then applies those principles to his/her operation. If something does not work after a reasonable trial, that part gets dropped. Of something does work, then it becomes routine practices. When the company has gotten as much

benefit as it can from one initiative, it drops treating it as a separate initiative and moves on to the next set of exciting new ideas. The result of this is that the company continues to learn and grow.

Obviously, we think it better to take a very flexible approach to any of these major initiatives. For one thing, these is tremendous overlap among them, for example, lean Manufacturing probably implies the use of Concurrent Engineering, TQM, Continuous Improvement, and JIT. Those suggest a strong need to integrate initiatives such as this when more than one is being attempted. We will briefly explore the connections between Concurrent Engineering and more of the initiative listed above.

1.3.1 Concurrent Engineering and Business Process Reengineering. Business Process Reengineering (BPR) is "the fundamental rethinking and radical redesign of business process to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed" (Hammer and Champy, 1993). The emphasis in BPR is on the business process, as opposed to functions. A business process is a thread running through your business which provides value to your customer. Product development is usually considered to be a business process; order fulfillment is another example. If you reengineer your product development business process, the end that you would have in mind would typically be concurrent engineering. Thus, BPR can be the "means" to the "end" of Concurrent Engineering. We need BPR for getting to Concurrent Engineering.

1.3.2 Concurrent Engineering and Lean Manufacturing. Lean Manufacturing is an approach to manufacturing in which you attempt to minimize everything, from work in process, to part count, to labor hours. "less of everything" not only inherently reduces cost, it increases pressure to get things done more quickly as well as correctly (no slack means you can not waster anything). Lean Manufacturing popularized in the U.S. by "The machine that changed the world", Lean

Manufacturing is currently the dominant paradigm in manufacturing – guiding many of the improvements now taking place around the world. Unfortunately, Lean Manufacturing has tended to focus on the shop floor, as opposed to product development. It is just as critical to make the product development process lean as it is to make the manufacturing system lean (Womack and Jones, 1996)

1.3.3 Concurrent Engineering and Agile Manufacturing. Agile Manufacturing is an approach to manufacturing in which groups of companies (enterprises) flexibly join together as needed to bring out new products on demand in any lot size. It is the result of flexible technology which allows for economic production in lot sizes of one, innovative management structures which permit instant reconfiguration of the enterprise, and a skilled base of knowledgeable works. Today Agile Manufacturing is more of a vision than a reality; tomorrow, we can expect enterprises to become more agile. However, whether they ever fulfill the complete vision remains a question. Regardless, Concurrent Engineering is a critical element of agility. This is partly because adoption of Lean Manufacturing is almost certainly a prerequisite for agility, and Concurrent Engineering is clearly a part of Lean Manufacturing. Moreover, Concurrent Engineering between customers and suppliers, i.e., including the entire supply chain, is central to the process of flexibly developing new products across company lines. As practiced, Concurrent Engineering is primarily a within company exercise. However, as agility becomes increasingly important, we believe it will expand to include large parts of the supply chain in a full lean enterprise. [15]

1.4 Concurrent Engineering Fundamentals

The fundamentals of concurrent engineering will be described as the following four.

(1) The increased role of manufacturing process design in product design decisions.

(2) The formation of cross-functional teams to accomplish the development process.

(3) A focus on the customer during the development process.

(4) The use of lead time as a source of competitive advantage.

All products have a need to incorporate constraints imposed by the manufacturing process on details of the product design. Depending on which manufacturing process is considered, these effects may be encoded into formal or computer-based rules, or else may be conveyed through individual experience and expertise. Addressing these design concerns early in the development process creates the opportunity to reduce manufacturing costs and improve product quality. The failure to account for these concerns is often due to a functional barrier within an organization between design and manufacturing.

Often the method of accomplishing the integration of design with other functions (and removing functional barriers) is the use of cross-functional teams. These teams may include people with expertise in production, marketing, finance, service, or other relevant areas, depending on the type of product. Persons from must be willing to collaborate, share information, and resolve conflicts quickly and effectively.

Beside the barrier between design and manufacturing, another important functional barrier is the separation between the engineering designer and the customer. Under the same philosophy as removing the design-manufacturing barrier, the designer can become more responsive to customer desires and thereby create a more successful product. This is known as design-marketing integration.

Lead time has proved to be a significant facet of modern competition. By reducing the development lead time a firm is able to respond more rapidly to market trends or to incorporate new technologies. A shortened lead time creates a market advantage for those firms who are able to produce products rapidly. [42]

1.5 Comparison with traditional product development cycle

In traditional engineering a relatively short time is spent defining the product, but a relatively long time is spent designing the product and a surprisingly long time is often spent redesigning the product. The key to shortening the overall design time is to better define the product and better document the design process.

In the traditional approach to launching a new product, the two functions of design engineering and manufacturing engineering tend to be separated and sequential, as illustrated in figure 2 (a). The product design department develops the new design, sometimes without much consideration given to the manufacturing capabilities of the company. There is little opportunity for manufacturing engineers to offer advice on how the design might be altered to make it more manufacturability. It is as if a wall exists between design and manufacturing. When the design engineering department completes the design, it tosses the drawings and specifications over the wall, and only then does process planning begin.

There are three arguments against traditional product development cycle.

1. You can not finalize the design of the product until you know how it will be made.

   As we all know, manufacturability issues are as important to the design of the product as knowing performance specifications. While design for manufacturability analysis and participation by manufacturing personnel on a design team can help a great deal, many problems will not be discovered until some work has begun on the manufacturing system. This is particularly true if your design is pushing the limits of produce-ability in some way (e.g., closer tolerances, higher production rates). Thus, some product design problems will not be discovered until work is significantly along on developing the manufacturing system or process plan. In other words, the traditional product development is inherently flawed – design is always an iterative process that covers the entire life cycle, not just the design of the product.

2. Sequential design takes too long.

It seems obvious that doing tasks sequentially will take longer than doing them in parallel. A key benefit of critical path analysis for project planning is that it forces you to consciously decide what needs to happen in sequence and what can happen in parallel. Doing more things at the same time would seem to be naturally faster than waiting to complete each one before staring the next. A less obvious benefit of working in parallel is the shorter feedback loops that can help you adjust each task based on feedback from the other. If we wait for the product to be "completed" before staring to design the manufacturing system, and then find a manufacturability error, we have to go back to the beginning and wait for the product to be redesigned before we can start all over again on the manufacturing system. This involves large amounts of waiting time and large engineering changes.

3. Ultimately, a traditional product development cycle results in a poor design.

Quite simply, management and the market won't wait for a sequential process to be completed. Some deadline will be reached and the product will be released, even if all its problems have not been solved. The customer will then find the flaws which were missed, provide feedback to the designers, and more changes will be made. The costs of changes at this time point in the process are incredibly expensive both in cash terms and in terms of customer satisfaction and later sales.

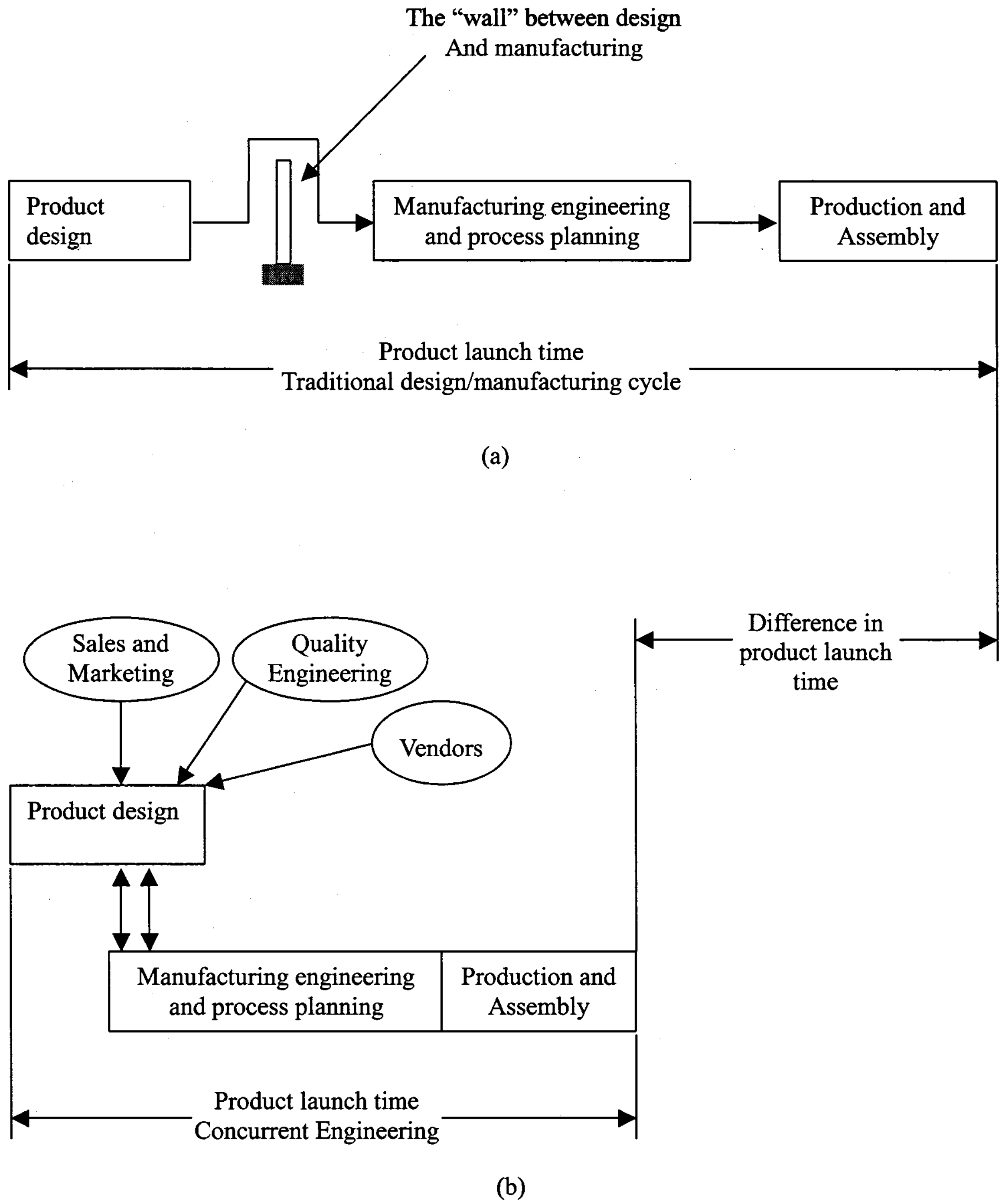

Figure 2 Comparison of: (a) traditional product development cycle and (b) product development using concurrent engineering

By contrast, in a company that practices concurrent engineering, the manufacturing engineering department becomes involved in the product development cycle early on, providing advice on how the product and its components can be designed to facilitate manufacture and assembly. It also proceeds with early stages of manufacturing planning for the product. This concurrent engineering approach is illustrated in figure 2 (b). In addition to manufacturing engineering, other functions are also involved in the product development cycle, such as quality engineering, sales and marketing, vendors supplying critical components, and in some cases the customers who will use the product. All of these functions can make contributions during product development to improve not only the new product's function and performance, but also its produce-ability, inspect-ability, testability, serviceability, and maintainability. Through early involvement, as opposed to reviewing the final product design after it is too late to conveniently make any changes in the design, the duration of the product development cycle is substantially reduced. [7]

1.6 Benefits of concurrent engineering

CE has led to dramatic benefits for a large number of companies from various industries. Some of the findings are presented here as a pointer towards the potential benefits of this best practice.

Benefits Obtained from Concurrent Engineering

Benefits and Metrics	Results
Decreased lead time	
Development time	30-70%
Time to market	20-90%
Improved quality	
Engineering changes	65-90% fewer
Scrap and rework	up to 75% less
Overall quality	200-600% higher

Reduced Cost	
Productivity	20-110% higher
Return on assets	20-120% higher
Manufacturing costs	up to 40% lower

Table 1. Benefits Obtained from Concurrent Engineering [29]

From the results, we can see that there are several benefits that concurrent engineering can bring to company, although it is difficult to exactly quantify many of these benefits by using spreadsheets and numbers. These are not only benefits which the participating company will experience, but ultimately the end users or customers also will reap these benefits by having a quality product which fits their needs and in many cases, costs them less to purchase. Therefore, concurrent engineering produces a unified profitable corporation and a satisfied consumer.

(1) Competitive Advantage

The reasons that companies choose to use concurrent engineering is for the benefits and competitive advantage that concurrent engineering can give them. Concurrent engineering can benefit companies of any size, large or small. While there are several obstacles to initially implementing concurrent engineering, these obstacles are minimal when compared to the long term benefits that concurrent engineering offers

(2) Increased Performance

Companies recognize that concurrent engineering is a key factor in improving the quality, development cycle, production cost, and delivery time of their products. It enables the early discovery of design problems, thereby enabling them to be addressed up front rather than later in the development process. Concurrent engineering can eliminate multiple design revisions, prototypes, and re-engineering efforts and create an environment for designing right the first time.

(3) Reduced Design and Development Times

Companies that use concurrent engineering are able to transfer technology to their markets and customers more effectively, rapidly and predictably. They will be able to respond to customers' needs and desires, to produce quality products that meet or exceed the consumer's expectations. They will also be able to introduce more products and bring quicker upgrades to their existing products through concurrent engineering practices. Therefore companies use concurrent engineering to produce better quality products, developed in less time, at lower cost, that meets the customer's needs. [37]

1.7 Enabling technologies for concurrent engineering

Technology can be a strong enabler of concurrent engineering. Many new computer applications improve the richness of communication among concurrent engineering, and improve the quality of product design. These technologies can be classified as follows: Communication Technologies, CAD/CAM/CAE systems, Product Data Management (PDM), and Group Technology/Coding systems.

Communication Technologies: The essence of concurrent engineering is that all the necessary design inputs are introduced as early as possible, so that the design evolves from a correct basis and separate activities can be carried out in parallel. Electronic mail and communications networks are powerful tools for rapidly communicating information and for providing to wide audiences easy access to product and project data. Information can also be stored on centralized computer aided design (CAD) databases. Data captured in these systems can be accessed by persons located around the world for use in product design, process planning, and computer aided manufacturing. [21]

CAD/CAM/CAE systems: Computer aided engineering (CAE) tools are frequently linked to CAD systems in ways that reinforce good design practices. These sophisticated systems create and analyze three-dimensional models of parts and assemblies, reducing the need to build expensive and time consuming physical prototypes. For example, CAD/CAE systems can automatically analyze assembly designs to identify areas of potential interference between parts. Further, many CAD systems embed process information and design rules directly into the design software so that they may be linked to certain design features. For example, when a designer draws a hole, he can then select a pull down window of information providing a list of processes that could create the hole, typical dimensional tolerance, defect rates associated with each process, and any other design rules related to the feature. Some companies have developed "expert systems" that aid the evaluation of design choices. In addition, numerous off the shelf CAE systems address stress and thermal analyses, mechanical assembly, printed circuit board (PCB) design, and integrated circuit (IC) design. [56]

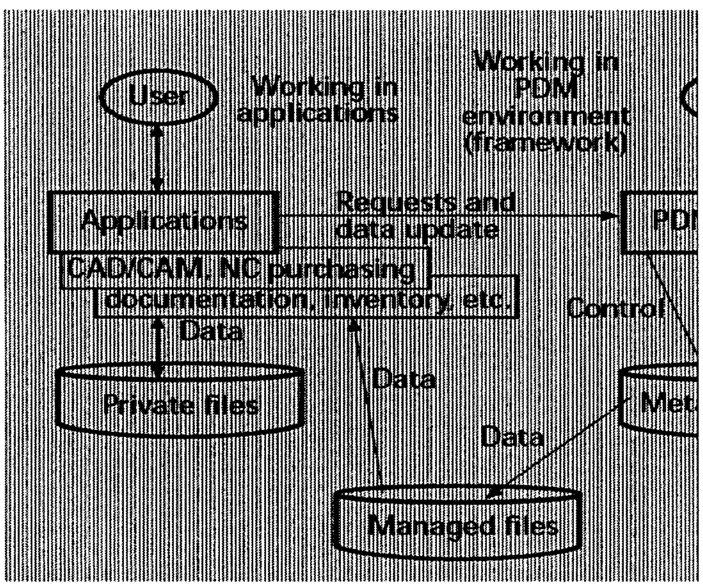

Figure 3. A functional view of a PDM system

Product Data Management (PDM): The complexity of implementing concurrent engineering through an organization has proved to be a major obstacle in achieving anticipated results, implementing it is a painful process in which a complete top to bottom understanding of an organization's processes is needed. There are few organizations which understand their own dynamics. For concurrent engineering to be successful, cross-functional design teams, along with their associated data, must be brought together. PDM assists in implementing a concurrent engineering strategy successfully because PDM has ability to manage all the product data and the processes in which the data will be exchanged. In the Extended Enterprise, PDM offers the enabling infrastructure for fast exchange of product data. [24]

Group technology/Coding systems: in a company, designers often waste time and resources by unknowingly recreating existing designs. CAD systems can be linked with databases that contain information on preferred components, existing designs from other products and suppliers of purchased items. Group technology – based classification and coding systems enable designers to easily search design database for existing designs which meet their current needs. Similarly, databases which prioritize certain components and vendors can speed up a designer's search for suitable parts. Coding systems also allow manufacturing planners to identify "families" of parts that have similar design or processing characteristics. These approaches reduce design time and reap enormous manufacturing benefits because fewer unique parts must be fabricated and inventoried, less special tooling is needed, production scheduling is simplified, and less disruption is experienced. [36]

1.8 Understand the Difficulties and caveats

The reasons for failing to implement concurrent engineering successfully are repeated in most companies. However, substantial positive results have been obtained by many companies with poor concurrent engineering implementations.

- Implementation of concurrent engineering is a major challenge for management.

- Many cross-functional change initiatives have high rates of implementation failure [50]
- Concurrent engineering is a particularly problematic cross-functional initiative as it involves, for its implementation, the company might change company's strategy or even company's culture.
- Overall finding from the cases that firms often underestimated the difficulties of implementing new approaches.
- Barriers exist in organizations that inhibit the successful implementation of CE. The two types of barriers are organizational and technical
  - Organizational barriers include lack of management support, protective functional managers, inadequate reward systems, lack of customer involvement, lack of supplier involvement, and fear of loss of creativity. As an illustration rewards based on departmental goals rather than organization-wide objectives can lead to sub-optimization of the organization's performance.
  - Technical barriers include availability of proper computer-aided design/manufacturing and communication tools.
- Implementing concurrent engineering principles in an industrial context often gives less than satisfactory results in practice because of practical problems such as:
  - Inadequate training and expertise in the concurrent development process
  - Difficulty in synergizing cross-disciplinary labor functions
  - Difficulty in managing or controlling technical processes in the concurrent development process [37]

Numerous cases of concurrent engineering success have been documented in a variety of industry and product development contexts. Even so, researchers continue to debate the appropriateness of concurrent engineering in different situations. On going research is investigating the dynamics of functional integration and concurrency by addressing such issues as to who should be integrated and when and how this is best achieved.

Some researchers and users of concurrent engineering argue that it is especially important when there is stiff competition, when new manufacturing processes are being used, and when reducing development lead time is very important. Indeed, managers may have little choice but to implement concurrent engineering when presented with a lucrative market opportunity or confronted by a particularly aggressive competitor. At the same time, there are indications that an over emphasis on concurrent engineering can hurt new product development performance outcomes in some circumstances. Heavy concurrency may increase development cost and lead time when new product development activities are risky with a high potential for failure. Because process design activities are begun earlier and with less complete information, there is an increased probability that some designs will need frequent rework.

Recent empirical research suggests that heavy manufacturing influences early in new product development can be detrimental to product innovation, and may unnecessarily increase lead time in new product development projects when they involve little new technology. For example, manufacturing personnel may sometimes be locked in to the firms current processing capabilities or remain unknowledgeable about new technologies or options outside the firm. In this case, their influence in new product development may work against the adoption of innovative new product features. In addition, R&D personnel sometimes complain that the inclusion of downstream process personnel early in NPD creates confusion and slows down decision making, especially at very early stages of NPD when design concepts are not well defined. These findings are tentative and need to be confirmed. However, it is important to remember that the primary goals of NPD should govern the training and participation of various functional groups and the usage of cross functional integration methods.

Good communication among marketers, product designers, process designers and manufacturing personnel is always crucial. However, communications across certain functional groups should be prioritized according to the objectives established for the project. For example, the use of an important new manufacturing technology would necessitate rich communications among the designers using the technology, the designers and installers of the technology, and the users of the technology. Further, each concurrent engineering team member should realize that the strategic importance of certain NPD program outcomes might sometimes out weight the importance of his or her own function's design guidelines. [38]

CHAPTER II. IMPLEMENTATION OF CONCURRENT ENGINEERING

2.1 Types of Concurrent Engineering

There are significant differences in the ways concurrent engineering is conceived and implemented in different projects, companies, and industries. Some programs address only narrow product produce-ability issues. More comprehensive concurrent engineering programs address the impacts of product design decision on competitive issues and product life cycle considerations.

One of the difficulties of implementing concurrent engineering is deciding what activities should be done concurrently and establishing where the most important points of integration are. Program priorities should drive these decisions. Customer desires and competitive threads influence the relative priories placed on design quality, product costs, and product introduction speed. So, there are three types of concurrent engineering. (1) Product concurrency, (2) Project phase concurrency, (3) Design concurrency. Figure 4 illustrates relationships among these three different types of concurrency.

Product concurrency is the overlap of separate but related new products requiring coordination between different products. Product concurrency exists in the concurrent development of first generation and next generation products. Project phase concurrency involves simultaneously development market concepts, product designs, manufacturing processes, and product support structures. Design concurrency involves the overlap of design disciplines so that system level and component level designs are produced concurrently. [36]

2.2 The Implementation Method

The implementation of concurrent engineering usually can be divided into three stages: (1) Preparation for implementation, (2) concurrent engineering pilot implementation, and (3) Full concurrent engineering implementation. (Details are illustrated in Figure 5 The stages of implementation of concurrent engineering)

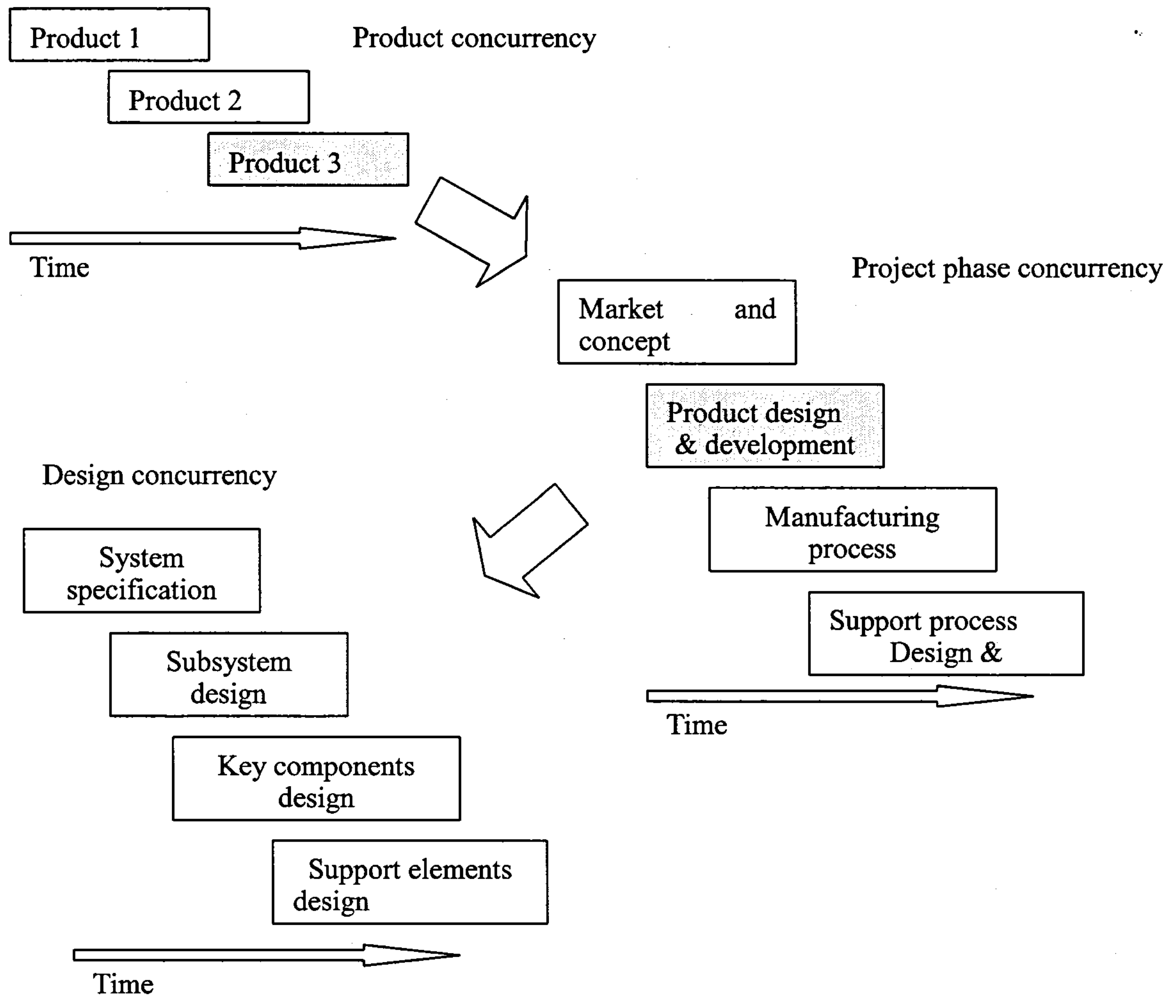

Figure 4. Relationships among three different types of concurrency [37]

Stage 1 –preparation for implementation

The first stage of the implementation is designed to introduce the basics of concurrent engineering to the senior management of a company. The three aims of this stage are: (1) Understand concurrent engineering and need for it, The manager must understand what concurrent engineering is, and how it should be best implemented. In today's business world,

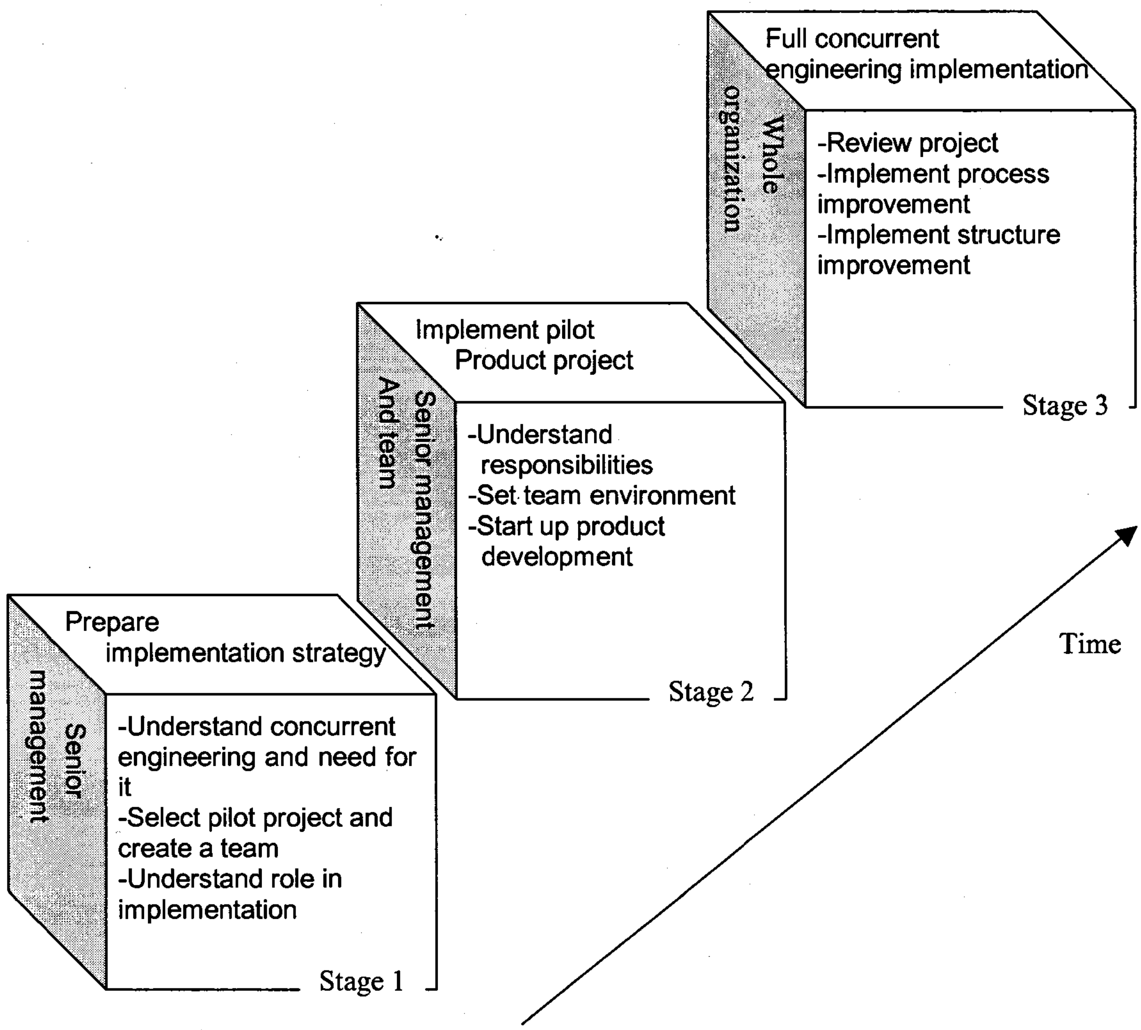

Figure 5 The stages of implementation of concurrent engineering

corporations must be able to react to the changing market needs rapidly, effectively, and responsively. They must be able to reduce their time to market and adapt to the changing environments. Decisions must be made quickly and they must be done right the first time out. Corporations can no longer waits time repeating tasks, thereby prolonging the time it takes to bring new products to market. Therefore, concurrent engineering has emerged as way of bringing rapid solutions to product design and development process. (2) Select a pilot project and create a team. While team arrangements vary, three organizational levels of teams frequently appear in concurrent engineering: a management team, a technical team, and design teams. (3) Understanding role in implementation of concurrent engineering.

Stage 2 –concurrent engineering pilot implementation

The second stage concentrates on beginning product development activities and launching the concurrent engineering implementation with a pilot concurrent engineering project. The three aims of this stage are: (1) Understand responsibilities, Management teams typically include the manager, marketing manager, operations manager, design manager. This group provides management oversight and planning, approves and controls the project budget, and manages the project schedule. The technical team provides technical oversight, approves key design decisions, and maintains consistency between design elements. Design teams replicate the technical project team with responsibility for components at the lower levels of product structure. Each team is oriented around a particular product component, with responsibility for delivering designs, prototype hardware, process plans, quality engineering. (2) Set team environment. Management team must create a supportive multidisciplinary team environment which is critical to the success of CE. A series of group exercises is then conducted. These are designed to involve the team members in discussing and developing the relationship statements further, and improving the clarity of the product specification and project target. (3) Start up product development.

Stage 3 –Full concurrent engineering implementation

Once the pilot concurrent engineering project has been finished and the product has been successfully launched into the marketplace, it should be reviewed, and lessons carried forward to subsequent projects. Concurrent engineering can now be introduced throughout the organization. This will mean that existing systems and structures will need to be realigned to accommodate a new way of working. The three aims of this stage are: (1) Review project, Once the pilot is complete and the business benefits have surfaced, concurrent engineering can spread into the wider organization. This will necessitate a review of existing performance measures. (2) Implement process improvement. This is a good time for the team to evaluate its needs for training and the use of new and enabling technology. It has been through an intense learning period and can now determine the most appropriate tools, techniques and technologies for the product development process. It is often to wait until the first pilot project has been completed to ensure maximum benefit from any such investments in the product development process. (3) Implement structure improvement. Concurrent engineering implementation will cause a shift in emphasis from vertical functions to horizontal processes. Teams and management will be responsible for maintaining a process focus for product development. The teams will look for ways to improve continually and streamline the whole product development process. Management will change the organizational infrastructure to support the process better and institutionalize change. [49]

2. 3 Case study: -Implementing Concurrent Engineering at Cadillac

Cadillac Automobile Company was founded in 1902. It is now a division of the General Motors Corporation. Cadillac facilities include ten sales zone offices across the United States, four manufacturing plants in Michigan, and administrative/engineering offices in the Detroit area. The entire organization involves the efforts of approximately 10,000 salaried and hourly Cadillac people.

Staying on top in a mature market that is fiercely competitive presents serious challenges for organizational leadership. During 1984, Cadillac's leadership had decided to implement the concept of concurrent engineering as one strategy to meet these challenges.

In the Concurrent Engineering environment, new quality improvement processes that required cooperation across the organization were more easily and effectively assimilated. The redesign of the 1988 Eldorado, accomplished in an industry record 125 weeks, was just one of the results of the newly developed Concurrent Engineering environment at Cadillac. Another result was a high level of customer satisfaction resulting in improved market position.

This case is about the implementation and development of concurrent engineering at Cadillac. Organization development issues addressed are leadership, strategy, structure, systems, processes, culture, and education and training. Each of these organization development issues are discussed as follows:

(1) Create a Vision with Organizational Support

In January of 1985, three workshops were designed and facilitated by an organizational development manager and co-chaired by executives from manufacturing engineering (process engineering) and vehicle engineering (product engineering). These meetings included not only the top engineering management but that of other staff as well. At these workshops what was known about the concept of concurrent engineering was shared. This management team then began to identify implementation issues. The output included a consensus to move forward, a proposed makeup for a Concurrent Engineering Steering Committee (SESC), and a consensus to empower the SESC to act on behalf of the organization in further study and planning. Not only were these outputs significant, but this groups' involvement was the forerunner of the teamwork culture that would develop with concurrent engineering.

(2) Organizational Design and Planning

In September 1985, the SESC and the executive staff participated in two concurrent engineering vision and implementation strategy development workshops to assure alignment prior to establishing concurrent engineering teams.

As Cadillac developed the structure for concurrent engineering, the car was sectioned into specific vehicle systems and created six corresponding vehicle system management teams. These were the exterior component/body mechanical, chassis/power train application, seats and interior trim, electric/electronic, body-in-white, instrument panel/heating, and air-conditioning systems. The role of each one of these vehicle system management teams was to manage their vehicle system in order to optimize the business decisions that are made in that area of the vehicle.

The vision was developed and the structure was determined. Roles and responsibilities were defined and the strategy for concurrent engineering was ready for the next stage of implementation. The new expectations of team members would require them to learn about other part of the business. In addition, most team members were familiar with planning and decision-making in the context of their individual staff, but not with cross-staff teams.

(3) Implementation

Change takes time and education. In November of 1985, an organization event was held to communicate the plan. It was considered important to communicate the design for concurrent engineering to those who had originally met in January as a follow-up since they had empowered the steering committee. It was also considered important to communicate to significant others who would eventually be called upon to staff the concurrent engineering teams. The meeting was designed to be interactive. All questions were documented and a response was given either by the panel of SESC members, executive staff, or included in forthcoming documentation of the work session.

(4) Development and Continuous Improvement

It's important to note that implementation alone is not enough. Organizations are too complex for the concurrent engineering change effort to be viewed only as a linear model. At Cadillac, developing concurrent engineering is a dynamic process; one which does involve vision, planning, and execution, but does not stop there. Yearly, the SESC, as well as the other concurrent engineering teams, assess the success and opportunity for improvement to the structures, processes, and systems, and incorporate what is learned into plans for continued improvement. This approach requires a culture supportive of honest and open communication of information with an urgency to continue to improve the quality of its products, processes, and people.

(5) Learning

Cadillac, through concurrent engineering, institutionalized teamwork. A formalized concurrent engineering structure was essential. Education and training was required, and management commitment and involvement was instrumental in effecting a cultural change- one that fostered teamwork, communication, and group decision-making. A key to Cadillac's success was the teamwork and communication that took place among the many different staffs in the various stages of the development process. There also was active participation of stakeholders at all levels of the organization in the decision-making process.

Concurrent engineering is now an important element in aligning the organization's business objectives. Through concurrent engineering, there is increased focus on people, process, and systems, as well as on the product. All levels are empowered and take personal responsibility for leadership for their part of the business.

The positive effects of concurrent engineering are being experienced at all levels of Cadillac. People now wear two hats: their traditional functional hat and an concurrent engineering team hat which, when coordinated by Cadillac's business plans, encourages every one involved to contribute as if they were running their own business. This involvement has had a tremendous impact on Cadillac's ability to improve its product and services. Open, two-way communication and continuing education is working. People share knowledge, giving each other information that will help everyone do their job more successfully.

Breaking down barriers, pooling resources, getting input form those affected by decisions-that's what concurrent engineering is all about. What started out as new way of engineering a vehicle developed into a whole new culture at Cadillac. Concurrent engineering today is a primary force in Cadillac's position as "America's luxury car leader", a distinction they have maintained for 40 consecutive years. In the long term, Cadillac believes concurrent engineering will help to maintain the focus on the achievement of its mission-to engineer, produce, and market the world's finest automobiles, and to continue as America's luxury car leader. [20]

CHAPTER III. CONCURRENT ENGINEERING ASSESSMENT MODEL

3.1 The purposes of concurrent engineering assessment model

So far we have covered a lot of ground, the definition of concurrent, the concurrent engineering Background, the Comparison with traditional product development cycle, Benefits of concurrent engineering, enabling technologies for concurrent engineering, the Difficulties and caveats and an implement method.

But it is all been on the conceptual level, but no specific way for you to figure out where you stand? And whether the concurrent engineering is for you? Whether you can get benefits from concurrent engineering? And when is the best time to implement concurrent engineering? This section will introduce the concurrent engineering assessment model which will answer these questions.

The purposes of concurrent engineering assessment model is provides information about your current state of affairs. It describes how things are done now and how well they are being done. The assessment model serves two very important purposes.

(1). Baseline. By telling you how things are going now, the assessment model provides a baseline against which you can compare future performance after you have introduced concurrent engineering. One obvious reason for wanting to do this is so you can demonstrate what a wonderful thing concurrent engineering is for your company. Of you can demonstrate that concurrent engineering resulted in performance improvements, and if you can quantify those improvements, you can make yourself look pretty good. Another, less obvious reason for doing this is so you can find out if anything has indeed changed after you introduce concurrent engineering. After all, you can "roll out" a program like concurrent engineering, but it does not necessarily mean that people's behavior will change. Without a baseline you would have no formal way of knowing if practices were indeed different.

(2). Identify Opportunities. By looking in detail at existing practices and structures, the assessment model provides you with the detailed information you need to identify opportunities for improvement which will provide the greatest benefit to your company. And you have to work with existing people and skills, and you have to change existing structures and practices. Of you are going to change something that currently exists, and then you have to pick your spots. Where are the greatest opportunities for improvement? Where can change be introduced with the least disruption to existing work?

We can not emphasize enough how vital the assessment will be for the success of concurrent engineering. For many "action oriented" managers and engineers, it can initially seem like a waste of time; after all, they say, "we know how this company operates – we work here." We can respond to that with three comments. First, how well do you really know how things work? Even in very small companies, there is often no one who really understands how things work in all areas of the company. In a large company it is all but impossible to get a small team together that fully understands how things work. Second, even when you get a team of functional exports together, they usually find it very difficult to communicate to people in other functions about what is happening in their area. Thus all the needed information may be in the heads of the people sitting around a table, but getting it out for use by the whole team can be very difficult. Third, a assessment model is needed to help classify and analyze the data in a useful way. The assessment model gets all of the needed information out around the table, in a single place, and in a form understandable to the whole team. [31]

3.2 Introduction of two existing models

Next we will introduce two existing concurrent engineering assessment model, one is the Assessment Chat, and another is the concurrent engineering Profile^{TM} Model

3.2.1 The Concurrent Engineering Assessment Chart.

A concurrent engineering assessment model was developed by Susan E. Carlson and Natasha Ter-Minassian, Their concurrent engineering assessment was based on three skeletal models of a design and development process, each representing a different level of complexity. Two project assessment tools are used to determine which model or combination of models to use, as well as which personnel are most important to include on the design team.

To begin the process, the project leader works with other individuals responsible for the inception of the project to complete an assessment chart. That chart tabulates the project's relative grades on each of 12 criteria: design type; product complexity; design standardization; required analytical resources; projected design cycle time; required level of precision, reliability, and durability; manufacturing process complexity; supplier requirements; size and scope of the project; project priority; risk; and cost. Each of the criteria is rated subjectively as A, B, or C based on the project manager's judgment about the company and its products and the design team's capabilities. A rating of A implies that the product needs a team that interacts often and a design process that is highly concurrent and systematic, while a rating of C implies a minimal amount of concurrency is required. The evaluation criteria are outlined in the following paragraphs.

Design Type. The type of design can vary from a completely new product, which would be rated A, to a simple feature change, such as adding a function or modifying some aspect of the user interface, which would be rated C. A B rating would be used when some of the decisions about the design have already been made because it will be based on a previous model, but substantial changes in the product's structure or function are to be made.

Product Complexity. In rating this category, the product is viewed at a micro level and its complexity is gauged based on the number and type of parts required. The number of parts is used as a measure of complexity because designing a product with many parts typically involves several design engineers who must coordinate their efforts.

For most small manufacturers, high-complexity, A-rated products are those with 50 or more parts, or with parts that will be largely designed in-house, which may present significant technological challenges for the design engineers; medium-complexity, B-rated products are those with between 20 and 50 parts, the majority of which will be purchased; and low-complexity, C-rated products have 20 or fewer parts, the majority of which will be purchased. It should be noted that the numbers cited are relative: for some well- established companies a highly complex product may have over 500 parts while a mid-level product might have 200. A particular product's rating must be based on the company's experience and capabilities.

Design Standardization. Either customer demands or the requirements of regulatory or other standards may restrict the potential number of design concepts that can be considered. An A rating is appropriate when there are few governing standards or specifications and many possible designs and approaches can be considered; a B rating should be given when standards or specifications may restrict parts of the design, but there is still significant room for exploring different concepts; and a C is appropriate when the number of concepts that can be considered is severely limited.

Analytical Resources. Ratings for this criterion are based on the amount of analysis required to complete the design and the analytical tools available. Such tools can include CAD systems, finite-element analysis codes, prototypes, or other methods used to verify the design before manufacturing. An A-rated product requires high levels of analytical resources, such as multiple prototypes at various stages of the design cycle and an in-depth analysis, computer aided or otherwise. A B-rated product requires fewer analytical resources, with some prototyping and computer-aided analysis, while a C-rated one needs only light prototyping and little or no computer-aided analysis.

Design Cycle Time. Long-term, medium-term, and short-term projects would be ranked A, B, and C, respectively. Again, this measure must be determined by the company, and be based on the time that the project is expected to take relative to that required by other projects in the organization.

Expected Level of Precision, Reliability, and Durability. In this category, a product would be rated A if high levels of precision, reliability, and durability are required. A product that satisfies all three of these requirements must be tested extensively under all expected operating conditions and must withstand excessive use and abuse. B and C ratings would be given if only medium or low levels of these characteristics were required.

Process Complexity. A product may be manufactured using a number of different processes, such as machining, injection molding, wave soldering, stamping, and casting. If many processes are necessary to manufacture and assemble the product, it should be rated A; if several processes are necessary to produce it, it should be rated B; and if few manufacturing processes are necessary, it should be given a C.

Supplier Requirements. This category reflects the level of supplier involvement in the product development process. When the product will include many components from outside suppliers and these parts are critical to the success of the design, a high level of supplier involvement will be needed and the product should be rated A. Similarly, a B-rated product requires that some suppliers be consulted during the design process, and a C-rated product is one that requires few or no parts or input from suppliers.

Project Size and Scope. A product design may require input from one or more engineering disciplines, such as mechanical, electrical, chemical, and software. A-rated products are those that require several engineering disciplines to participate in the design process, B-rated products require that representatives of only two disciplines work together, and C-rated ones require input from only one engineering discipline. The latter rating may include projects where the primary component of the new product will be purchased or will be designed in-house by a mechanical engineer.

Priority. The priority of a project is established on the basis of four factors: the customers' required delivery date (or the market's window of opportunity), the importance of the customers and their required level of satisfaction, the amount of capital invested in the product's development and manufacture, and the product's potential profitability. An A rating is an indication that all four factors are important, a B rating indicates that two or three factors are important, and a C rating suggests that only one of the factors is considered important.

Risk Analysis. In this assessment exercise, the term risk analysis is applied to the potential marketing life cycle of the product. For example, the manufacturer of a simple tool is likely to have a single product on the market for many years, while a computer manufacturer's product may be obsolete within six months of its release. The potential for discontinuing the project because of a volatile market should also play a role in risk analysis and priority evaluation. Low-risk, A-rated products are those that are least likely to be discontinued and are likely to have a long market life; moderate-risk, B-rated products are those where the market risk and design and development investment are in balance; and high-risk, C-rated products are those that are very likely to be discontinued and have a short-term market life.

Cost. A, B, and C ratings indicate high, medium, and low design and production costs, respectively. To accurately evaluate such costs, the project must be thoroughly researched by marketing and sales personnel, and cost estimators should be used at the outset. Cost estimation may be based on a product's prior design history or on market research.

Upon completion of the project assessment chart, the results are entered on a bull's-eye graph. The plot was devised to provide an indication of the optimal composition of the design team and the appropriate concurrent engineering model. It is divided into three rings, labeled A, B, and C, and 12 numbered sectors representing the categories on the assessment chart.

Based on which ring the most points are plotted in, a best concurrent engineering model is recommended to use. The scattering of points in the bull's-eye plot's 12 sections indicates which company functions the design team should be drawn from. [44]

3.2.2 Concurrent engineering Profile™ Model

An concurrent engineering Profile™ Model was developed by Mitchell Fleischer and Jeffrey K. Liker, their model provides a checklist that can be completed in about 20 minutes that give you a quick answer to the question, "How are we doing?"

They created the concurrent engineering profile from the structure of the five elements; they are work process, internal organization issues, supply chain involvement, people systems, and technology. They took each of the main topics in each element and created a set of questions about them. With only a few exceptions, each question is scored Yes/No. There are four requirements for a company to do a concurrent engineering Profile.

(1). Be informed. It is better for a company to work on the concurrent engineering Profile with a cross-functional team. (2). Live with uncertainty. For a Profile, maybe companies can not effort to really know all the answers. Do this fairly quickly with whatever information the company can gather at a relatively low level of effort. (3). Be conservative. If the company is unsure about how to answer because your realty is not quite so black and white as the Yes/No answers, make the answers conservative. (4). Be honest. Do not kid yourself, it would not help company to stay in business if cheat to get a high score.

Any Yes/No type of assessment can never be extremely accurate. An in-depth assessment inevitable takes lots of time and effort, and user have to find a balance between accuracy and the effort involved.

After answering each question in the concurrent engineering Profile questionnaire (Total 96 questions), you will get your raw score, your raw score is the number of times you checked "Yes" under each element. Multiply your raw score for each element by its weight. This gives you a weighted score for each concurrent engineering Element. The maximum possible total score is 100.

They suggest a very familiar method for interpretation of this type of scoring:

90-100 = A : outstanding structure and processes for CE

80-90 = B : good structure and processes for CE

70-80 = C : marginal structure and processes for CE

60-70 = D : could do a whole lot better at structure and processes for CE

below 60 : is not suitable for CE

There are two types of scores will be get out of the concurrent engineering Profile. The first is the total concurrent engineering score. What it tells is how effective your context and support systems are for concurrent engineering. If we have a low total score, our systems to support concurrent engineering are weak. If we improve them, we will likely improve the effectiveness with which we can do concurrent engineering and sustain that success in the long run. This type of scores tells us if we need to change at all, but it does not tell us anything about what should change. The second type of score is the concurrent engineering Element score, those for Work Process, Internal Organization, etc. Low element scores indicate weaknesses in the five specific areas. Working on low score areas would probably result in the biggest improvement in support for concurrent engineering. [31]

3.3 New Assessment Model

3.3.1 The problems of existing concurrent engineering assessment model.

From the introductions of above, we can see that both of these models are highly subjective and not very accurate, they both focus on where we are now, they do not care about where you were yesterday, and where you will go to tomorrow.

Assessment Chart give user three rates to choose from, A, B or C; concurrent engineering Profile™ Model only give user two rates to choose from, just Yes or No. These types of assessments are highly subjective and can never be extremely accurate. Another very important problem is that they only assess the right now situation, they do not assess the past situation, and the future situation, for example, for a high growing company, its assessment results maybe is not good enough to implement concurrent engineering in company, but actual situation maybe is it is a good time to implement concurrent engineering in company, because the company is growing very fast. For a company which is in its downward situation, also its assessment value is high enough to support the company to implement concurrent engineering, but the actual situation maybe is it is not a good time to implement concurrent engineering in the company, because the company is going down, the company's situation will be worse.

Nowadays, there are lots of books and journal papers about concurrent engineering, each of which has its own model. Why create yet another one? In looking at the existing models of concurrent engineering assessment model, we find that most are not really models, but rather lists of processes or tools or activities which seem to be associated with effective concurrent engineering. Most of these models look like a questionnaire; same as two models we introduced at previous chapter, no model is a mathematical model. We want to say that there is nothing wrong with these models; they are all "true" in some sense. But they are unorganized and include items of varying specificity. They all focus on the present situation; they do not consider the company's context, company's history. In contrast, we want a simple, organized mathematical model which describes the history and the future of company, assessing the company's performance, exposing practical problems and identifying potential improvements.

3.3.2 The new model factors

We still can create the new assessment model from the structure of the five elements; they are work process, internal organization issues, supply chain involvement, people systems, and technology. In each element, we can define several factors, total 30 factors, each factor's value can be any number from 0 to 10, "0" denote most weak value, does not support to implement concurrent engineering, "10" denote most strong value, strongly support to implement concurrent engineering.

3.3.2.1 Work process:

The "work processes" of product development are the set of activities and the connections between those activities that are used to develop a product and the processes for making it. They include:

- Activities: this is the actual work that adds value to the product, e.g., creating specifications, collecting information on customer wants, making a sketch of a mechanical part, creating a 3-D model, building a prototype.

- Flow of information and physical objects between activities: A few activities can proceed independently, while most require information from other activities. Delays in the flow information may cause delays in downstream activities. The flow information can be modeled and planned.
- Ordering and timing of activities: some activities can occur in parallel, while others can only begin when another activity is complete. In the case of design, this is generally because they must wait on information from the prior activity. In some cases, the wait is due to capacity constraints. By modeling and planning the order and timing of activities, we are in a better position to monitor and ensure they take place when desired.
- Control mechanisms: these are the mechanisms used to ensure that activities remain aligned and that the project remains on target. Most companies will have some mechanism in place to ensure the project will meet its goals, but few also work to make sure activities remain aligned. By, we mean how well activities fit together.

A complete model of work processes needs to address all four of these elements. None of the commonly used modeling methods does a really complete job of providing such a model. We will choose following factors as our model factors:

(1) Design Type and Product Complexity. The type of design can vary from a completely new product, which would be rated 0 to 2, to a simple feature change, such as adding a function or modifying some aspect of the user interface, which would be rated 8 to 10, this rating would be used when some of the decisions about the design have already been made because it will be based on a previous model, but substantial changes in the product's structure or function are to be made. In rating this category, the product is viewed at a micro level and its complexity is gauged based on the number and type of parts required. The number of parts is used as a measure of complexity because designing a product with many parts typically involves several design engineers who must coordinate their efforts. For most small manufacturers, high-complexity, "0

to 3"-rated products are those with 50 or more parts, or with parts that will be largely designed in-house, which may present significant technological challenges for the design engineers; medium-complexity, "4 to 6"-rated products are those with between 20 and 50 parts, the majority of which will be purchased; and low-complexity, "7 to 10"-rated products have 20 or fewer parts, the majority of which will be purchased. It should be noted that the numbers cited are relative: for some well- established companies a highly complex product may have over 500 parts while a mid-level product might have 200. A particular product's rating must be based on the company's experience and capabilities. [52]

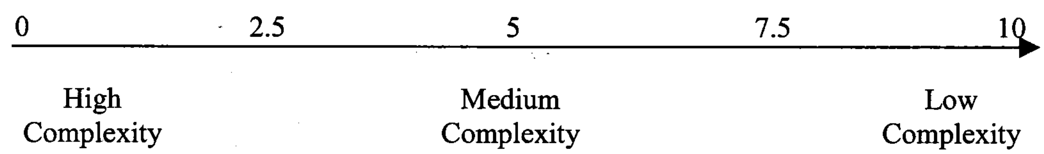

Figure 6. Design type and product complexity rating.

<u>(2) Design demands and cycle time</u>. Either customer demands or the requirements of regulatory or other standards may restrict the potential number of design concepts that can be considered. An "0 to 3" rating is appropriate when there are few governing standards or specifications and many possible designs and approaches can be considered; a "4 to 6" rating should be given when standards or specifications may restrict parts of the design, but there is still significant room for exploring different concepts; and a "7 to 10" is appropriate when the number of concepts that can be considered is severely limited. Long-term, medium-term, and short-term projects would be ranked from 0 to 10, respectively. Again, this measure must be determined by the company, and be based on the time that the project is expected to take relative to that required by other projects in the organization.

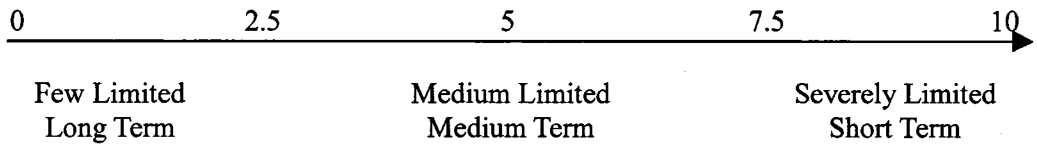

Figure 7. Design demands and cycle time rating.

(3) Design Standardization. Either customer demands or the requirements of regulatory or other standards may restrict the potential number of design concepts that can be considered. A 0 to 4 rating is appropriate when there are few governing standards or specifications and many possible designs and approaches can be considered; a 4 to 6 rating should be given when standards or specifications may restrict parts of the design, but there is still significant room for exploring different concepts; and a 6 to 10 is appropriate when the number of concepts that can be considered is severely limited.

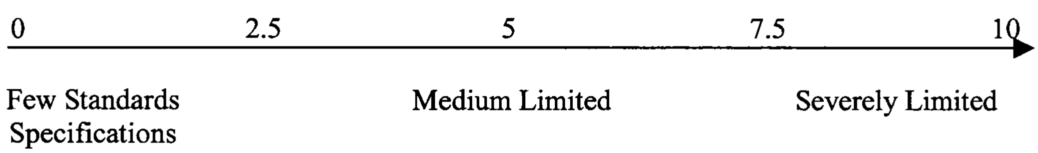

Figure 8. Design Standardization.

(4) Design and Production Costs. A 0 to 4 rating indicate high design and production costs; A 4 to 6 rating indicate medium design and production costs; a 6 to 10 indicate low design and production costs. To accurately evaluate such costs, the project must be thoroughly researched by marketing and sales personnel, and cost estimators should be used at the outset. Cost estimation may be based on a product's prior design history or on market research.

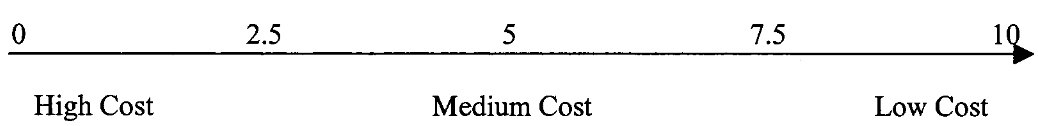

Figure 9. Design and Production Costs rating.

(5) The flexibility of Manufacturing Systems. Manufacturing flexibility could refer to the capability of a manufacturing system to adapt successfully to changing environmental conditions, as well as changing product and process requirements. It could refer to the ability of the production system to cope successfully with the instability induced by the environmental. Flexibility provides the manufacturing plant the ability to maintain customer satisfaction and profitability under conditions of change and uncertainty. There are total seven types of flexibility in manufacturing: machine flexibility, production flexibility, mix flexibility, product flexibility, routing flexibility, volume flexibility, and expansion flexibility. According to how many types of flexibility do a company have, we can rate this company at different level. [52]

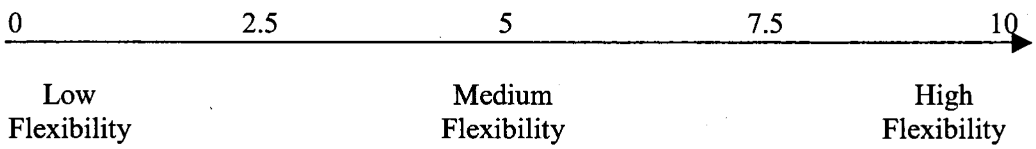

Figure 10. The flexibility of manufacturing systems rating.

(6) Process Complexity. A product may be manufactured using a number of different processes, such as machining, injection molding, wave soldering, stamping, and casting. If many processes are necessary to manufacture and assemble the product, it should be rated 0; if several processes are necessary to produce it, it should be rated 5; and if few manufacturing processes are necessary, it should be given a 10.

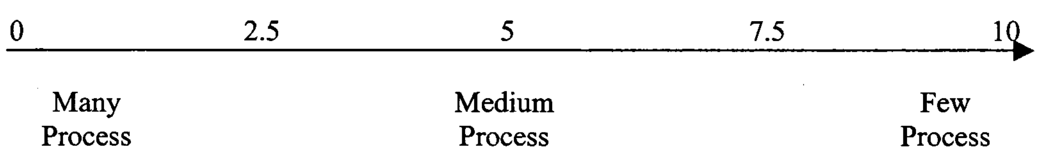

Figure 11. Process complexity rating.

(7) Quality Control System. In the 1980s, the issue of quality control became a national concern in the United States. The automobile industry had demonstrated that high quality cars could be

produced at relatively low cost. How did the automobile company achieve such great success in manufacturing? There is no single answer that explains their success. It was a combination of factors, including: (1) a well developed work ethic and orientation toward quality that is instilled into workers, (2) design features incorporated into products that reduce labor content and increase reliability and quality, (3) a philosophy of continuous improvement, and (4) attention to the use of QC techniques. Quality control has traditionally been concerned with detecting poor quality in manufactured products and taking corrective action to eliminate it. Operationally, QC has often been limited to inspection of the product and its components and deciding whether the measured or gauged dimensions and other features conformed to design specification. The modern view of QC encompasses a broader scope of activities that are accomplished throughout the enterprise, not just by the inspection department. The position of the quality control systems in the larger production system is shown in figure 10.

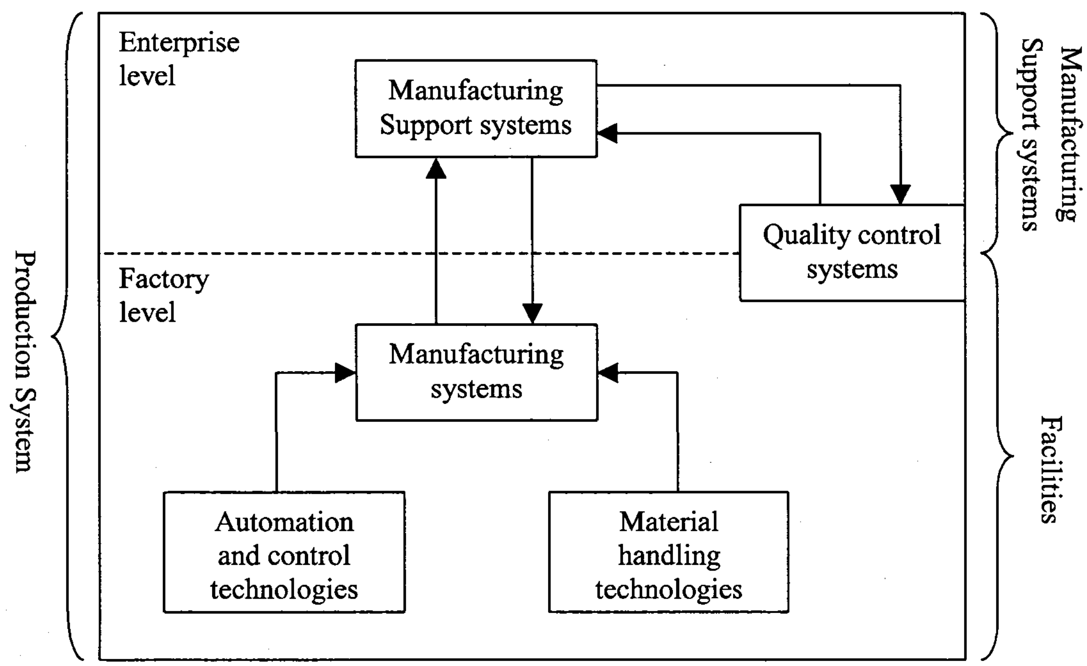

Figure 12. Quality control systems in the production system.

Traditional quality control focuses on inspection. In many factories, the only department responsible for quality control is the inspection department. Total quality management is the next level quality control system; it denotes a management approach that pursues three main objectives: achieving customer satisfaction, continuous improvement, and encouraging involvement of the entire work force. ISO quality control standard establishes standards for the systems and procedures used by a facility that affect the quality of the products and services produced by the facility. The standard includes a glossary of quality terms, guidelines for selecting and using the various standards, models for quality systems, and guidelines for auditing quality systems. ISO quality control standard is concerned with the set of activities undertaken by a facility to ensure that its output provides customer satisfaction. According to company's quality control system, we can rate company from 0 (No quality control system) to 10 (ISO quality control system).

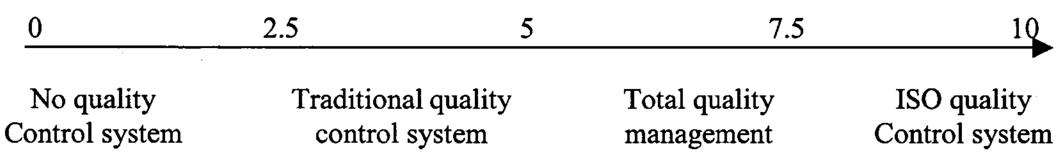

Figure 13. Quality control systems rating.

3.3.2.2 Internal organization issues

This includes reporting relationships, project management structure, job descriptions, communication, coordination mechanisms, and performance measurement systems. The internal organization is important because it is the social infrastructure for getting work done in complex systems. In a traditional organization the focus is on staffing individual functions, and on the parts of the system. In Concurrent Engineering the focus is on monitoring, communication, and coordination mechanism to ensure that the various parts of a design project actually work together.

(8) Organization Architecture. Functional organization, functional organizations group people by the kind of specialized activity they perform. Generally this involves a core work process and a certain body of specialized knowledge and skill. In the product organization, individuals are grouped based on their contributions to a particular type of output, such as products or services. In a pure product organization, once the category of output or customer grouping is defined, all of the specialists who are needed to produce that output or service for that customer grouping are put together in a self-contained organization unit. Matrix organization combines functional and product organizations. This is often used in engineering organizations where tasks are grouped into projects. Each person has at least two bosses – one functional manager and one product manager. There are many variations on the pure types we just described. For example, functional organizations are often nested within product organizations. In fact, most organizations of any size or complexity are likely to be some hybrid – pure organizational forms are the exception, not the rule. There is no perfect organizational architecture. Each has its benefits and disadvantages. for this thesis research direction, the hybrid organization is most positive for concurrent engineering, and the functional organization is most negative for concurrent engineering. [40]

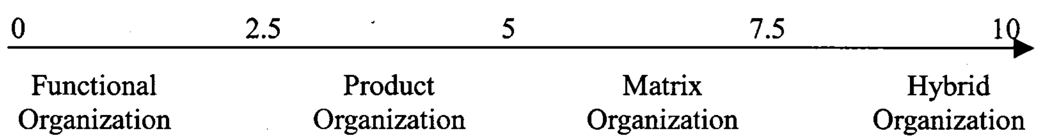

Figure 14. Organization Architecture rating.

(9) Project Management Structures. Concurrent engineering is often organized around projects. The project management structure describes the assignment and distribution of administrative and relationship responsibilities and authority for specific projects. We can divide project management structure into the following five types: absent, liaison, lightweight, heavyweight, and autonomous. Absent means project manager in a pure functional organization. The role of

maintaining the linkage between two organizations is known as a liaison role, the liaison usually reports to one department and is responsible for coordinating between the home department and a target department. The lightweight project manager is often a design engineer or product marketing manager, mainly responsible for such coordinating activities as sharing information across functional groups, setting project goals, scheduling, updating time lines, and expediting across groups. The heavyweight project manager directly supervises project members' work, and may be responsible for their hiring and evaluation for the project, although overall performance evaluation and longer term career development usually rests with a functional manager. In the autonomous project management structure, the project manager has full control over members of the project, including hiring, firing, and evaluation. The rating is shown as figure 15. [40]

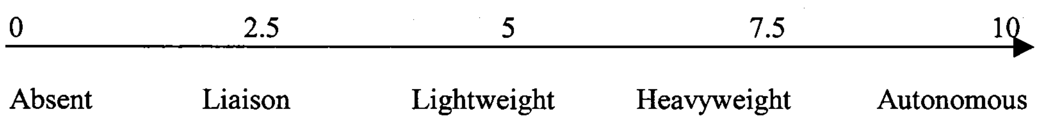

Figure 15. Project Management Structures rating.

(10) Distance. The distance between two individuals will influence the need for coordination, and finally it will influence the implement of concurrent engineering. The distance includes physical distance, organization distance, and culture distance. Physical distance means people in different states or even different countries can not spontaneously have a face to face meeting and would not naturally run across each other each day. Organizational distance can be crudely measured by the number of steps in the hierarchy an individual must go through to reach another individual. Count up from the first person to a common boss or boss's boss and then count down to the second person. Organization distance is almost as important as physical distance. Thus, two engineers who are located in adjacent offices may find it hard to collaborate because of their location in the organization structure. Culture distance arises when several distinct cultures have conflicting beliefs or values. This can occur between different firms, or within a firm. There are

many different ways to slice up and combine organizational members to identify distinct cultural groupings. We can give a overall value for these three types of distances. [40]

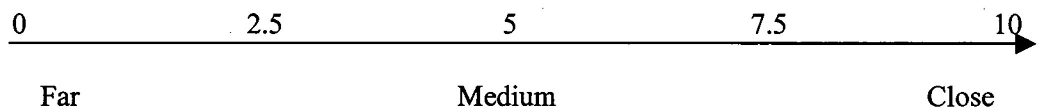

Figure 16. Distance rating.

(11) Standardization of Work Processes. The standardization of work processes means that there are specific rules for how work gets done. In some sense, this means the work can be programmed to follow a specific set of steps and approaches, but not necessarily in the sense of being programmed for performance by a computer. Jobs that can be heavily programmed in this way would have low task uncertainty. If we look at the work of product development, it should be obvious that the work of designers and design engineers can not be programmed in the same way assembly line task can; thus they have relatively high task uncertainty. On the other hand, we see a wide variety of rules and standards for how design work is to be done. Some of these rules, such as DFM rules, define the interfaces between functions, others define how parts of the work will be done, which helps ensure that coordination issues will not arise. There are at least five approached to standardizing work processes: standard operating procedures, planning and scheduling systems, monitoring systems, structured development processes, and tools and techniques.

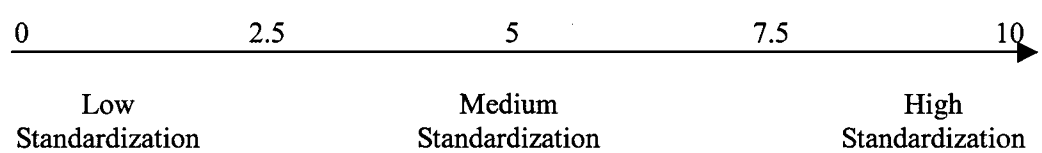

Figure 17. Standardization of Work Processes rating.

(12) Monitoring Systems. Once standards and targets have been set, monitoring systems are needed to provide a feedback loop on how the project is doing. Anything one can observe or measure can be monitored – quality of final or intermediate work products, amount of activity, schedule compliance, compliance with standardized practices, and so on. In the traditional view, monitoring systems are a means to simply control workers. Manager can look at the measures and reward or discipline workers as appropriate. In fact, the measures are often designed to be tamper proof and may not even be shown directly to the workers. By contrast, as an enabling mechanism, monitoring systems are an important source of feedback to workers. In general, it is known that measures are only used to externally control people and are tied to external rewards and punishment, a serious negative consequence will follow: people will work to manipulate the measures regardless of whether this is effective in reaching project objective. This leads to inaccurate information, wasted effort beating the system, and misdirected activity.

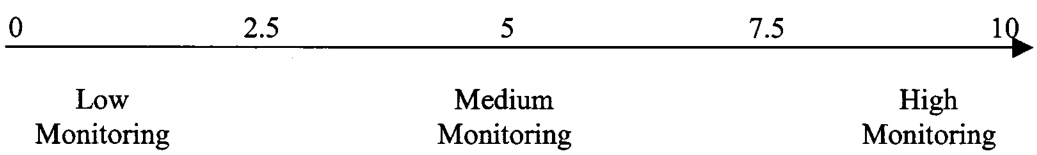

Figure 18. Monitoring Systems rating.

(13) Organization Culture. For many engineers, "culture" seems to be just about anything "soft" that they can not measure using engineering methods. Even for many managers, culture seems to be anything in organization that they just do not know how to deal with by the usual management tools. For many people, culture really represents the mysterious, the unknown, the unknowable, the dark side of the organization. And indeed, when we look more formally at culture, there are some aspects of this that is an unknown part of the organization. We can define culture as follows: "A pattern of shared basic assumptions that the group learned as it solved problems of external adaptation and internal integration, which has worked well enough to be considered valid and

therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems." Usually there are three levels of culture. First level is Artifacts. These are visible organization structures and physical objects. Artifacts are relatively easy to find, but often hard to understand. Second level is Espoused Values. These are strategies, goals, and philosophies that are openly stated. Third level is Basic Underlying Assumptions. These are beliefs and feelings that are unstated and taken for granted.

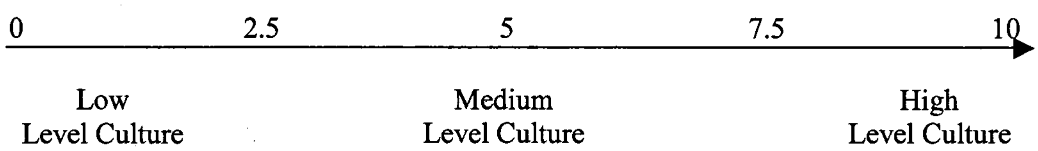

Figure 19. Organization Culture rating.

3.3.2.3 Supply Chain Involvement and Financial Resources.

For most manufacturing companies, a very large percentage of their product is actually made by their suppliers, who produce the individual parts and components which make up the product. These "supplied components" are often in critical areas of the product, yet just as often suppliers are almost an afterthought in the product development process. Typically, a manufacturer will design a product and all of its non-commodity parts, and then go look for a supplier to make those parts which can not be made efficiently in-house. Just given what we know today about the need to design for manufacture and assembly, it is quite clear that such an "arm's length" relationship is no longer viable. If it makes sense for manufacturing to be involved up front with engineering in the early stages of product development, then it also makes sense for suppliers to be just as involved; otherwise the benefits of early involvement by manufacturing will only be obtained for that small production of parts made in-house.

Early and strong involvement of suppliers in product development is a hallmark of best practice in CE. Unfortunately, many companies treat their suppliers like they were the enemy – to be taken advantage of as much as possible, and then forgotten until the next time they are needed. Ideally, the product development process of the suppliers should be seamlessly integrated into the company's process. Even in the contractual role, where suppliers are building parts to customer specifications or supplying parts off the shelf, the supplier may play an important role in some stages, such as in the prototyping process. As suppliers move up the ladder of responsibility toward the partnership role, they will play a more integral part in your process. [45]

(14) Supply Chain Management. The primary objective of supply chain management is the elimination of barriers that inhibit communication and cooperation among different members of the entire supply chain. To eliminate these inter-organizational barriers, managers must understand and manage the flow of goods and information from the initial source of raw material all the way to the final customer. The typical supply chain involves the firm various tiers of materials suppliers, service providers, and one or more levels of customers. The essence of supply chain management is for the firm to focus on doing exceptionally well a few things for which the firm has unique skills and advantages. Non-core activities and processes are then obtained from firms that possess superior capabilities in those areas, regardless of the firms' position in the supply chain. Close relationships are formed to assure outstanding and seamless performance levels. The most successful supply chain team are those that not only have the best players but that have established true chemistry – a common understanding of supply chain success factors, an understanding of individual roles, an ability to work together, and a willingness to adjust and adapt in order to create superior value for the customers. [50]

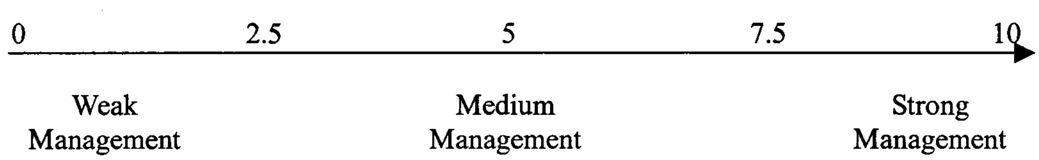

Figure 20. Supply management rating.

(15) Supplier Requirements. This category reflects the level of supplier requirements in the product development process. When the product will include many components from outside suppliers and these parts are critical to the success of the design, a high level of supplier requirement will be needed and the product should be rated 0.0. Similarly, a 5.0-rated product requires that some suppliers be consulted during the design process, and a 10-rated product is one that requires few or no parts or input from suppliers.

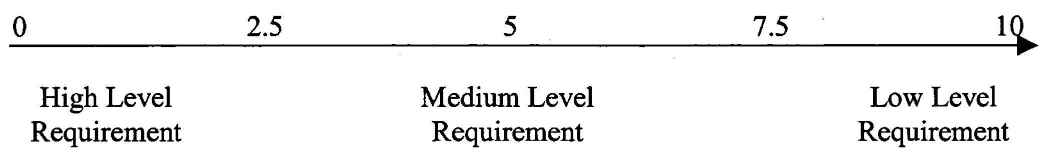

Figure 21. Supplier Requirements rating.

(16) Supplier Involvements. This category reflects the level of supplier involvements in the product development process. When the product will include many components from outside suppliers and these parts are critical to the success of the design, we need involve suppliers in design. A high level of supplier involvement will be needed and the product should be rated 1.0. Similarly, a 0.5-rated some suppliers are consulted and involved during the design process and a 0.0-rated product is one that few or no involvement from suppliers.

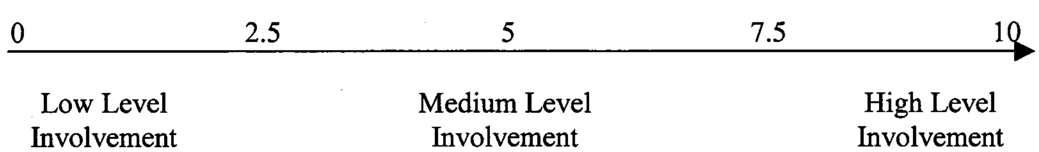

Figure 22. Supplier Involvements rating.

(17) Supplier roles in product development. There are many different roles in which the nature of the relationship varies substantially. We can divide these roles into four levels: contractual,

consultative, mature, and partner. The contractual role is not very different from a traditional "parts supplier" role. The customer designs the component and only asks the supplier to provide simple parts. A complete design is provided to the supplier who has virtually no influence on the specifications. The consultative role brings the supplier more fully into the product development process. The supplier may provide a simple assembly and have a joint responsibility for product development with its customer. The mature role shifts much more responsibility to the supplier. Typically they are producing a complex assembly. The customer only provides critical specifications and the supplier does all the design work. This negotiation process can enable new capabilities which the supplier has developed to be brought into the early product design, or it may simply allow the specifications to be set more realistically. The partner role is the ultimate full service supplier. The supplier is involved from the very beginning in their customer's product development process, and is responsible for a complete system or subsystem. The customer provides a concept for the overall product, while the concept for the supplier's particular subsystem is likely to be based on collaboration between the customer and the supplier. The supplier is apt to have extensive long-term R&D capabilities, and to be leading the industry in that subsystem technologically. In effect, they can as a specialty subsidiary of the customer and are given the trust and responsibility of an internal organization.

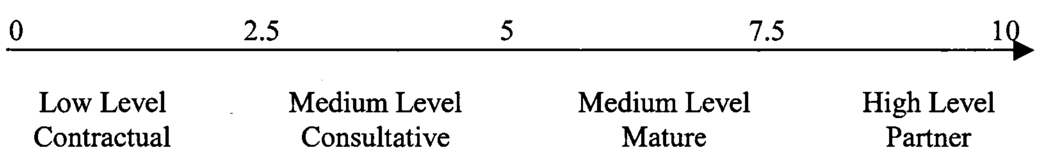

Figure 23. Supplier roles in product development rating.

<u>(18) Financial Resources.</u> This is primarily concerned with the availability of financing, including characteristics of the stock market, banks, and private investors. While these will appear to be relatively constant, the financial resources environment reacts differently to different companies.

Thus, one member of the chain may find it easy to obtain financial resources, while another may have great difficulty.

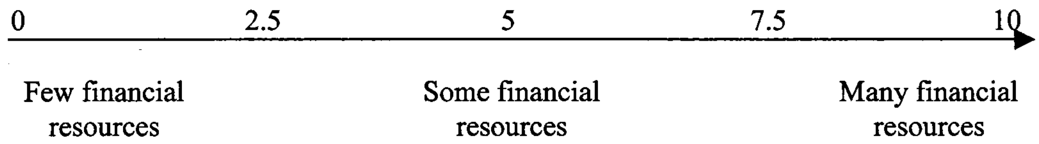

Figure 24. Financial Resources rating.

3.3.2.4 People Systems

So far we have talked about the work that needs to be done and the organizations in which it will take place. But organizations do not design things, people do. People systems are those parts of the organization which help bring the right people with the right skills together and motivate them to work toward common organizational goals.

The people systems in any company take up a very large portion of its effort, from performance appraisals to health and safety programs to benefits plans to hiring and firing processes. While all of these systems are needed to run a company, they do not all have a significant impact on concurrent engineering. There are three primary people systems which have the greatest impact on concurrent engineering and which often need to be changed in order to do concurrent engineering effectively. These are job design, skill acquisition systems, and motivation systems.

(19) Job design issues in concurrent engineering. Job design is the process of taking a set of work tasks and combining them into a "job" that a person can perform. This does not imply that a "job" is something a person does all alone. Work (especially product development work) obviously involves a lot of interaction with others, on both a one-on-one and a larger team basis. Nonetheless, each individual person has a job, and should know what tasks he/she is to perform, even if those tasks include working with others.

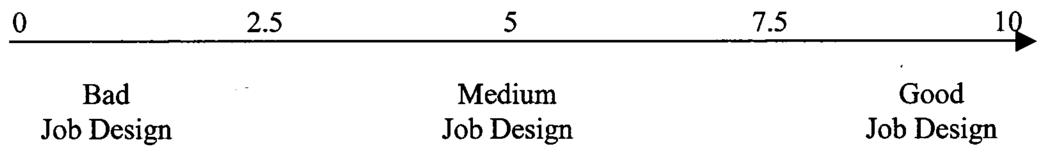

Figure 25. Job design issues in concurrent engineering rating.

(20) Skill acquisition systems. Job designs pretty much determine what skills are needed for each position – if you know what you want an individual to do, you are then in a position to know what skills he/she will need to do those things. We will focus on the kinds of skills necessary to improve concurrent engineering. These skills usually can be divided into two parts: technical skills and social skills. Technical skills are those required to do the work of their job, and required to work together with those from other functions. These are needed to enable the individual to understand what the other function does, to communicate needs to the other function, and to understand needs expressed by the other function. Social skills are required in order to be able to work with other people. It is a common stereotype of engineers that they lack social skills. As with many stereotypes, this one holds a germ of truth – many engineers to tend to focus more on technical details and less on the social situation in which those technical details will be used. This may result in the engineer having the right answer, but not being able to get anyone to listen to it. Or it may result in the engineer having the right answer to the wrong question, since he/she did not spend enough time listening to what was wanted. These social skills include communication skill, conflict resolution skill, group facilitation skill and leadership skill. [53]

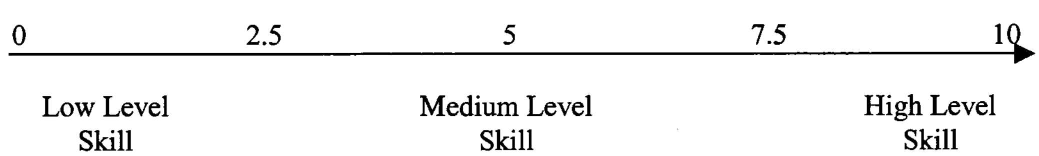

Figure 26. Skill acquisition systems rating.

(21) Motivation toward common goals and appraisal systems. The final people system element that affects how concurrent engineering works is the system to motivate people to work toward common goals and appraisal systems.. There are two related methods used by most organization to enhance and maintain motivation: measurement and rewards. Both have traditionally caused people to focus primarily on local, functional interests, but both can be used effectively to motivate people toward concurrent engineering. Everyone needs feedback on their performance. In particular, they need feedback about how well they are doing toward meeting their individual goals and how well they are contributing toward their group goals. This feedback is the purpose of an appraisal system. The essential features of a good appraisal system are that it be fair and accurate. [53]

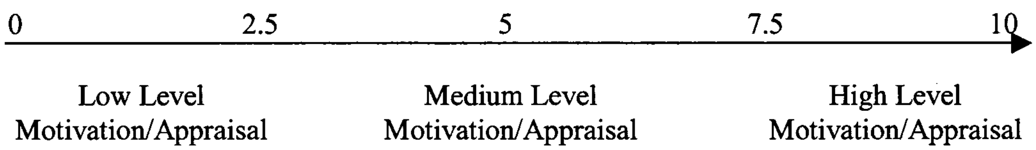

Figure 27. Motivation toward common goals and appraisal systems rating.

3.3.2.5 Technology

The final piece in our model for assessing concurrent engineering is technology. Technology includes all of the tools and methods used by people in the product development process. We will focus on how these tools and methods affect implement concurrent engineering in a company.

Technology is vitally important in concurrent engineering because technology mediates many of the work processes performed during product development. If we can think of the fundamental work being done during product development as a series of decisions, with the results being stored and managed in some way, then it becomes easy to see why technology plays such a central role. Designs are created using computer aided design (CAD) systems, analyzed using computer aided engineering (CAE) systems, stored in databases, accessed and managed with product data management (PDM) systems, and communicated to others using computer networks. In a sense, the work of product development and its technology is inextricably linked. The very nature of the work changes depending on the technology being used. Work process which once required a series of manual steps being done by different people and which were difficult to coordinate are now tightly integrated, to be performed by one or two people, and instantly communicated to anywhere in the world. Our primary emphasis in technology is its ability to help integrate across various boundaries, be they functional boundaries inside a company, boundaries between companies, or operational boundaries between steps in a work process. Technology affects and is affected by three primary concurrent engineering elements: work process, internal organization, and supplier relations (Figure 23). The internal organization and supplier relations provide the concurrent engineering requirements for the technology. The work process provides work requirements for the technology. The technology also "pushes back" on the work process, in work possible and other kinds impossible. Finally, the technology influences skill, motivation, and job design requirements of the people systems which must be considered when designing the technical systems.

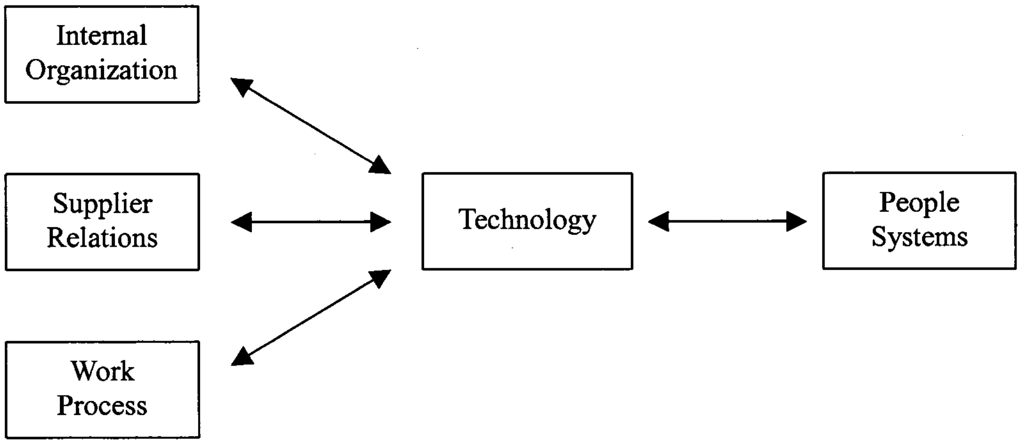

Figure 28 . Technology and work process, internal organization, and supplier relations.

(22) Communication Technologies: The essence of concurrent engineering is that all the necessary design inputs are introduced as early as possible, so that the design evolves from a correct basis and separate activities can be carried out in parallel. Electronic mail and communications networks are powerful tools for rapidly communicating information and for providing to wide audiences easy access to product and project data. Information can also be stored on centralized computer aided design (CAD) databases. Data captured in these systems can be accessed by persons located around the world for use in product design, process planning, and computer aided manufacturing. [21]

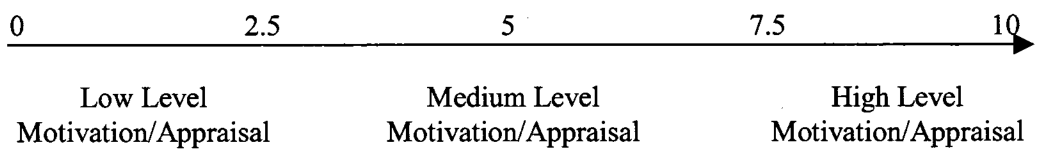

Figure 29. Communication Technologies rating.

(23) CAD/CAM/CAE systems: Computer aided engineering (CAE) tools are frequently linked to CAD systems in ways that reinforce good design practices. These sophisticated systems create and analyze three-dimensional models of parts and assemblies, reducing the need to build expensive and time consuming physical prototypes. For example, CAD/CAE systems can automatically analyze assembly designs to identify areas of potential interference between parts. Further, many CAD systems embed process information and design rules directly into the design software so that they may be linked to certain design features. For example, when a designer draws a hole, he can then select a pull down window of information providing a list of processes that could create the hole, typical dimensional tolerance, defect rates associated with each process, and any other design rules related to the feature. Some companies have developed "expert systems" that aid the evaluation of design choices. In addition, numerous off the shelf CAE systems address stress and thermal analyses, mechanical assembly, printed circuit board (PCB) design, and integrated circuit (IC) design. [56]

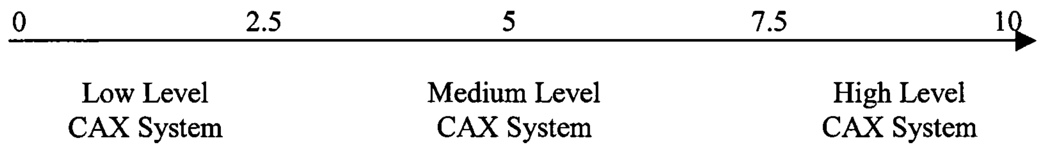

Figure 30. CAD/CAM/CAE systems rating.

(24) Product Data Management (PDM): The complexity of implementing concurrent engineering through an organization has proved to be a major obstacle in achieving anticipated results, implementing it is a painful process in which a complete top to bottom understanding of an organization's processes is needed. There are few organizations which understand their own dynamics. For concurrent engineering to be successful, cross-functional design teams, along with their associated data, must be brought together. PDM assists in implementing a concurrent engineering strategy successfully because PDM has ability to manage all the product data and the processes in which the data will be exchanged. In the Extended Enterprise, PDM offers the enabling infrastructure for fast exchange of product data. [24]

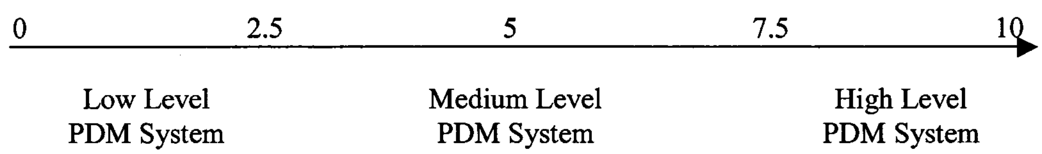

Figure 31. Product Data Management (PDM) rating.

(25) Group technology/Coding systems: in a company, designers often waste time and resources by unknowingly recreating existing designs. CAD systems can be linked with databases that contain information on preferred components, existing designs from other products and suppliers of purchased items. Group technology – based classification and coding systems enable designers to easily search design database for existing designs which meet their current needs. Similarly, databases which prioritize certain components and vendors can speed up a designer's search for

suitable parts. Coding systems also allow manufacturing planners to identify "families" of parts that have similar design or processing characteristics. These approaches reduce design time and reap enormous manufacturing benefits because fewer unique parts must be fabricated and inventoried, less special tooling is needed, production scheduling is simplified, and less disruption is experienced. [53]

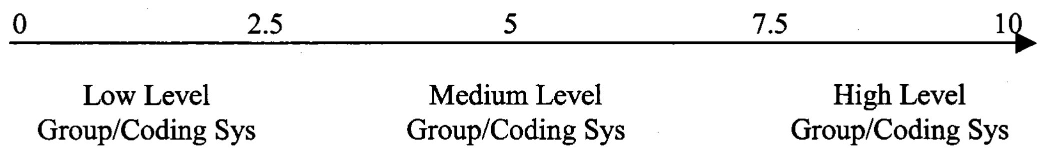

Figure 32. Group technology/Coding systems rating.

	Factor	0	2.5	5	7.5	10
Work Process	1. Design Type and Product Complexity	High Complexity		Medium Complexity		Low Complexity
	2. Design demands and cycle time	Few Limited Long Term		Medium Limited Medium Term		Severely Limited Short Term
	3 Design Standardization	Few Standards Specifications		Medium Limited		Severely Limited
	4. Design and Production Costs	High Cost		Medium Cost		Low Cost
	5. The flexibility of Manufacturing Systems	Low Flexibility		Medium Flexibility		High Flexibility

Table 2. The factors of element Work Process.

Work Process	6. Process Complexity	0	2.5	5	7.5	10
		Many Process		Medium Process		Few Process
	7. Quality Control System	0	2.5	5	7.5	10
		No quality Control system	Traditional quality control system		Total quality management	ISO quality Control system
Internal Organization	8. Organization Architecture	0	2.5	5	7.5	10
		Functional Organization	Product Organization		Matrix Organization	Hybrid Organization
	9. Project Management Structures	0	2.5	5	7.5	10
		Absent	Liaison	Lightweight	Heavyweight	Autonomous
	10.Distance	0	2.5	5	7.5	10
		Far		Medium		Close

Table 3. The factors of element Internal Organization Issues.

Internal Organization	11. Standardization of Work Processes	0	2.5	5	7.5	10
		Low Standardization		Medium Standardization		High Standardization
	12. Monitoring Systems.	0	2.5	5	7.5	10
		Low Monitoring		Medium Monitoring		High Monitoring
	13. Organization Culture	0	2.5	5	7.5	10
		Low Level Culture		Medium Level Culture		High Level Culture
Snpply Chain and Financial	14. Supply Chain Management.	0	2.5	5	7.5	10
		Weak Management		Medium Management		Strong Management
	15. Supplier Requirements	0	2.5	5	7.5	10
		High Level Requirement		Medium Level Requirement		Low Level Requirement

Table 4. The factors of element Supply Chain Involvement and Financial Resources .

Element	Factor	0	2.5	5	7.5	10
Supply Chain and Financial	16. Supplier Involvements.	Low Level Involvement		Medium Level Involvement		High Level Involvement
	17. Supplier roles in product development	Low Level Contractual	Medium Level Consultative		Medium Level Mature	High Level Partner
	18. Financial Resources	Few financial resources		Some financial resources		Many financial resources
People Systems	19. Job design issues in concurrent engineering	Bad Job Design		Medium Job Design		Good Job Design
	20. Skill acquisition systems	Low Level Skill		Medium Level Skill		High Level Skill

Table 5. The factors of element People Systems.

People Systems	21. Motivation toward common goals and appraisal systems	0 → 10	2.5	5	7.5	10
		Low Level Motivation/Appraisal		Medium Level Motivation/Appraisal		High Level Motivation/Appraisal
Technology	22. Communication Technologies	0	2.5	5	7.5	10
		Low Level Motivation/Appraisal		Medium Level Motivation/Appraisal		High Level Motivation/Appraisal
	23. CAD/CAM/CAE systems	0	2.5	5	7.5	10
		Low Level CAX System		Medium Level CAX System		High Level CAX System
	24. Product Data Management (PDM):	0	2.5	5	7.5	10
		Low Level PDM System		Medium Level PDM System		High Level PDM System
	25. Group technology/Coding systems	0	2.5	5	7.5	10
		Low Level Group/Coding Sys		Medium Level Group/Coding Sys		High Level Group/Coding Sys

Table 6. The factors of element Technology.

3.3.3 Constructing New Assessment Model

So far, we have got all scores we defined before; next we will construct a mathematics model to analysis the deep meaning behind these scores.

First, we can get the sum of these scores by using following formula:

$$S_f = \sum_{i=1}^{m} F_i \qquad (1)$$

Where S_f -- is sum of all factors' score.

m — is the numbers of total factors.

F_i – is the score of factor number i.

Next we will use moving average technique to get the average value of S_f, Moving averages are one of the oldest and most popular technical analysis tools. A moving average is the average value of a serious of values over a given time period (the period unit could be a month, a quarter, or a year). When calculating a moving average, we specify the time span to calculate the average value. The moving average represents the developing trend over the indicated period of time. If the value is above its moving average, it means that current expectations (i.e., the current value) are higher than their average ones over the last period of time, and that value are becoming increasingly higher. Conversely, if today's value is below its moving average, it shows that current expectations are below the average ones over the last period of time. The classic interpretation of a moving average is to use it in observing changes in values. Typically the value will up more when the value rises above its moving average and down when it falls below its moving average. By using an average of values, moving averages smooth a data series and make it easier to spot trends.

There are four different types of moving averages: Simple (also referred to as Arithmetic), Exponential, Smoothed and Linear Weighted. Moving averages may be calculated for any sequential data set, including each score, highest and lowest scores or any other values. It is often the case when double moving averages are used. The only thing where moving averages of different types diverge considerably from each other is when weight coefficients, which are assigned to the latest data, are different. In case we are talking of simple moving average, all scores of the time period in question are equal in value. Exponential and Linear Weighted Moving Averages attach more value to the latest values. So we will use Exponential Moving Average to calculate the average value of S_f,

Exponential Moving Average: Exponentially smoothed moving average is calculated by adding the moving average of the last value to the previous value. With exponentially smoothed moving averages, the latest scores are of more value.

The formula for an exponential moving average is:

$$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1} \qquad (2)$$

Where: n — is the number of calculation periods.

S_f — is sum of all factors' score.

A_n — is the current n-period exponential moving average.

A' — is the previous period's exponential moving average.

The most common way to interpreting the value of the moving average is to compare its dynamics to the value action. When the value rises above its moving average, upwards signal appears, if the value falls below its moving average, what we have is a downwards signal. From the formula of exponential moving average, we can see that the exponential moving average is a lagging indicator. For this reason, we will use another model to analysis the exponential moving average.

Convergence Divergence is one of the simplest and most reliable mathematics models available. It is used to analysis securities and stocks. Convergence Divergence uses moving averages, which are lagging indicators, to include some trend-following characteristics. These lagging indicators are turned into a momentum oscillator by subtracting the longer moving average from the shorter moving average. The resulting plot forms a line that oscillates above and below zero, without any upper or lower limits. Convergence Divergence is a centered oscillator and the guidelines for using centered oscillators apply.

The most popular formula for the Convergence Divergence is the difference between a value's longer periods and shorter period's exponential moving averages. Using shorter moving averages will produce a quicker, more sensitive and responsive indicator, while using longer moving averages will produce an insensitive and slower indicator. For our purposes in this thesis, the longer periods 6 and shorter periods 3 will be used for explanations.

$$C_d = A_3 - A_6 \qquad (3)$$

Of the two moving averages that make up C_d, the 3-period EMA is the faster and the 6-period EMA is the slower. The average values of each period are used to form the moving averages. Usually, a 3-period SMA of C_d is calculated and to be a compared with moving average convergence divergence. An upward crossover occurs when C_d moves above its 3-period SMA and a downward crossover occurs when C_d moves below its 3-period SMA.

Convergence Divergence C_d measures the difference between two moving averages. A positive C_d indicates that the 3-period EMA is above the 6-period EMA. A negative C_d indicates that the 3-period EMA is below the 6-period EMA. If C_d is positive and rising, then the gap between the 3-period EMA and the 6-period EMA is widening. This indicates that the rate-of-change of the faster moving average is higher than the rate-of-change for the slower moving average. Positive momentum is increasing and this would be considered upward trend. If C_d is negative and declining further, then the negative gap between the faster moving average and the slower moving average is expanding. Downward momentum is accelerating and this would be considered downward trend. C_d Centerline crossovers occur when the faster moving average crosses the slower moving average.

Simple Moving Average (SMA): Simple, in other words, arithmetical moving average is calculated by summing up the values over a certain number of single periods (for instance, 3). This value is then divided by the number of such periods.

$$S_{cd} = \frac{1}{n}\sum_{m=1}^{n} D_m \quad (4) \qquad \text{(Where: D — is } C_d\text{)}$$

By now, we have got two values:

1. One is the moving average convergence divergence C_d,

2. Another is simple average S_{cd} of the moving average convergence divergence.

From the analyses of moving average before, we know that when the value rises above its moving average, upwards signal appears, if the value falls below its moving average, what we have is a downwards signal, what this means is that upwards signal means the company is developing towards the positive direction, downwards signal means the company is developing towards the negative direction.

If we plot these two formulas on a chart, we will get a chart like this:

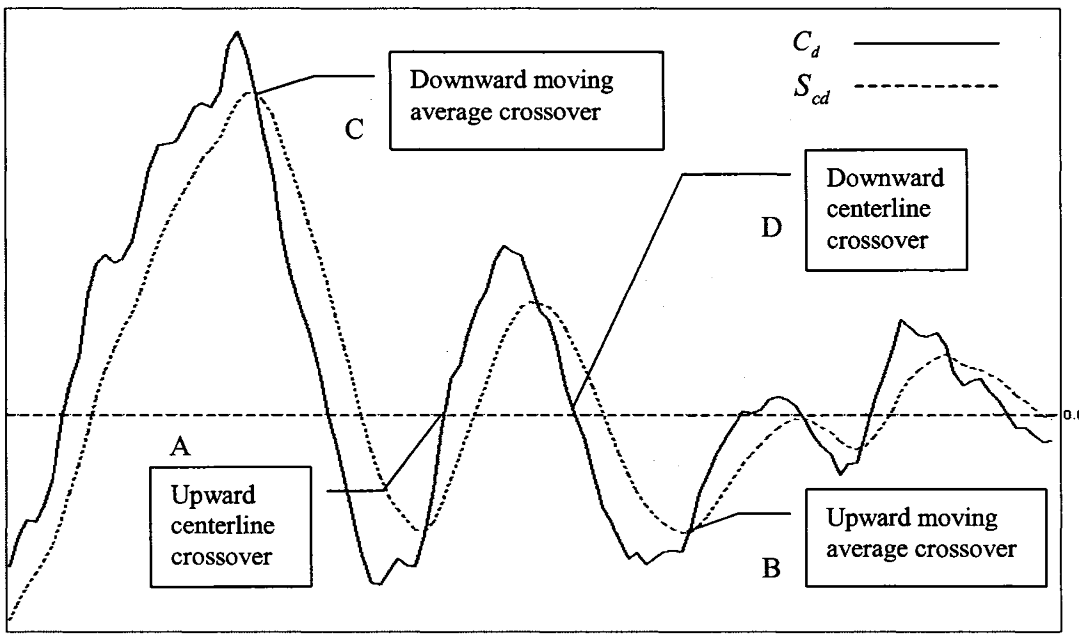

Figure 33. C_d and S_{cd} chart. (Guoli Jian)

These two values have four situations:

1. Situation A: Upward Centerline Crossover $C_d > 0$

An upward centerline crossover occurs when C_d moves above the zero line and into positive territory. This is a clear indication that momentum has changed from negative to positive, or from downward to upward. That means the company has an outstanding structure and processes for implementing concurrent engineering.

2. Situation B: Upward Moving Average Crossover $0 > C_d > S_{cd}$

An upward moving average crossover occurs when C_d moves above its 3-period SMA or trigger line S_{cd}. In this situation, the company does not have an outstanding structure and processes for implementing concurrent engineering, but if we consider that $C_d > S_{cd}$, this company still can implement concurrent engineering, because the company is developing toward a positive direction. We still can say that the company has a good structure and processes for implementing concurrent engineering.

3. Situation C: downward moving average crossover $S_{cd} > C_d > 0$

The most common signal for C_d is the moving average crossover. A downward moving average crossover occurs when C_d declines below its 3-period SMA. When a downward moving average crossover occurred, it signaled that upside momentum was slowing. This slowing momentum should have served as an alert to monitor the company's situation for further clues of weakness. Weakness was soon confirmed and C_d continued its decline and moved below zero. That means the company has a marginal structure and processes for implementing concurrent engineering.

4. Situation D: Downward centerline crossover $C_d < S_{cd} < 0$

A downward centerline crossover occurs when C_d moves below zero and into negative territory. This is a clear indication that momentum has changed from positive to negative, or from upward to downward. The centerline crossover can act as an independent signal, or confirm a prior signal such as a moving average crossover or negative divergence. Once C_d crosses into negative territory, momentum, at least for the short term, has turned downwards. That means the company is not suitable for implementing concurrent engineering.

The Benefits of Convergence Divergence C_d. One of the primary benefits of Convergence Divergence C_d is that it incorporates aspects of both momentum and trend in one model. As a trend-following model, it will not be wrong for very long. The use of moving averages ensures that the model will eventually follow the movements of the underlying value. By using exponential moving averages, as opposed to simple moving averages, some of the lag has been taken out.

As a momentum model, Convergence Divergence C_d has the ability to foreshadow moves in the underlying value. Convergence Divergence can be key factors in predicting a trend change. A negative divergence signals that upward momentum is waning and there could be a potential change in trend from upward to downward. C_d represents the convergence and divergence of two moving averages. The standard setting for C_d is the difference between the 12 and 26-period EMA. However, any combination of moving averages can be used. The set of moving averages used in C_d can be tailored for each individual value.

3.3.4 The Case Study.

For 35 years, J company has been committed to their customers' success. From their humble beginnings as a precision manufacturer of titanium vanadium connecting rods for the NASCAR and Formula 1 racing industry, their reputation for quality, trust, and customer focus has driven their growth. Today, J company is a full service manufacturer of Powertrain, Transmission, and

Driveline components serving the Automotive, Heavy Forge and Equipment, Aerospace, and HVAC industries.

To remain competitive in today's global marketplace, it is important to team strengths and synergies between companies the world over. J company has successfully partnered with forward thinking Asian companies who employ North American business practices and are certified to TS16949. By leveraging their partners vast experience in cast, forged and stamped products, they are able to provide value added machining, assembly and warehousing locally in North America and support just in time delivery to their customers.

Product and Process Development is a team effort. Their engineering capabilities encompass a data exchange model employing FTP, Autoweb, and CAD Exchange applications. CAD software utilized includes Pro/E, Catia, Autocad, Mechanical Desktop, Solidworks, SDRC I-DEAS, and UNIGRAPHICS, on both Windows and Unix platforms. With this robust array of software, they design and build their own tooling and gauging in house, allowing fast lead times and reduced production costs. They also provide 3D modeling, reverse engineering, and CAE development services, including static and dynamic Finite Element Analysis modeling for their customers. In addition, they have committed 8% of annual sales to R & D activities. These programs focus in on those activities that support cost reduction, continuous improvement, product and process development, new equipment, and innovation.

Their product experience and machining expertise covers a wide range of Transmission, Powertrain and Suspension components and assemblies for the Automotive, Heavy Equipment, Agricultural, and HVAC industries. Their spectrum of manufacturing process capabilities include:

•CNC turning •CNC Machining •Gundrilling

•Hard Turning	•Grinding	•Honing & Microsizing
•Balancing	•Assembly	•Cleaning
•Shot Blasting & Peening	•Automated Deburring	•Kitting & Packaging

In addition, their partnerships and strategic alliances expand their capabilities to include:

•Castings [Offshore]	•Forgings [Offshore]	•Stampings [Offshore]
•Plastersol & PVC Coating	•Powder Coating	•Fluidized Dip
•Heat Treating	•Carbonitriding	•Tempering

From Sep 2004 to Nov 2004, the company's main product was Connecting Rod, this product was almost same as the connecting rod the company made before. From Dec 2004 to May 2005, the company's main product was Pinion Gear Blank, this product was new for the company, except for the tight tolerance, and all other features were not difficulty for the company. From Jun 2005 to Aug 2005, the company's main product was Housing, this housing was make on the CNC lathe, and it is similar as the product the company made before.

We had an internship at J company from Sep 2004 to Aug 2005, the table 7 shows the data we collected based on the assessment model we introduced above.

	Factors \ Time	Sep 04	Oct 04	Nov 04	Dec 04	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05
Work Process	1. Design Type and Product Complexity	10	10	10	5	5	5	5	5	5	9	9	9
	2. Design demands and cycle time	8	8	8	6	6	6	9	9	9	3	3	3
	3 Design Standardization	7	7	7	4	4	4	5	5	5	8	8	8
	4. Design and Production Costs	3	3	3	5	5	5	8	8	8	5	5	5
	5. The flexibility of Manufacturing Systems	8	8	8	8	8	8	8	6	6	6	6	6
	6. Process Complexity	9	9	9	9	9	3	3	3	3	8	8	8
	7. Quality Control System	5	5	5	5	5	3	3	3	8	8	8	8
Internal Organization	8. Organization Architecture	4	4	4	4	4	4	5	5	5	5	5	5
	9. Project Management Structures	6	6	6	6	6	6	6	6	8	8	8	8
	10.Distance	8	8	8	3	3	3	3	3	3	5	5	5
	11. Standardization of Work Processes	4	4	4	4	4	8	8	8	8	8	8	8
	12. Monitoring Systems.	3	3	3	3	3	3	7	7	7	7	7	7
	13. Organization Culture	5	5	5	5	5	5	5	5	5	5	5	5
Supply Chain and Financial	14. Supply Chain Management.	3	3	3	3	3	7	7	7	7	7	7	7
	15. Supplier Requirements	8	8	8	6	6	6	6	6	6	3	3	3
	16. Supplier Involvements.	3	3	3	7	7	7	7	7	7	9	9	9
	17. Supplier roles in product development	7	7	7	5	5	5	5	5	5	8	8	8
	18. Financial Resources	5	5	5	5	5	5	5	8	8	8	8	8
People Systems	19. Job design issues in concurrent engineering	4	4	4	4	4	4	6	6	6	6	6	6
	20. Skill acquisition systems	3	3	3	3	5	5	5	5	7	7	7	7
	21. Motivation and appraisal systems	3	3	3	3	3	3	8	8	8	8	8	8
Technology	22. Communication Technologies	2	2	2	2	8	8	8	8	8	8	8	8
	23. CAD/CAM/CAE systems	3	3	3	5	5	5	5	5	8	8	8	8
	24. Product Data Management (PDM):	3	3	3	3	3	3	7	7	7	7	7	7
	25. Group technology/Coding systems	5	5	5	5	5	5	5	5	5	5	5	5

Table 7. Concurrent Engineering assessment model work sheet.

Overall		Sep 04	Oct 04	Nov 04	Dec 04	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05
Sum	$S_f = \sum_{i=1}^{12} F_i$	129	129	129	118	126	126	149	150	162	169	169	169
A_3	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	114.5	121.8	125.4	121.7	123.8	124.9	137.0	143.5	152.7	160.9	164.9	167.0
A_6	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	104.1	109.2	113.8	116.1	118.3	120.2	125.0	130.3	136.7	143.6	149.7	154.6
C_d	$C_d = A_3 - A_6$	10.4	12.6	11.6	5.6	5.6	4.7	12.0	13.2	16.1	17.3	15.2	12.3
S_{cd}	$S_{cd} = \frac{1}{n} \sum_{m=1}^{n} D_m$ (n=3)			11.5	9.9	7.6	5.3	7.4	10.0	13.8	15.5	16.2	15.0

Table 8. Case study - Assessment model overall result.

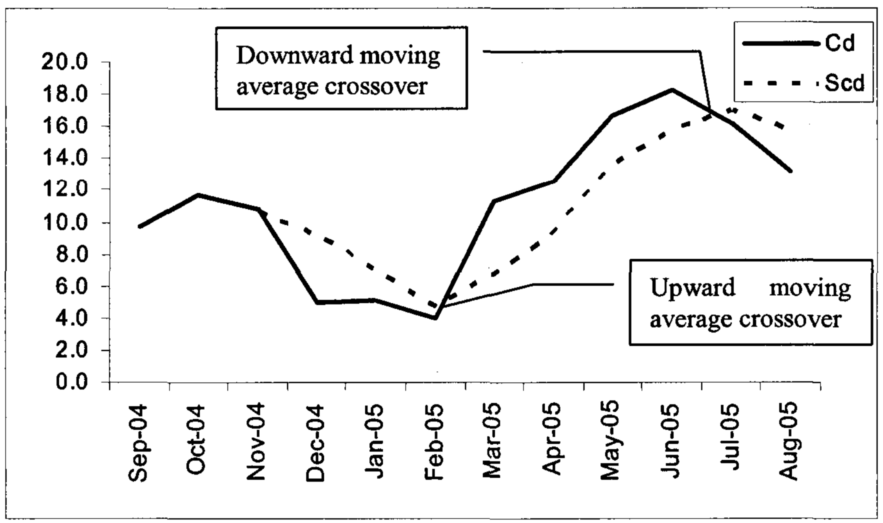

Figure 34. Case study - Overall C_d and S_{cd} chart.

From overall C_d and S_{cd} chart, we can see that:

1) From Sep 04 to Feb 05, $C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing concurrent engineering.

2) From Feb 05 to Jul 05, $C_d > S_{cd}$. That means the company has an outstanding structure and processes for implementing concurrent engineering.

3) From Jul 05 to Aug 05, $C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing concurrent engineering.

Work Process		Sep 04	Oct 04	Nov 04	Dec 04	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05
Sum	$S_f = \sum_{i=1}^{12} F_i$	50	50	50	42	42	34	41	39	44	47	47	47
A_3	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	37.5	43.8	46.9	44.4	43.2	38.6	39.8	39.4	41.7	44.4	45.7	46.3
A_6	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	28.6	32.9	36.9	39.1	40.2	39.8	39.8	39.7	40.3	41.4	42.6	43.7
C_d	$C_d = A_3 - A_6$	8.9	10.8	10.0	5.4	3.0	-1.2	0.0	-0.3	1.4	2.9	3.0	2.6
S_{cd}	$S_{cd} = \frac{1}{n} \sum_{m=1}^{n} D_m$ (n=3)			9.9	8.7	6.1	2.4	0.6	-0.5	0.4	1.4	2.5	2.9

Table 9. Case study – Element Work Process result.

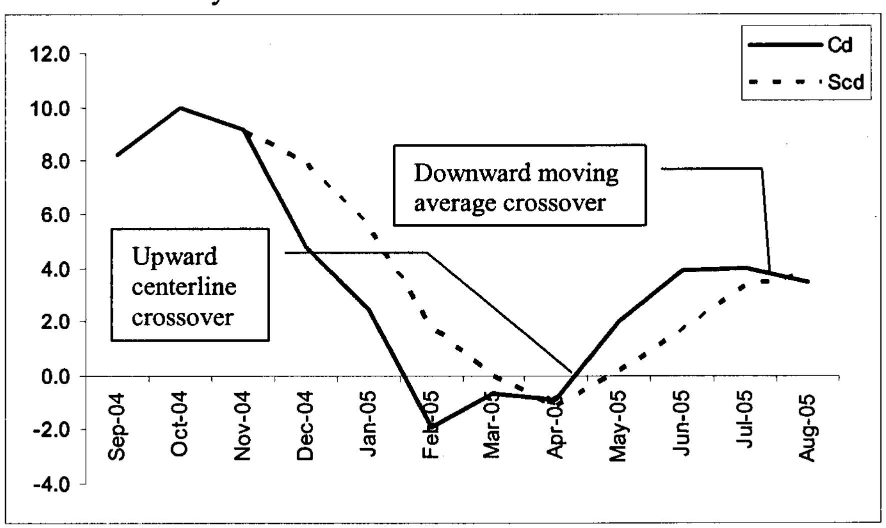

Figure 35. Case study - Element Work Process C_d and S_{cd} chart.

From element work process C_d and S_{cd} chart, we can see that:

1) From Sep 04 to Feb 05, $C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing concurrent engineering.

2) From Feb 05 to Apr 05, $0 < C_d < S_{cd}$. That means the company is not suitable for implementing concurrent engineering

3) From Apr 05 to Aug 05, $C_d > S_{cd} > 0$. That means the company has an outstanding structure and processes for implementing concurrent engineering.

Internal Organization		Sep 04	Oct 04	Nov 04	Dec 04	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05
Sum	$S_f = \sum_{i=1}^{12} F_i$	30	30	30	25	25	29	34	34	36	38	38	38
A_3	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	25.0	27.5	28.8	26.9	25.9	27.5	30.7	32.4	34.2	36.1	37.0	37.5
A_6	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	21.4	23.2	24.8	25.4	25.5	26.1	27.4	28.8	30.4	32.0	33.4	34.6
C_d	$C_d = A_3 - A_6$	3.6	4.3	4.0	1.5	0.4	1.4	3.3	3.5	3.8	4.1	3.6	2.9
S_{cd}	$S_{cd} = \frac{1}{n} \sum_{m=1}^{n} D_m$ (n=3)			4.0	3.3	2.0	1.1	1.7	2.7	3.6	3.8	3.8	3.5

Table 10. Case study – Element Internal Organization result.

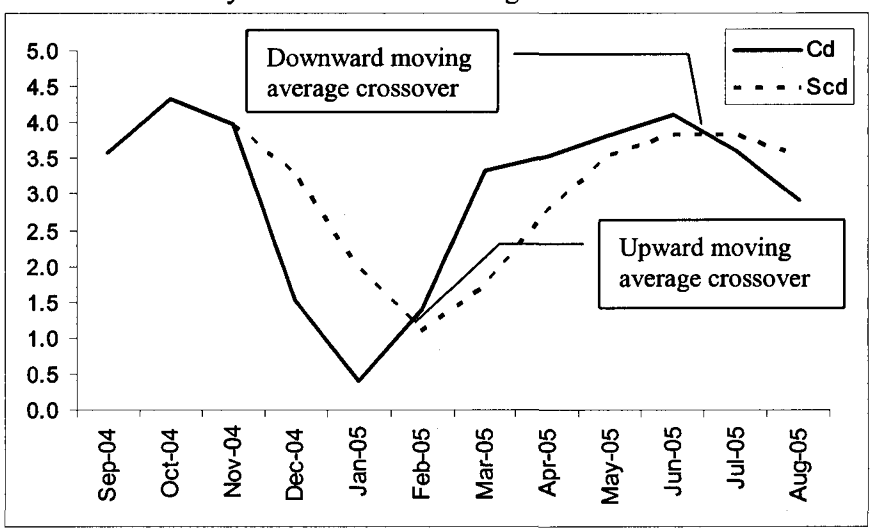

Figure 36. Case study - Element Internal Organization C_d and S_{cd} chart.

From Element Internal Organization C_d and S_{cd} chart, we can see that:

1) From Sep 04 to Feb 05, $0 < C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing concurrent engineering.

2) From Feb 05 to Jul 05, $C_d > S_{cd} > 0$. That means the company has an outstanding structure and processes for implementing concurrent engineering.

3) From Jul 05 to Aug 05, $0 < C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing

Supply Chain and Financial		Sep 04	Oct 04	Nov 04	Dec 04	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05
Sum	$S_f = \sum_{i=1}^{12} F_i$	26	26	26	26	26	30	30	33	33	35	35	35
A_3	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	23.0	24.5	25.3	25.6	25.8	27.9	29.0	31.0	32.0	33.5	34.2	34.6
A_6	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	20.9	21.9	22.9	23.6	24.3	25.3	26.3	27.7	28.9	30.2	31.4	32.3
C_d	$C_d = A_3 - A_6$	2.1	2.6	2.4	2.0	1.5	2.6	2.6	3.3	3.1	3.3	2.9	2.3
S_{cd}	$S_{cd} = \frac{1}{n} \sum_{m=1}^{n} D_m$ (n=3)			2.4	2.3	2.0	2.0	2.3	2.8	3.0	3.2	3.1	2.8

Table 11. Case study – Element Supply Chain and Financial result.

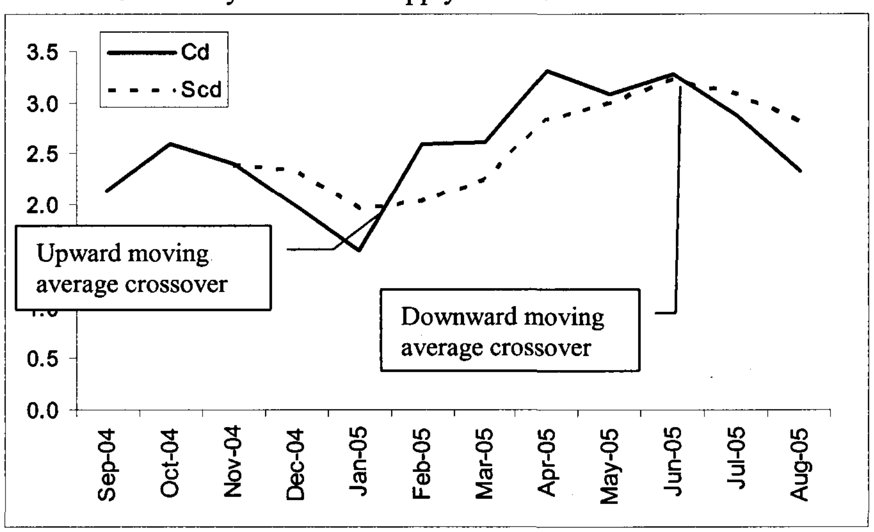

Figure 37. Element Supply Chain and Financial C_d and S_{cd} chart.

From Element Supply Chain and Financial C_d and S_{cd} chart, we can see that:

1) From Sep 04 to Jan 05, $0 < C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing concurrent engineering.

2) From Jan 05 to Jun 05, $C_d > S_{cd} > 0$. That means the company has an outstanding structure and processes for implementing concurrent engineering.

3) From Jun 05 to Aug 05, $0 < C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing concurrent engineering.

People Systems		Sep 04	Oct 04	Nov 04	Dec 04	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05
Sum	$S_f = \sum_{i=1}^{12} F_i$	10	10	10	10	12	12	19	19	21	21	21	21
A_3	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	12.5	11.3	10.6	10.3	11.2	11.6	15.3	17.1	19.1	20.0	20.5	20.8
A_6	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	14.3	13.4	12.6	12.0	11.7	11.7	12.7	14.0	15.4	16.8	17.8	18.7
C_d	$C_d = A_3 - A_6$	-1.8	-2.2	-2.0	-1.6	-0.6	-0.1	2.6	3.2	3.6	3.3	2.7	2.1
S_{cd}	$S_{cd} = \frac{1}{n} \sum_{m=1}^{n} D_m$ (n=3)			-2.0	-1.9	-1.4	-0.8	0.6	1.9	3.1	3.4	3.2	2.7

Table 12. Case study – Element People Systems result.

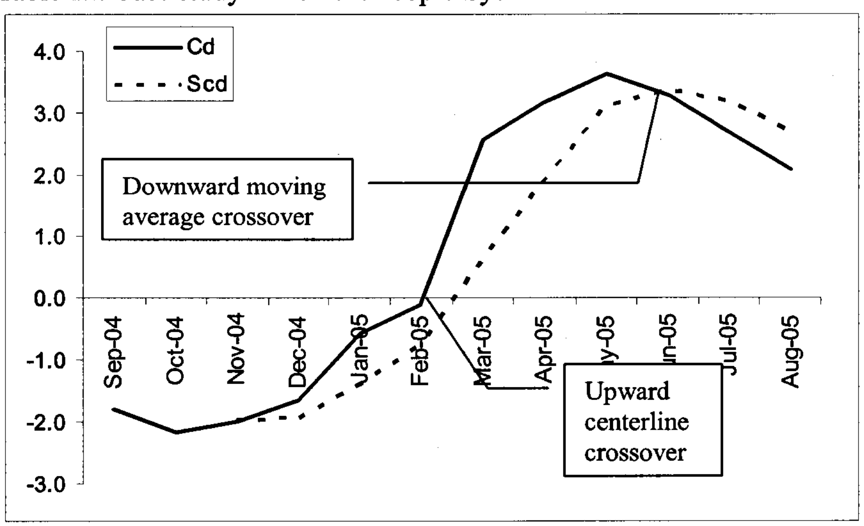

Figure 38. Case study - Element People Systems C_d and S_{cd} chart.

From Element Internal Organization C_d and S_{cd} chart, we can see that:

1) From Sep 04 to Feb 05, $0 > C_d > S_{cd}$. That means the company has a good structure and processes for implementing concurrent engineering.

2) From Feb 05 to Jun 05, $C_d > S_{cd} > 0$. That means the company has an outstanding structure and processes for implementing concurrent engineering.

3) From Jun 05 to Aug 05, $0 < C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing

Technology		Sep 04	Oct 04	Nov 04	Dec 04	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05
Sum	$S_f = \sum_{i=1}^{12} F_i$	13	13	13	15	21	21	25	25	28	28	28	28
A_3	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	16.5	14.8	13.9	14.4	17.7	19.4	22.2	23.6	25.8	26.9	27.4	27.7
A_6	$A_n = \frac{2 \times S_f + (n-1) \times A'}{n+1}$	19.0	17.8	16.7	16.0	16.5	17.3	18.7	20.1	21.7	23.2	24.4	25.4
C_d	$C_d = A_3 - A_6$	-2.5	-3.0	-2.8	-1.6	1.2	2.0	3.5	3.5	4.1	3.7	3.0	2.4
S_{cd}	$S_{cd} = \frac{1}{n} \sum_{m=1}^{n} D_m$ (n=3)			-2.8	-2.5	-1.1	0.5	2.2	3.0	3.7	3.7	3.6	3.0

Table 13. Case study – Element Technology result.

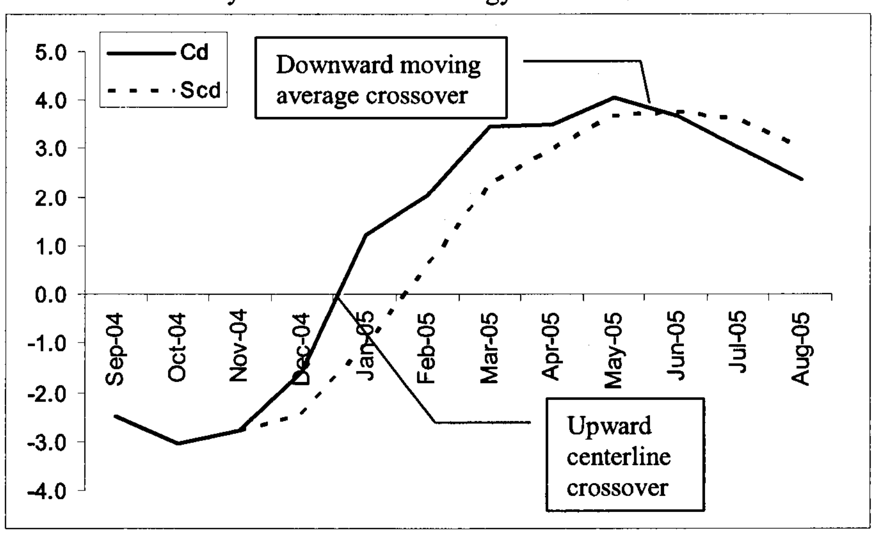

Figure 39. Case study - Element Technology C_d and S_{cd} chart.

From Element Technology C_d and S_{cd} chart, we can see that:

1) From Sep 04 to Dec 04, $0 > C_d > S_{cd}$. That means the company has a good structure and processes for implementing concurrent engineering.

2) From Jan 05 to Jun 05, $C_d > S_{cd} > 0$. That means the company has an outstanding structure and processes for implementing concurrent engineering.

3) From Jun 05 to Aug 05, $0 < C_d < S_{cd}$. That means the company has a marginal structure and processes for implementing concurrent engineering.

Element	Sep 04	Oct 04	Nov 04	Dec 04	Jan 05	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05
Work Process	B	B	B	B	B	C	C	C	A	A	A	A
Internal Organization	C	C	C	C	C	C	A	A	A	A	A	C
Supply Chain and Financial	C	C	C	C	C	A	A	A	A	A	C	C
People Systems	B	B	B	B	B	B	A	A	A	A	C	C
Technology	B	B	B	B	A	A	A	A	A	C	C	C
Overall	C	C	C	C	C	C	A	A	A	A	C	C
A : outstanding B : good C : marginal D : not suitable												

Table 14. Case study – Summary.

From above table, we can easily find out when was the best time for this company to implement concurrent engineering, and when was not suitable. And at same time we can find out the company's weakness and strength at different time. For example, from Sep 2004 to Feb 2005, this company had a marginal structure and processes for implementing concurrent engineering, the company's weakness were Internal Organization , Supply chain and financial. From Mar 2005 to Jun 2005, this company has an outstanding structure and processes for implementing concurrent engineering, but the company still had weakness, that were work process and technology. From Jul 2005 to Aug 2005, this company also had a marginal structure and processes for implementing concurrent engineering, the company's weakness were Internal Organization , Supply chain and financial, people systems, and technology.

CHAPTER IV. SUMMARY AND PROPOSED FUTURE DIRECTION

This thesis firstly gave a definition and briefly introduction of concurrent engineering, including its fundamentals, and the Benefits of concurrent engineering, its difficulties and caveats. After that this thesis introduced an implementation method for concurrent engineering.

From the above analysis, we can see that this thesis focused on concurrent engineering assessment model; the purposes of concurrent engineering assessment model is provides information about company's current state of affairs. It described how things were done and how well they were being done. And finally, this thesis constructed a mathematical assessment model, making the assessment much more objective and accurate, this assessment model can tell company when the best time to implement concurrent engineering is, when is not suitable to implement concurrent engineering, and at the same time this assessment model can figure out the company's weakness and strength.

The future study direction will be to compare the results of new mathematical model with two existing models, and try to use another methodology (for example: AHP model) to assess concurrent engineering. Further, we can develop a method and corresponding model or tool for suggesting potential improvements and solutions for implementing concurrent engineering practices within the company. The solution will be based on the assess model results we introduced above. Together, these models will provide an interactive; model based consulting service system for the manufacturing companies on their way to concurrent engineering. The figure below outlines a draft concept of this consulting system architecture.

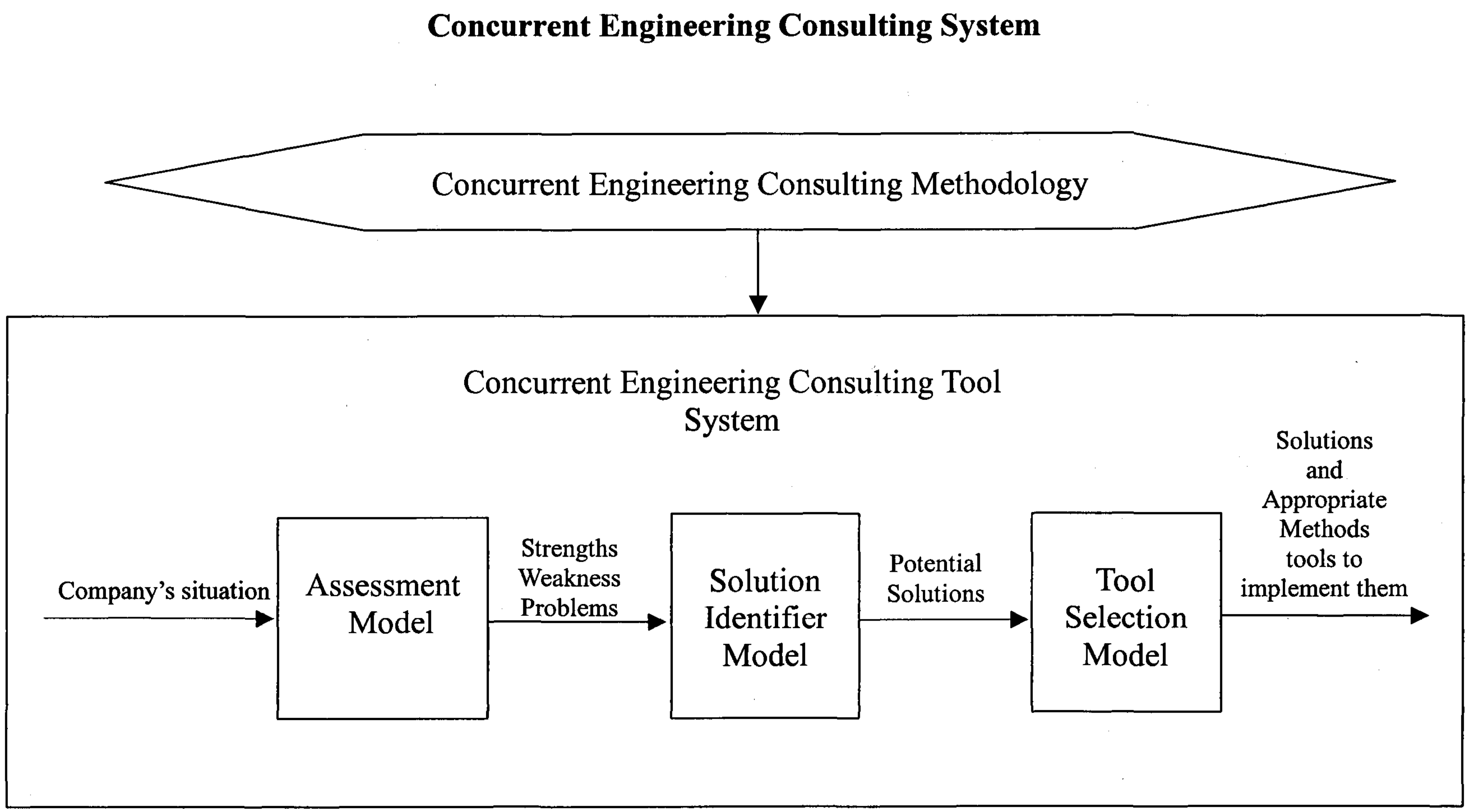

Figure 41. Draft Concept of Concurrent Engineering Consulting System Architecture.

References

[1] Ali A. Yassine, Kenneth R. Chelst, and Donald R. Falkenburg, A Decision Analytic Framework for Evaluating Concurrent Engineering, IEEE Transactions On Engineering Management, Vol. 46, No. 2, May 1999

[2] Albin, S. L.: Crefeld, P.: Getting started: concurrent engineering for a medium-sized manufacturer, Journal of Manufacturing Systems, Vol.13, No.1, 1994, pp.48-58.

[3] Ainscough, M. and Yazdani, B. (2000), ``Concurrent engineering within British industry'', Concurrent Engineering: Research and Applications, Vol. 8 No. 1, pp. 2-11.

[4] Bill Gascoigne, PDM: the essential technology for concurrent engineering, World Class Design to Manufacture, Volume 2 · Number 1 · 1995 · pp. 38–42

[5] Badr Haque, Problems in concurrent new product development: an in-depth comparative study of three companies, Integrated Manufacturing Systems, 14/3 [2003] 191-207

[6] Bill Gascoigne, PDM: the essential technology for concurrent engineering, World Class Design to Manufacture, Volume 2 ·Number 1 1995 pp. 38–42

[7] Brown, M. L.; Benhadj, R.: Implementation of modern new product development and introduction theory in a small manufacturing company, Proceedings of the 1997 5th International Conference on Factory 2000 - The Technology Exploitation Process, pp.57-62, Cambridge, UK, Apr 2-4, 1997.

[8] Brookes, N.J. and Backhouse, C.J. (1998), ``Understanding concurrent engineering implementation: a case study approach'', International Journal of Production Research, Vol. 36 No. 11, pp. 3035-54.

[9] C.J. Anumba, C.E. Siemieniuch and M.A. Sinclair, Supply chain implications of concurrent engineering, International Journal of Physical Distribution & Logistics Management, Vol. 30 No. 7/8, 2000, pp. 566-597.

[10] Carter, D.E. and Baker, B.S., Concurrent Engineering: The Product Development Environment for the 1990s, Addison-Wesley, Reading, MA, 1992.

[11] Concurrent Engineering Research Center, "Process issues in implementing concurrent engineering in DICE", CERC Technical Report Series CERC-TR-RN-93-003, West Virginia University, Morgantown, WV, 1992.

[12] CIMdata, PDM Buyer's Guide, CIM data, Ann Arbor, MI, 1993.

[13] C. L. Bausch, "Coordination of research and engineering with production and sales," Trans. Amer. Soc. Mech. Eng., vol. 54, no. MAN-54-4a, pp. 21–24, 1999.

[14] C. J. Anumba,1 A. N. Baldwin and D. Bouchlaghem, Integrating Concurrent Engineering Concepts in a Steelwork Construction Project, 2000 Technomic Publishing Co., Inc. Volume 8 Number 3 September 2000.

[15] Clark, K.B. and Fujimoto, T., Product Development Performance, Harvard Business School Press, Boston, MA, 1991.

[16] Dean, E.B. and Unal, R. (1992), "Elements of designing for cost", paper presented at The AIAA 1992 Aerospace Design Conference, Irvine, CA, 3-6 February, AIAA-1057.

[17] De Graaf R.: Lessons Learned from Implementing Change in Product Development, Proceedings of Concurrent Engineering Research and Applications, McLean, USA, 1995, pp. 549-556.

[18] Design in the new Millennium – Advanced Engineering Environments – Phase 2, Committee on Advanced Engineering Environments, National Academy of Engineering, National Academy Press Washington, D.C. 2000.

[19] Ettlie, J.E. and Reza, E.M., "Organizational integration and process innovation", Academy of Management Journal, Vol. 35 No. 4, 1992, pp. 795-827.

[20] Ettlie & Stoll. Implementing Simultaneous Engineering at Cadillac Introduction, Managing the Design – manufacturing Process, Mc Graw - Hill, Inc. Chapter 11, page 243 - 253.

[21] Eversheim, W.; Roggatz, A.; Zimmermann, H.J.; Derichs, T.: Information management for concurrent engineering, European Journal of Operational Research, Vol.100, No.2, 1997, pp.253-265.

[22] G. Boothroyd, P. Dewhurst, and W. Knight, Product Design for Manufacture and Assembly. New York: Dekker, 1994.

[23] Gatenby, D. A.; Lee, P. M.; Howard, et al: Concurrent Engineering: an enabler for fast, high-quality product realization, AT&T Technical Journal, Vol.73, No.1, 1994, pp.34-47.

[24] http://w3.mor.itesm.mx/~smic/ceic/definitions.html

[25] Haque, B. (1999), ``The development and implementation of a methodology for analyzing organisational related issues in concurrent product development'', PhD thesis, University of Nottingham.

[26] Huthwaite, B., Strategic Design: A Guide to Managing Concurrent Engineering, The Institute for Competitive Design, Rochester, MI, 1994.

[27] Hong Sen Yan, Jian Jiang, Agile concurrent engineering, Integrated Manufacturing Systems, 10/2 [1999] 103-112

[28] I. Black, "Back to the future with CAD: Its impact on product design and development," Design Studies, vol. 11, no. 4, pp. 207–211, 1990.

[29] Lawson, M. and Karandikar, H.M., "A survey of concurrent engineering", Concurrent Engineering International Conference: Research and Applications, 1994.

[30] Lake J, "Implementation of Multi-Disciplinary Teaming," Eng Management J, 4(2):913, 1992.

[31] Mitchell Fleischer and Jeffrey K. Liker, Concurrent Engineering Effectiveness, Hanser Gardner Publications, 1997

[32] Melanie Hatch and Ralph D. Badinelli, A Concurrent Optimization Methodology for Concurrent Engineering, IEEE Transactions On Engineering Management, VOL. 46, NO. 1, FEBRUARY 1999

[33] Maylor, H. and Gosling, R. (1998), ``The reality of concurrent new product development'', Integrated Manufacturing Systems, Vol. 9 No. 2, pp. 69-76.

[34] Maylor, H. (1997), ``Concurrent new product development: an empirical assessment'', International Journal of Operations & Production Management, Vol. 17 No. 12, pp. 1196-214.

[35] M. Lawson, CERC Technical Report Series Research Note, Cerc-Rn-93-070 Justifing CE, 1993

[36] Mikell P. Groover, Automation, Production systems, and Computer-Integrated Manufacturing, Second Edition, Prentice Hall.

[37] Paul M. Swamidass, Innovations in Competitive Manufacturing, Kluwer Academic Publishers, 2000

[38] Pallot, M.; Sandoval, V.: Concurrent Enterprising: Towards the Concurrent Enterprise in the era of the Internet and Electronic Commerce, Kluwer Academic Publishers, 1998.

[39] Pawar, K.S., Horton, A.R., Gupta, A. et al: Inter-Organisational Knowledge Management: Focus on Human Barriers in the Telecommunications Industry, Proceedings of the International Conference in Concurrent Engineering: Research & Applications (CE2001) Anaheim, CA, 2001.

[40] Pawar, K.S.; Sharifi, S.: Physical or virtual team location: Does it matter? International Journal of Production Economics Vol 52, 1997, pp. 283-290.

[41] Rob Kinna, Team working and concurrent engineering– a success story, World Class Design to Manufacture, Volume 2 · Number 3 · 1995 · pp. 5–9

[42] Robert P. Smith, The Historical Roots of Concurrent Engineering Fundamentals, IEEE Transactions On Engineering Management, VOL. 44, NO. 1, Februry 1997 67

[43] Robert P. Smith, The Historical Roots of Concurrent Engineering Fundamentals, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, VOL. 44, NO. 1, FEBRUARY 1997

[44] Susan E. Carlson and Natasha Ter-Minassian, DESIGN Planning for Concurrent Engineering, Medical Device & Diagnostic Industry , May 1996

[45] Sev Nagalingam, A Guide To Introducing Concurrent Engineering In Your Organisation, www.smartlink.net.au. National Institute for Manufacturing Management

[46] Shina, S.G. (Ed.), Successful Implementation of Concurrent Engineering Products and Processes, Van Nostrand Reinhold, New York, NY, 1994.

[47] Smart PK: An empirical investigation of the factors that contribute to a successful implementation of CE. The CIM Institute, Cranfield University, UK

[48] Salamone, T.A.: What every engineer should know about Concurrent Engineering, Marcel Dekker Inc., 1995.

[49] Stephen Evans, Fiona Lettice and Palminder Smart, A faster, cheaper and safer route to CE, World Class Design to Manufacture, Volume 2 · Number 2 · 1995 · P10–16

[50] SDRC, “The Boeing Company selects SDRC to Supply Product Data Management Software and Services”, Boeing/SDRC press release, August 1994.

[51] Shina, S.G. (1994), Successful Implementation of Concurrent Engineering Products and Processes, Van Nostrand Reinhold, New York, NY.

[52] Stahl, Juergen, Luczak, Holger, Concurrent engineering of work and production systems, Jul 16, 1997.Vol.100, Iss. 2; pg. 379, 20 pgs

[53] The human-resource implications of concurrent engineering, Management Development Review Volume 10 · Number 6/7 · 1997 · pp. 241–243

[54] Usher, J.M.: Implementing concurrent engineering in small manufacturing enterprises, Engineering Management Journal, Vol.8, No.1, 1996, pp.33-43.

[55] Victor Paashuis, Organizing for concurrent engineering: an integration mechanism framework, Integrated Manufacturing Systems, 8/2 [1997] 79–89

[56] Walker, R.; Weber, F.: PACE '97 - A Practical Approach to Concurrent Engineering. Proceedings of European Workshop on Conc. Engineering, , 15 May 1997, Centimfe, Marinha Grande, Portugal, 1997.

[57] www.stockcharts.com/index.html, StockCharts.com, Inc.

VITA AUCTORIS

NAME:	Guoli Jian
PLACE OF BIRTH	Xianyang, China
YEAR OF BERTH	1968
EDUCATION	No. 7 High School, Xianyang
	1980 – 1986
	Beijing Institute of Technology, Beijing, China
	1986 – 1990
	University of Windsor, Windsor, Ontario
	2004 - 2006