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Concurrent Engineering Approaches within Product Development Processes for Managing Production Start-up phase

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This thesis work is performed at School of Engineering within the subject area of Production System: Production Development and Management. The work is part of the university's two-year master degree. The authors are responsible for the given opinions, conclusions and results.

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Summary

Nowadays in a turbulent market, developing and launching a new product is one of most competitive strategies implemented by many large and small enterprises. In fact, launching a new product depends upon the performance of four critical functions: design, manufacturing, distribution and marketing. Their performances would increase or decrease the total time-to-market and consequently time-to-money. Time-to-market would be improved if the manufacturing system can diminish time-to-volume/quality/cost during production start-up phase. In order to overcome the impediment during a start-up phase, the significant parameters which are influencing a production start-up phase should be identified and managed. Hence, a system-wide approach would facilitate a product realization process so as to achieve global optimization throughout the entire process. One of such systems is Concurrent Engineering which can be applied owing to being enable to choose the best practice to improve product introduction process, being capable to improve cross functional integration and communication, and being empowered to apply a set of comprehensive methods for design analysis so that designers can select the most optimal design solution which is not only considering the design constraints, but also taking the constraints of production system, logistics and distribution into account. Hence, it can cover majority of problems in start-up phase which are generated due to lack of empathy between design and manufacturing.

This research studied the significant parameters influencing a production start-up phase. Then, it investigated whether the principle of concurrent engineering would support an efficient start-up phase. The selected research methodology is based on a conceptual and supportive literature review of the current scholars. The research design is according to a three-step process which is applied to catch most relevant literatures. The research implements an analogy reasoning logic to establish the outcome of the research through the comparison between principles of a concurrent engineering program and significant parameters. As a result of the research, the significant parameters are identified, in addition, a managerial framework is structured that can present the requirements to manage an efficient start-up phase. Moreover, the results indicate how a concurrent engineering program would support a start-up phase.

Key Words

Start-up phase, Concurrent Engineering, Concurrent Engineering Principles, Start-up Management

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1 Introduction

1.1 Background and Problem Definition

Nowadays in a turbulent market, developing and launching a new product into the market is one of competitive strategies considered by many large and small enterprises. This strategy enables a company to earn larger market penetration than competitors; consequently, achieving a shorter time-to-money period and increasing the rate-of-return. Establishing this strategy demands that all functions within a supply chain – such as marketing, design, procurement, manufacturing, and distribution – to perform as a unique body of a system. "The economic success of most firms depend on their ability to identify the needs of customers and quickly create products that meet these needs and can be produced at low cost. Achieving these goals is not solely a marketing problem; it is a product development problem involving all of these functions" (Ulrich and Eppinger, 2008, p.2). Product development and Production development are two important processes, which are playing critical role in achieving this competitive capability.

Whereas the center of gravity is in design engineering function (Wheelwright, 1985), meaning that a design must satisfy various and dynamic customer requirements; the competence of manufacturing must be able to produce designed product rapidly. Product realization process involves both product development and production development processes as two integrated and dependent processes for achievement of efficient development and realization process (Bellgran and Säfsten, 2009).Thereupon, it is essential to manage product realization process, form concept development to manufacturing of the commercial product, efficiently and effectively. The ultimate purpose of the company is achieving high degree of quality in the shortest time and with as lowest cost as possible. Hence, a central area is the collaboration between product developers (i.e. designers) and production developers (i.e. production engineers) in order to generate the fitness between product design and manufacturing competence.

There are three sorts of interfaces throughout a product realization process; the first interface is between applied research and product development where a new technology can be introduced as a new design solution, and the second interface is between product development and production development where a new designed product must be produced by current or new manufacturing system. The third interface is between production development and marketing where the manufactured product must be distributed within a market in a way that attain customer attention and market penetration.

The more fitness between two parties of these interfaces, the shorter product development time as well as time-to-market and manufacturability problems will be, and the earlier product launching, consequently, the greater rate of return will be (Ulrich et al. 1993). The integration between design and production is an essential factor in reducing time-to-market (Pawar and Riedel, 1994).

The extent of fitness between product development (design) and production development (manufacturing) generates through production start-up process, where product design is signed off and manufacturing trial stages start. And gradually, the production rate increases going towards target quality and quantity. This phase is called “start-up” in which the major portions of learning and problem solving are carried out (Bellgran and Säfsten, 2009). The workforces learn new work methods as well as using new technology. The operational problems of machines and equipments are revealed when they should accommodate new metrics and values of a new developed product.

There are few researches concerning the approaches for managing the production start up. First sets of researches are explaining how start-up phase can be planned and integrated within a normal production planning. For example, (Clark and Fujimoto, 1991), (Wheelwright and Clark, 1992) and (Terwiesch and Xu, 2004) have explained the operational concepts during production start-up phase. Ulrich and Krishnan (2001) have pointed out that poor product-design decisions can slow the rate of production start-up. (Johanson and Karlsson, 1998), (Almgren, 1999a), and (Berg and Säfesten, 2006) have studied the critical operational and managerial factors which are affecting the performance of production system during start-up phase. Other sets of researches have tried to establish a framework for managing production ramp-up phase. The frameworks, in fact, constitute of different elements, which are influencing a ramp-up phase. For example, (Merwe, 2004) has introduced a framework for ramp-up compromising of three dimensions by which the body of production ramp-up management is forming. These three dimensions are novelty, learning, and ramp-up performance. A conceptual holistic ramp-up approach introduced by (Schuh et al, 2005) has made up of three thematic dimensions: ramp-up strategy, ramp-up planning, and ramp-up evaluation. (Berg and Säfesten, 2006) has pointed out that critical factors affecting ramp-up performance as well as the production ramp-up complexity must be considered when managing a ramp-up phase.

Most of the mentioned researches consent that the empathy and integration between design and manufacturing would help to avoid the problem during a start-up phase or generate a solution to resolve the problem in a resourceful way. There are various approaches by which the integration can be created throughout a product development process. For instance, Concurrent Engineering (CE), System Engineering (SE), Design for X abilities (DFX), and Product Life Cycle Management (PLCM) are considering the entire development process in a systematic and structured way.

Concurrent Engineering is “a widely recognized approach to improve product introduction” (Brookes and Backhouse, 1998, p. 3035). The research presents a result of a case study comprised of nine companies in UK that have been implementing concurrent engineering approach in their product development processes. Swink, (1998) indicates that there are two basic managerial initiatives for implementing a concurrent engineering program. First one is improving cross-functional integration and communication. The latter is improving methods for design analysis and decision making so that designers can cultivate a design excellence. CE approach is a philosophy that would be beneficial for an enterprise via focusing on customer demands, allowing a right first time philosophy to be practice, and shortening time for introducing a product to market (Ainscough and Yazdani, 2000). Therefore, the reason for selecting CE is (1) to use a specific approach which is famous in the field of product introduction improvement, (2) CE can improve cross functional integration and communication, hence, it can cover majority of problems in start-up phase which are generated due to lack of empathy between design and manufacturing, (3) CE employ a set of comprehensive methods for design analysis so that designers can select the most optimal design solution which is not only considering the design constraints, but also taking the constraints of production system, logistics and distribution into account.

During last two decades, Concurrent Engineering (CE), a.k.a. Simultaneous Engineering (SE), has radically changed the ways by which new products are developed. Most of the researchers e.g. (Prasad, 1996), (Swink, 1998), (Foster, 2001) have found that CE can improve product design while lowering development time and cost. CE is the simultaneous performance of product design and process design (Foster, 2001). Concurrent Engineering is comprised of three basic principles: early involvement of participants, the cross-functional team approach, and the simultaneous work on different phases of product development (Swink, 1998), (Koufteros et al, 2001) and (Foster, 2001). Nowadays CE has divers applications and the core concepts that defines CE is becoming more vague, but following definition is the most common referred definition: “Concurrent Engineering is a systematic approach to the integrated, concurrent design of product and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements” (Winner et al, 1988; modified from (Prasad, 1996)). CE is paralleling life cycle functions and tries to implement simultaneous design of all downstream processes during upstream phases of product development. Hence, critical downstream phases such as production start-up would be manageable via implementing a set of principles, instructions, and tools, which are the core competence of the CE approach.

Even though mentioned researches are considering parameters and factors which must be considered in start-up management and presenting frameworks for managing start-up phase, each of them encompasses partial discussions; that is, the parameters that can ensure an efficient start-up is dispersed among different literatures. In addition, some of the researches are discussing the overall situation during a start-up phase, rather than being analytical and identifying the root cause of problem. Hence, there is a need for a comprehensive framework in which various effective parameters in managing a start-up phase are included. Moreover, all of the reviewed literatures concur that the empathy of design and manufacturing activities is the decisive and supreme approach to overcome the problem during start-up phase; however, there is a lack of theoretical or practical approaches to explain if the efficient production start-up can be arranged by means of the frame of CE approaches.

1.2 Purpose

In order to accomplish a successful production start up and get along a smooth production start-up a two-stage mindset can be developed, first the significant factors and elements in managing a production start-up phase should be determined. And then, a structured approach and methodology, or a managerial framework would be established, based on the CE approaches. This mindset can bring about a proper perspective within a product realization process to get along with a production start-up phase. The perspective can help managers to identify potential risk parameters related to the integration point of product development and production development processes. Owning to the mentioned mindset the purpose of this research is:

- To identify and structure significant parameters that affect production start-up performance
- To analyze which principles of Concurrent Engineering and how can support an efficient production start-up

1.3 Delimits and Scopes

The scope of analysis begins when a product design signs off and it is ready to start a pilot run. And, it continues unless the primitive production targets are achievable. Therefore,

1) it is assumed that a technology is achieved the degree of maturity enabling it to use in production start-up process, thereby the technology development effects on product development process as well as production start up are not considered, but selecting the proper technology is. This assumption makes it possible to discuss that the manufacturing must achieve required competency when a tailored technology is available; thereupon, the lack of manufacturing competency cannot be blamed due to immature level of implemented technology.

2) Assuming a product is about to launch at a right market at the right time; therefore, the distribution requirements and marketing dynamic attitudes are not comprised in this research. Nevertheless, identifying customer needs and establishing corresponded product concept is involved through discussion.
Hence, this thesis makes no specific attempts to consider any functional areas other than design and manufacturing. Other functional areas, such as marketing, require an in-depth treatment of additional investigations.

The term ‘new product’, as used in this paper may refer either to a brand-new product coming from a radical innovative procedure or to an incremental improvement of an existing product. The focus of this thesis is on a breath of Concurrent Engineering tools and not on a depth of the tools presented in the report.

1.4 Outlines

The first chapter of the thesis includes the problem definition and research questions. The thesis scope and considered delimits are also discussed in first chapter. The second chapter deals with the methodological framework of the thesis. The research design, statistical data of reviewed literature as well as the logic of data analyzing and the logic of reasoning is presented in this chapter. Chapter 3 and 4 include the theoretical exposition of reviewed literature. Chapter 3 is dedicated to the references which discuss the matters related to the production start-up phase. Chapter 4 compiles the discussions related to the principle of a Concurrent Engineering approach. Chapter 5 entails the analysis of gathered data and answering the research questions. Finally, a brief conclusion and discussion of the thesis is provided in Chapter 6, wherein, the interpretation of the result is discussed.

2 Methodology

2.1 Scientific Research Approach

A scientific research is defined as "the systematic process of collecting and analyzing information (data) in order to increase our understanding of the phenomenon about which we are concerned or interested" (Leedy and Ormrond, 2001, p.10); therefore, the purpose of research can be either improvement of current practice (problem solving), anticipating the likelihood of particular events (forecasting and simulation), explaining why or how (analysis), looking for novel pattern (exploration), or compiling existing facts among various resources and making logical relationship across them (description).

According to (Williamson, 2002), there are different ways for categorizing a research; the categorizing can be done in terms of applied reasoning style (i.e. deductive or inductive), implemented research method (i.e. survey, case study, action research, and etc.), a historical perspective of research (i.e. empirism or rationalism), and a form of collected data (i.e. qualitative or quantitative). Whatever the research type is, the search and review of literature is the basic part in formulation of the theoretical framework, and to some extent, for building a ground theory. The literature search and review consists of identifying, locating, synthesizing, and analyzing the conceptual literature, as well as completed research reports, articles, conference papers, books, thesis, and other materials about the specific problem or problems of a research topic (Williamson, 2002).

A research base on literature review can entail the data in the form of words as well as numbers; however, the literature review would be considered as a qualitative research since the data is collected by means of qualification and context-specific description. A literature review can focus on research outcomes, research methods, theories, applications or all these.

(Cooper, 1998) pointed out that a literature review can endeavor to integrate what others have done and said, to criticize previous scholar work, to build bridge between related topic areas, to identify central issues in a field.

(Huff, 2009) provided an extensive comparison of four distinct sorts of literature review. These four kinds of literature reviews are: *survey*, *critical review*, *systematic review*, and *supportive search*. This classification is mainly based on the purpose, the source of information, the search styles, written outputs, and criteria for closure.

Among these four kinds of literature review, supportive research is trying to resolve specific problems or support new ideas that occur as the research is carrying out. The information source belongs to the journals or books, which are relevant to the problem area. The search style is problem-driven search. According to Huff's classification, this thesis is designed based on a conceptual and supportive review. In this research, as a master thesis, the foundation for the research is generated by reviewing and researching relevant references to the main topic, in order to investigate the different aspects of decisions through product development process.

2.2 Research Design

This thesis follows an extensive, systematic search within the academic peer-reviewed literature. The review also contains both empirical and non-empirical studies focusing mainly on the previous accomplished researches, which are related to the process, management, and project management rather than on engineering, technical and physical design. The essential bone of a research design would establish a breadth and width as well as efficient method to process literatures while, at the same time, capturing the important elements of the overall picture. In this way a comprehensive research can be established.

Based on (Machi and McEvoy, 2009) the scientific approach in literature review is divided into two different kinds; a basic literature review and an advanced literature review. The selected approach through this research report is corresponded to the latter one. [Figure 1] suggested literature review model is illustrated.

Concerning mentioned model for reviewing scientific literature, a systematic way of searching scientific databases is designed. [Figure 2] presents the building blocks of the systematic search methodology employed in this thesis. First stage involves searching the databases, finding different references and clustering information based on keywords and relevancy of the topic discussed in each reference. Stage two entails the full-text reading of relevant references which is followed by broad and in-depth information capturing; this process would, therefore, enable the researcher to analysis numerous concepts comprehensively. Moreover the reference chasing, by means of the reference list existing in each article, can help researcher to find other proper sources of information, which would not be discovered at the first stage. The last stage is a critical part of the research where various concepts should be synthesized in order to answer the research question appropriately.

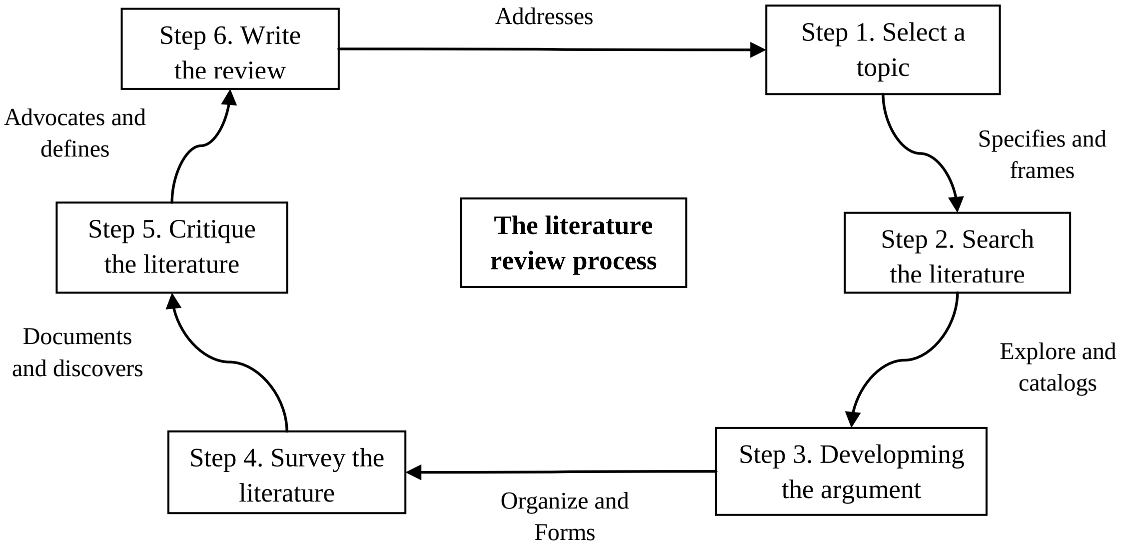

Figure 1; the literature review model, modified from (Machi and McEvoy, 2009)

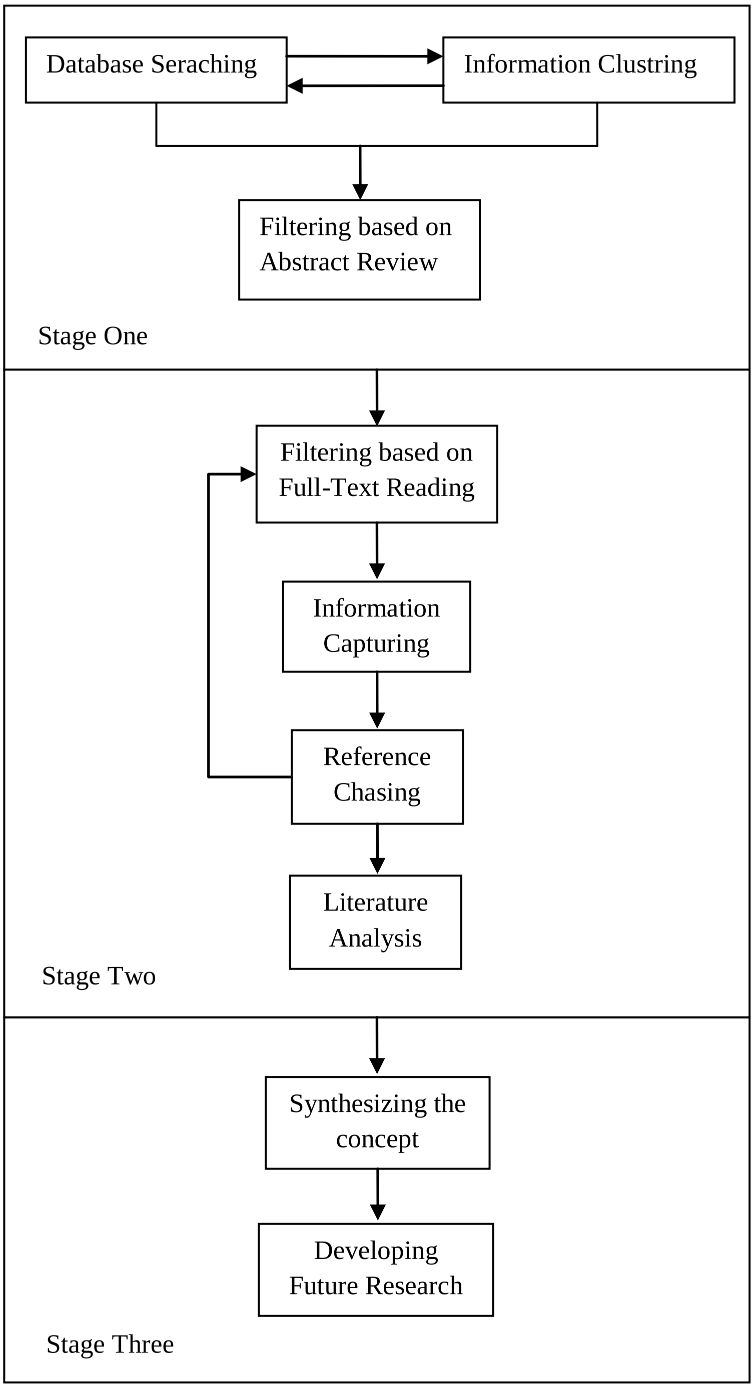

Figure 2; The Research Design of the thesis

2.3 Data Collection

This study will focus on literature published between 1985 and 2010, with their citations being cross-checked to ensure that any earlier publications were also captured. Since there are numerous research works, either theoretically or empirically, of prior research related to production start-up, the archetype research works are solely cited.

The search strategy is developed at first by identifying the relevant data sources, the time frame of literatures, and keywords. Initially, a very broad selection of databases would be identified to cover a diverse range of publications (e.g. journal articles, conference proceedings, theses, books). These databases included e-data sources such as EBSCO, Science Direct, Springer Link, Emerald, and Scopus (reference data base) along with the more traditional library cataloguing systems. Moreover, the references in items that had been found and bibliographies in books can be another appropriate way to use.

The Scopus citation database (http://www.scopus.com) was searched to identify the appropriate papers. It is a citation database that covers more than 15,000 journals in most subjects from 1996-. Scopus is the largest abstract and citation database of peer-reviewed literature and quality web sources with smart tools to track, analyze, and visualize a research.

The citation-count criterion provided more high quality papers, while the random selection enabled us to include some of the recently published papers with low citations. According to the systematic procedure, mentioned in section 2.2 *Research Design,* initially reading the abstracts was the next step of the process in order to scan the irrelevant papers by employing academic judgment. The abstract-selected set of papers was then subjected to full-text reading during which information capturing, final screening, and classification of the papers were carried out. Information captured and extracted from full-text reading was fed into a template form for further use and analysis. Reference chasing was also performed whilst reading the full-text, and the relevant references were added to the list of papers to be analyzed.

Following list of Keywords is applied for searching through databases and journals. Many of these key words were combined with “interface”, “interaction” or “integration” as well as the search operators such as “AND”, and “OR” in order to ensure their relevance to this study. This set was then expanded and refined as appropriate articles were discovered. List of applied key words for searching through databases and journals are as following:

Product Realization
Product Development
Process Development
Design for Manufacturing
Production Ramp-up
Production Start-up
Manufacturing Stat-up
Process Planning
Design and Manufacturing Interfaces
Design and Manufacturing Integration
Concurrent Engineering
Concurrent Engineering Methodology
Concurrent Engineering Tools

2.3.1 Statistics of Literature Search Process

Following table, [Table 1], presents the statistics of the search result. The middle column presents the total number of found literatures in first stage of search where the information clustering and the abstract reviews has been done based on search keywords and relevancy of the topic discussed in each reference. The right column presents the total number of selected hits at the end of stage two whereat a full-text reading of relevant references followed by broad and in-depth information capturing would determine which one of literatures are most related to the subject of this thesis.

Reference/Journal/Book	**Total number of hit from literature search**	**Total number of selected hit at the end of stage two**
Journal of product innovation Management	87	3
Journal of manufacturing technology management	65	3
International council on system engineering	1	1
International journal of production research	102	7
Harvard business review	20	1
Research policy	34	3
Business horizon	5	1
Sloan management review	10	3
Integrated manufacturing systems	45	7
International journal of product development	23	1
3rd international conference on reconfigurable manufacturing systems	3	1
Journal of operation management	98	4
Harvard business school press	2	1
International journal of production economics	76	10
Robotics and computer integrated manufacturing	2	1
Management science	4	1
IEEE transaction on engineering management	10	2
International journal of operations and production management	66	2
Research engineering design	27	2
Technovation	43	2
Journal of intelligent manufacturing	15	3
Annals of the CIRP	18	3
European journal of operational research	6	3
Concurrent Engineering: research and applications	91	6
Decision Science	1	1
International journal of product economics	13	1
International journal of advanced manufacturing technology	7	4
Organization science	15	1
Journal of manufacturing systems	4	1
Concurrent Engineering	11	2
BOOK (McGraw Hill, The Free Press, PhD thesis/master thesis, paper in the book, conference paper etc)	33	24
Total	937	105

Table 1; statistics of literature search process

2.4 Logic of Data Analyzing and Logic of Reasoning

The form of data analysis in this thesis implements the analogy between the parameters affecting production start-up performance and the elements of concurrent engineering; this comparison would enable the researcher to analysis the data in a way that they can consider the significant parameters and find a tailored correspondent principle of concurrent engineering. The logic of reasoning would facilitate answering the research questions. The purpose of analogy reasoning is to study the root cause of effective parameters and then look for an appropriate element within the structure of concurrent engineering by which the negative impacts of parameters on production start-up can be managed. [Figure 3] illustrates the mindset of reasoning in the thesis.

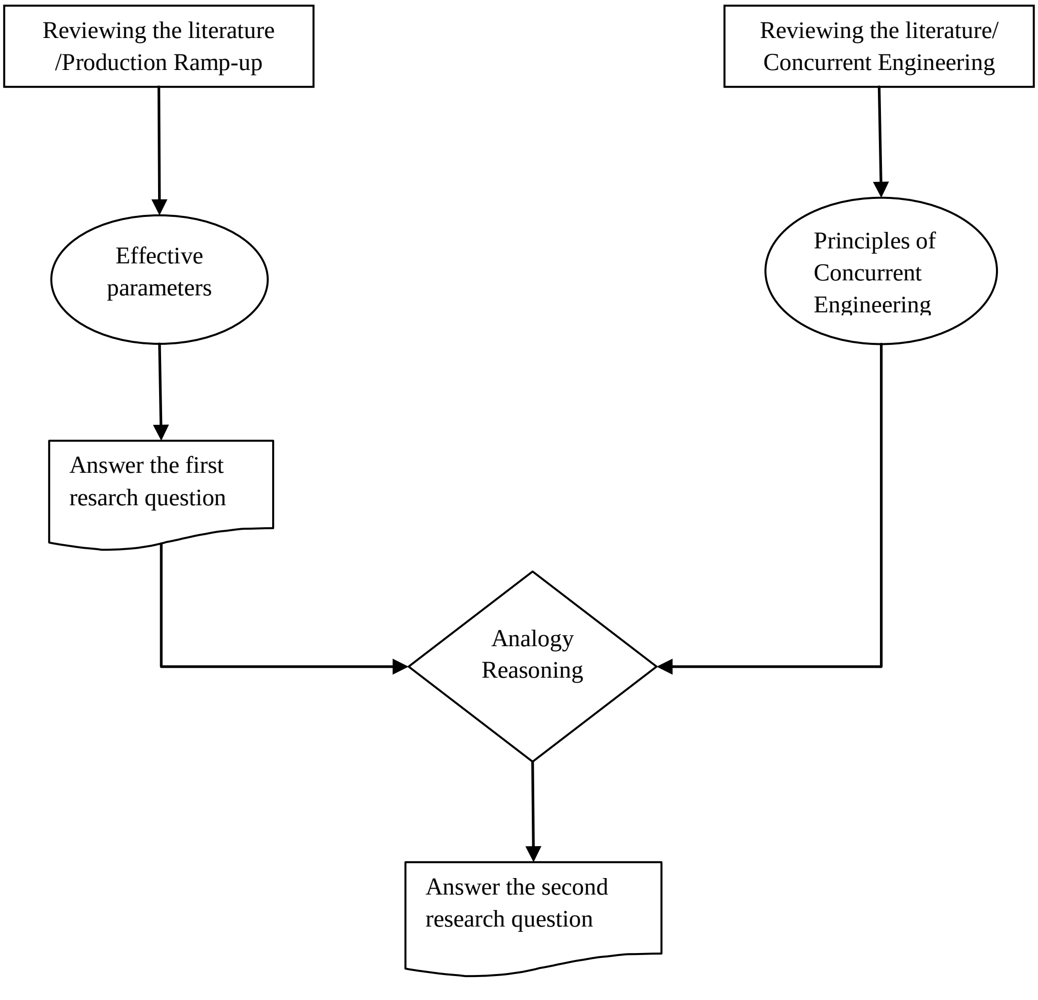

Figure 3; the logic of data analyzing and reasoning

2.5 Validity and Reliability

(Golafshani, 2003) has compared the concept of reliability and validity from quantitative and qualitative research's perspectives. She has noted that the reliability and validity of a research are conceptualized as trustworthiness, rigor and quality in qualitative paradigm. [Table 2] presents the common criteria of a classification for trustworthiness.

Criteria	Qualitative research	Quantitative research
Truth value	Credibility	Internal validity
Applicability	Transferability	External validity
Consistency	Dependability	Reliability
Neutrality	Conformability	Objectivity

Table 2; Lincoln and Guba's Criteria for Trustworthiness [Source: adopted from Huff, S., A., (2009), based on "Comparison of qualitative and quantitative research in Lincoln, Y., & Guba, E., (1985). ***Naturalistic inquiry.*** **Beverly Hills, CA: Saga Publication]**

The validity of a research is investigated in two dimensions: internal and external. Internal validity evaluates the credibility of a research study meaning to what extent a measurement instrument is measuring what it is designed to measure. External validity evaluates the possibilities of generalization and transferability of the result meaning that whether the result of one study is valid in another similar situation. Reliability gages the consistency of the research meaning whether a study can be repeated with the same result.

In this thesis, the researcher tries to search broad and comprehend databases in order to establish credible source of information. Thereby, the articles are sought through five massive and voluminous databases. In addition, when writing the outputs the researcher does criticize, compare, or cite directly rather than interpret and manipulate without supporting source. When clustering the information and chasing the references, the researcher attempts to involve the most relevant resources, either as a book or article, to keep logical and dependable chain of information in order to facilitate reading and understanding flow for readers. In summary, the trustworthiness and authority of the research across the thesis can be considered in three areas: Searching the resource of information, Reading and clustering the information, and Writing the outputs. [Table 3] summarizes the effort of this thesis to institute the acceptable degree of trustworthiness and authority.

Considered Area	How to become trustworthiness
Searching the resource of information	Search broad and comprehend databases
Reading and clustering the information	Attempts to involve the most relevant resources, either as a book or article, to keep logical and dependable chain of information
Writing the outputs	Not interpreting the body of knowledge without providing proper support by former research

Table 3; How to keep trustworthiness in this thesis

3 Theoretical Exposition; Part One

Even though the main focus of this thesis is on the start-up phase, a brief preface of product development process would help a reader to realize the start-up phase position and its significance.

3.1 Preface to start-up phase

3.1.1 Production Realization

The pipeline, at which an attractive product is designed for the customer, manufactured and then dispersed into the market, is called Product Realization Process. It refers to a broader concept starting from the process from product planning to the marketing of a complete product, besides it is defined as a systematic process that the identification and formulation of customer needs are an input of this process, while realization of customer needs is the output. Moreover, product development and production development are essential sub-processes within a product realization process. The entire process is supported by the cooperation of suppliers, consultants, and other supportive functions. (Bellgran and Säfsten, 2009)

Through product realization process, as product design has signed off, prototypes and early pilot products have been built and tested, and manufacturing tools and equipments have been installed, the main remaining objective is to bring product and production system together.

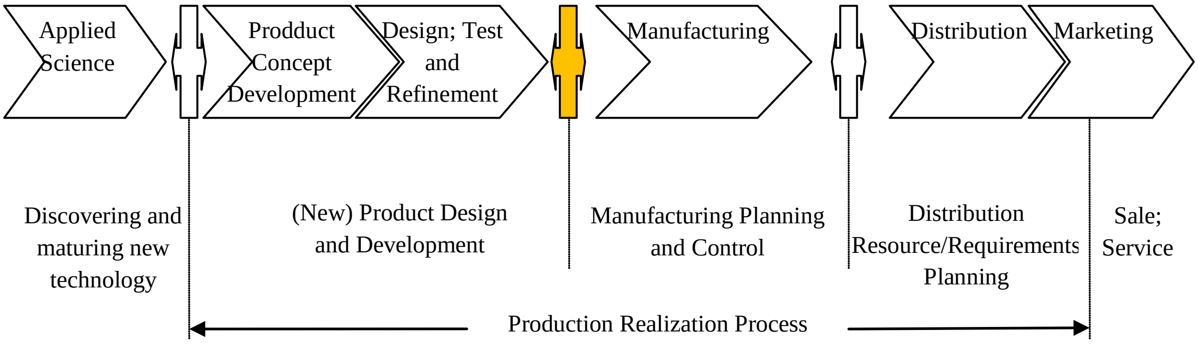

Figure 4; Product Realization Process

[Figure 4] is illustrating a product realization process as well as three critical milestones, which would determine the productivity of a product realization process. It is starting with the product concept development and product planning whereas the maturity of an employed technology would be a critical parameter for establishing a fruitful product development process. The second critical milestone is bringing about when the result of tests are expressing that the required product specification and attitudes are fulfilled, and that it is time to produce a developed product; this is the production start-up phase where the fitness between designed attitudes and the competency manufacturing system will be put through its paces. The last critical milestone but not the least is to distribute a finished product into the market. In this point, it is so significant to evaluate the fitness between the employed manufacturing strategy, the distribution resource and requirements planning because an appropriate logistical approach, such as postponement strategy, can decrease the complexity of upstream processes.

3.1.2 Product Design and Development Process

A product development (PD) is a transformation of customers needs/desires or a market opportunities into what can be sold in available markets for a logical price and reasonable production cost; "the set of activities beginning with the perception of the market opportunity and ending in the production, sale, and delivery of the product" (Ulrich and Eppinger, 2008, p.2). A product development process (PDP) "is a sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product" (Ulrich and Eppinger, 2008, p.12).

Many of steps within a PDP are intellectual and organizational rather than physical. The conclusion of the product development process is the product launch meaning; when a product becomes available for distribution and procurement in a marketplace (Ulrich and Eppinger, 2008, p.13).

There are two types of product development process – stage-gate and spiral processes. Each one of them constitutes the generic product development phases, but they differ in the arrangement of the sequence of phases. The stage-gate product development process is comprised of distinct stages or phases as well as a review or gate at the end of the each phase in order to evaluate whether the previous phase is successfully completed. If the review fulfills the requested conditions the project proceeds to the next phase, otherwise the project will iterate through former phase. Sometimes this iteration can be difficult and costly (Unger and Eppinger, 2009). The spiral product development process includes several planned iterations that span various phases of product development process. It is mainly implemented by software industry (Unger and Eppinger, 2009).

3.1.2.1 A Generic Product Development Process

The generic product development process consists of six phases which based on their chronological sequence are as following: planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up.

Planning; this phase includes three overall dimensions. The basic approach to markets and products with respect to the competitor's activities should be determined. This approach is called corporative strategy. Hence the assessment of technology development and the evaluation of market objectives should be accomplished in this phase. The output of this phase is named as mission statement (Ulrich and Eppinger, 2008).

Concept Development: "A concept is a description of the form, function, and features of the product which are accompanied by a set of specification, an analysis of competitive products, and justification of project" (Ulrich and Eppinger, 2008, p. 15). This phase needs more coordination among different functions. (Ulrich and Eppinger, 2008)

System-level Design*:* this phase pertains a definition of the product architecture and the decomposition of the product into subsystems. The architecture is usually presented as a geometric layout. The final assembly scheme for production system and a preliminary process flow diagram for the final assembly process are other outputs of system-level design phase. (Ulrich and Eppinger, 2008)

***Detailed Design**:* Two important issues are addressed in this phase; the production cost and the robust performance of product/process design. In addition, the complete specification of geometric value, materials metrics, and tolerances of all of the unique parts in the products as well as the identification of the all of the parts that should be provided by supplier are determined. The outputs of this phase are process plan for fabrication and assembly, tooling design, control documentation for the product. (Ulrich and Eppinger, 2008)

Testing and Refinement: in this phase, multiple preproduction prototypes are constructed and evaluated. The various types of prototypes constructed through different phases of product development process. There are different kinds of prototypes to identify: whether the product satisfies the customer needs, whether it is working as designed, as well as to test product's reliability and performance in order to figure out necessary engineering changes. (Ulrich and Eppinger, 2008)

***Production ramp-up**:* in the production ramp-up phase intended production system will be implemented in order to train workforces and identify any remaining flaws and the solution to resolve the problems (Ulrich and Eppinger, 2008).

3.2 Production Start-up phase

3.2.1 Terminologies and Definitions

Within different literatures related to production start-up discussions, there are a few terminologies, which are not clearly defined, thereafter; different terminologies are used for same circumstances. [Figure 5] presents the anatomy of production start-up phase and applied terminologies for various sub-phases.

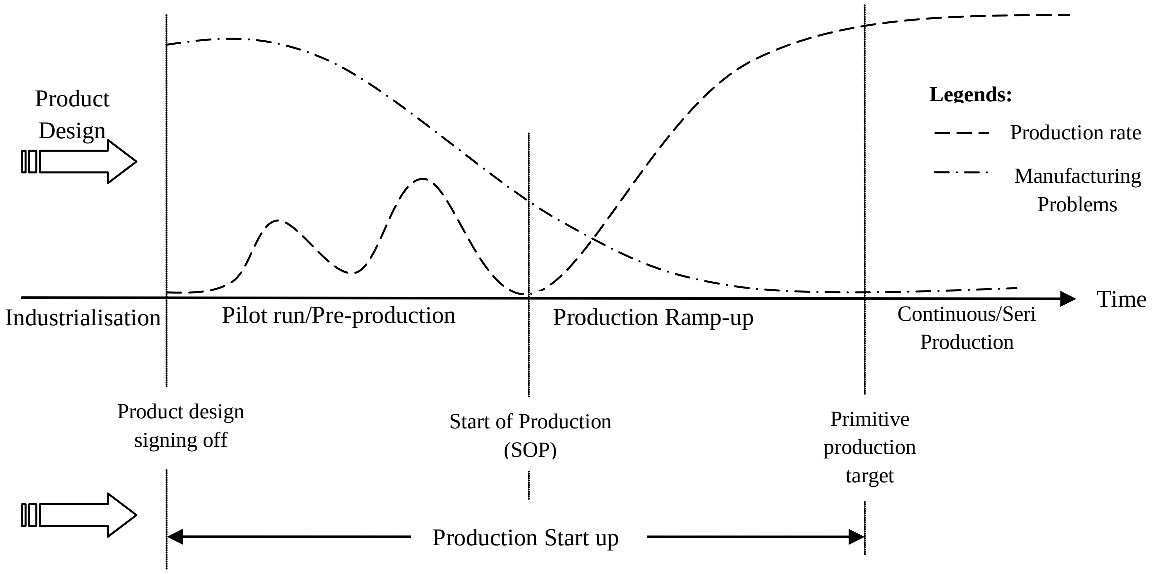

Figure 5; Production Start up & the changing the rate of production

The horizontal axis represents ***Time*** parameters in the figure. At the left hand of figure, the product design is approaching towards production start-up phase; it is referred as ***Industrialization*** period, a. k. a *Product Introduction*, and *Method Planning.* Industrialization is defined as the engineering design to production that is compromised of activities by which a product can become producible. (Bellgran and Säfsten, 2009)

Product design signing off is a point when the engineering design process ends and the manufacturing process can be started. It is important to mention that *design singing off* differs from *design frozen* point. Design frozen point can be later than design singing off point through production start-up process.

At a specific point in the development process, the design team must stabilize or freeze the product's specifications, design principals, components and material choices. Design freeze can be implemented for specific parts of design. There are always engineering changes during production start-up phase. (Langowitz, 1989)

Production Start-up process encompasses activities by which an appropriate production process can be realized until the execution of production process (Bellgran and Säfsten, 2009). After designing, building, testing and refining prototypes, the next phase brings everything together at tailored production system. This phase is called production start up and will be continued till reaching anticipated production rate. Start up phase is constituted of two steps; pilot run and production start-up. (Clark and Fujimoto, 1991)

Pilot run, a. k. a. Pre-production phase is "a full-scale rehearsal of the commercial production system including parts, tools, dies, jigs and fixtures, and assemblies". (Clark and Fujimoto, 1991, p.188)

Pilot run which uses volume production lines is often called pre-production, while generally pilot run is refered only to the trials using separate pilot lines (Clark and Fujimoto, 1991)

This phase involves producing prototypes, which are not intended to send to customer. These prototypes will be used to discover the problems in production processes (Bellgran and Säfsten, 2009). Over the pilot run step the process is completely engineered. (Clark and Fujimoto, 1991)

The objective of pilot run is "to produce pilot products for testing, training (learning), and problem solving" (Almgren, 1999a, p.155).

During pilot production, pilot vehicles are built and assessed from a product and production system perspective. Training is an important activity during pilot production. The objective of pilot production is to identify and prevent disturbances affecting final verification performance before the start of volume production. Almgren H., (2000)

Start of Production (SOP) is the commercial start of production. In the other word, it is the point in time when the products are produced for the actual market (Johanson and Karlsson, 1998).

***Production Start-up, a. k. a. Manufacturing Start-up*:** Once pilot production has ended and the requirements for the start of production have been approved, manufacturing start-up begins (Almgren, 1999a and 2000). Different terminologies have been used among literatures to address this phase; production ramp-up used by (Clawson 1985), (Clark and Fujimoto, 1991), (Terwiesch and Bohn, 2001), (Terwiesch and Xu, 2004), (Juerging and Milling, 2006), (Bellgran and Säfsten, 2009), manufacturing start-up used by (Wheelwright, 1985), (Terwiesch et al, 1999), (Almgren, 1999a), and debugging phase used by (Terwiesch et al 1999), are the most common applied terminologies.

Production ramp-up is the period between completion of development and full capacity utilization. (Terwiesch and Bohn, 2001),

Production Ramp-up is the successive increase of the production rate, up to the point that primitive planned targets in terms of production volume, yield and quality, are reached. During production ramp-up phase, finished products can be delivered to the customer. (Almgren, 1999a), (Bellgran and Säfsten, 2009) and (Fjällström et al, 2009)

In order to measure time-to-volume, definition of two kinds of measures is needed: quality yield and quantity yield. The yield is defined as how well the company fulfils its goals regarding time-to-quantity and time-to-quality (Johanson F., Karlsson M., 1998).

It is also pointed out by (Juerging and Milling, 2006), that the production ramp-up is a time span, which is equal to the differences between time-to-market and time-to-volume.

Production ramp-up is also defined as the period of time following the introduction of a new process into a production facility. The main objective is scaling up production output from the small batches used in prototyping to the large volumes demanded by a market. (Terwiesch and Xu, 2004)

Clark and Fujimoto (1991) have reported “Japanese automotive industries are enable to run both pilot production and commercial production simultaneously at the same time, at the same place” (Clark and Fujimoto, 1991, p.191). In their study of the global automotive industry they have observed significant regional differences in ramp-up performance in Japanese companies versus US and European companies. Their data shows that the time to full-scale production varied from one to six months, while time to normal quality can range between one month and a year. For both measures, on average, Japanese companies ramped-up faster than their American counterparts.

Contiguous (Seri) Production is referred to producing a product in the targeted volume in order to saturate the market. “Time to full-scale production varies from one to six month” (Clark and Fujimoto, 1991, p.192)

In [Figure 5], two kinds of dashed lines are expressing the situation of production rate and manufacturing problems. As the manufacturing problems are removed, a production ramp-up phase progresses forward and gets close to primitive production targets.

3.2.2 Managing Production Start-up Phase

In this section, the articles related to production start-up phase are reviewed. The ultimate purpose is to recognize the significant parameters for managing a production start-up phase, and to study the previous researches that have established a certain approach in managing production start-up. The effective parameters involve variables by which the production start-up performance is boosted and the ones which hindrance the pre-planned norm of functions. The performance of different functions, e.g. quality control, engineering validation, production planning, and etc which, are involved in product and process development procedure, will affect the functionality of a start-up phase. The disturbance variables are the causes and effects of any inconvenience and unplanned event, which reduce the productivity during production start-up. The disturbance variables can occur due to internal or external reasons. The internal reasons can be under control since their causes belong to inner processes. The external variables impose by exterior reasons, which their changes cannot be controlled by the power of organization such as market demand. These variables are, for instance, affecting the quality performance, machines/equipments/tooling functionalities, work methods, human resource efficiency and etc.

A few numbers of scholars, e. g. (Langowitz, 1988), (Merwe, 2004), (Schuh et al, 2005), Berg and Säfsten (2006), have tried to form a framework to explain the cause of effective parameters while some of them, e. g. (Clawson, 1985), (Langowitz, 1989), (Almgren, 1999a), have enumerated a list of variables affecting production start-up performances. Considering both types of researches, in this thesis, the effective parameters are categorized into following managerial scopes:

1- Empathy from Design to Process planning and to Manufacturing
2- Interdepartmental Interface Management
3- Project Architecture
4- Project Management
5- Human Resource Management
6- Supply Chain Management
7- Information Management and learning organization
8- Product Development Organization
9- Ramp-up strategy & Ramp-up planning
10- Manufacturing system capability in process planning and process responsiveness
11- Complexity of product and production systems
12- Late Engineering Changes

3.2.2.1 Empathy from design to process planning and to manufacturing

The decisions of product design result in determining the geometric models of assemblies and components, a bill of material, and control documentation of production. The detailed design is also addressing the interactions between product design and production process. The decision involved in this area will answer the question such as what the values of key design parameters are, what the configuration of the components and assembly precedence relations is, and what the design of components are, including material and process selection. (Krishnan and Ulrich 2001)

One of the most significant parameters in production start-up performance is associated with establishing a manufacturing system so it can satisfy the demands of a new designed product. In other words, there should be empathy within three critical sections of product development processes: product design, process planning and manufacturing process. The empathy can be defined in terms of software and hardware fields. The software fields involve such cogitating schemes as strategy alignment between design and manufacturing, organizational structure, project management, and etc; while, the hardware oriented fields concerns technological ability and facility resources. (Langowitz, 1988), (Vandevelde and Dierdonck, 2003), (Gindy et al, 1999), (Wheelwright, 1985)

The research by (Langowitz, 1988) has taken this argument into account that “Problems occurring in manufacturing due to a mismatch between the new product’s demands and the factory’s manufacturing capability can only be avoided by managing the potential for mismatch” (Langowitz, 1988, p. 46). Thereafter, a conceptual framework is presented by which the implementation of new product development and manufacturing is focused at the project level. [Figure 6] illustrates a graphical summarized of the framework.

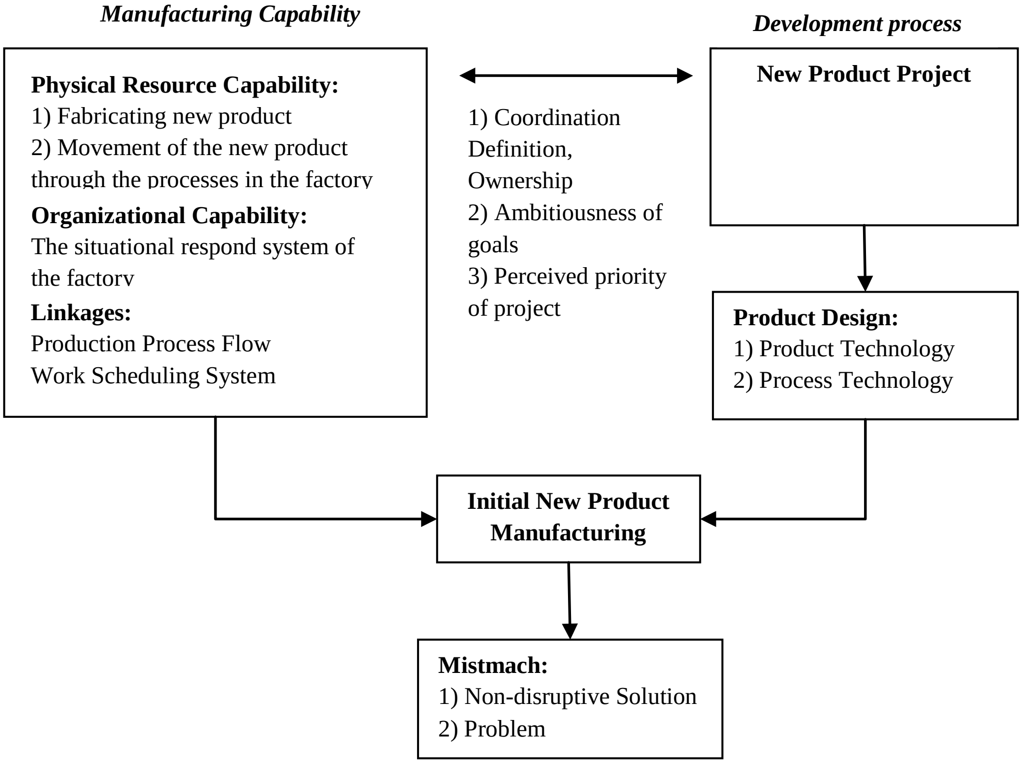

Figure 6; the conceptual frameworks of a new product’s initial commercial manufacturing (modified from (Langowitz, 1988))

The framework points out the mismatches between the manufacturing capability and the development process of a new product project. The manufacturing capability involves two sources: physical resources capability and organizational capability. These two sources are linked to each other by means of production process flow and production planning systems. Physical resource capability can be considered as means of fabricating a new product and movement of the new product within the factory. The organizational capability can mean an organization’s ability in monitoring an activity, identifying issues that are in need of an alternative, evaluating the situation and responding to issues. As a basic condition, the manufacturing capability and the development process of a new product project should not only be in harmony with each other, but also must priorities the strategies of the new product project. The mismatch occurs when the requirements of a new product, cannot be accommodated by the factory's current manufacturing capability. The situational response system can either enable the organization to resolve the mismatch, or may not be able to adequately fulfil the requirements of a new product. In the first circumstance, there will be no substantial disruption of a new product or current manufacturing system whereas the latter circumstance will bring about a substantial disruption for both parties. (Langowitz, 1988)

However, the question is how the problem can be avoided? As an answer for this question; there are two possibilities. "First, the new product may be designed to match the factory's existing competence. Second, the factory may prepare in advance of the new product's manufacture for mismatches which are expected, based on the requirements of the new product's design" (Langowitz, 1988, p. 46). (Langowitz, 1989) has argued that management during a new product development process is a critical factor of success, and one of the vital areas to manage is the fit between product design and corresponded manufacturing process, referred to as "*factory fit*". Moreover one determining factor for the manufacturers for being flexible and reconfigurable in order to respond to volatile market, is to be capable of introducing the new product across a new or existing production system successfully at the shortest possible time window. The level of fitness (i.e. the extent of mismatches) between product development process and manufacturing capability varies considering discussed conceptual framework.

The optimal fitness between design specification and manufacturing competence would occur when a new designed product can be tailored to the existing manufacturing system. The manufacturability evaluation of a design at the early stage of product design can assess the design-manufacturing interfaces so that an appropriate interface management can be established between design and manufacturing Vandevelde and Dierdonck (2003).

The essential tasks through a manufacturing system are to manage the flow of material effectively, to utilize the resources such as machines/equipment/people, and to satisfy the customer requirements by utilizing the capacity of the supplier as well as internal facilities (Vollmann et al, 2005). These tasks are planned and controlled by usage of a manufacturing planning and control system (MPC).The manufacturing planning and control systems must be able to not only respond to the customer needs in terms of proper delivery time and quality, but also to facilitate and maintain a process by which required attributes of a product can be fulfilled.

The production ramp-up phase is executed through a common manufacturing system in a company, hence, when planning a ramp-up, capability and attributes of manufacturing system should be considered. (Gindy et al, 1999) has pointed to the Process Planning as a critical bridge between design and manufacturing where design information should be translated into the manufacturing instructions and technical manufacturing functions. Manufacturing responsiveness is defined as "the ability of a manufacturing system to make a rapid and balanced response to the predictable and unpredictable changes" (Gindy et al, 1999, p. 2399).By improving manufacturing responsiveness, a factory's reacting conditions against changes can become boosted.

Nowadays Process Planning is carried out through CAD-CAM integration; the computer integrated process planning (CAPP) is a software-oriented approach to generate the integration. Besides Process Planning, production planning is another manufacturing function through which the operations are scheduled and manufacturing resources are assigned to the operations indicated in process plan. (Gindy et al, 1999)

(Gindy et al, 1999) has argued that the process planning and production planning are usually performed sequentially; whereas, the integration of them can improve the manufacturing responsiveness in terms of setting and meeting due dates as well as responding to the internal and external disturbances such as machine breakdowns and market demand changes. (Gindy et al, 1999)

A production ramp-up phase is the frontline of manufacturing process wherein planned manufacturing processes must fulfil conditions to approach a high volume production, Hence, managers might think about coping with various internal and external disturbances that can happen during a normal manufacturing process. Throughout the review of other literature, the manufacturing disturbance factors will be discussed in this thesis. Thereafter, an effective parameter in production ramp-up performance is coordinated process planning and production planning. This coordination will bridge the gap between design and manufacturing.

The fitness between design specification and manufacturing system capabilities would be generated through two areas. Firstly, the design and management interfaces must be managed and controlled when the concept for a product design is created. For instance, Design-for-Manufacturing/Assembly (DFM/A) approaches are common tools for handling the interfaces between design and manufacturing in this area. (Almgren, 1999a)

3.2.2.2 Interdepartmental Interface Management

A manufacturing start-up program is the phase of interfaces between different functions such as engineering, procurement, quality, and production. Therefore, an effective interdepartmental management strategy would manage and control the activities according to the master plan of the start-up program. The better planning and scheduling of upstream activities, the more adequate time window for downstream activities such as production start-up will be. (Clawson, 1985)

The decisions made by managers would generally influence the overall procedure of development process (Schloz-R et al, 2007); hence, it is necessary to identify the decisions which are essential and significant for a start-up success. This discussion is also proved by (Juerging and Milling, 2006) via modeling the interdependencies of product development decisions the production start-up performances. Ulrich and Krishnan (2001) have pointed out that poor product-design decisions can slow the rate of production start-up. Clawson (1985) has remarked that the decisions coming from significant functions, such as purchasing, quality assurance, engineering, manufacturing, and suppliers are affecting the manufacturing start-up phase.

Ulrich and Krishnan (2001) divided decision areas into two groups; first decisions in setting up a development project will be reviewed, and then, decisions within a product development project. The decisions associated with setting up a product development project are a) product strategy and planning b) product development organization, c) project management. The decisions associated within a development projects are a) concept development, b) supply chain design, c) product design, d) performance testing and validation, e) product launch and production ramp-up. (Ulrich and Krishnan, 2001)

More integration between engineering design and manufacturing can facilitate managing interdepartmental interfaces within the most critical bottleneck of development process. Swink and Calanton, (2004) have described the integration as a degree by which interdependencies among product design specification and process design capabilities are recognized and solved. The integration of design engineering and manufacturing process knowledge does ensure that the product will be produced efficiently and without defect, thus improving product reliability. (Swink and Calanton, 2004)

The most important activities of a start-up phase consist of discovering and removing bugs between design and manufacturing processes, problems, and missed improvement opportunities that could have introduced earlier in the development. Thus well-established and executed product and process design phases will lead to easier ramp-ups. The way design and manufacturing are coordinated will affect the number of problems and missed opportunities for improvement. (Clawson 1985)

Vandevelde and Dierdonck (2003) have described the barriers across the design and manufacturing interfaces and argued that establishing stable integration between design and manufacturing can provide a smooth production start-up. [Figure 7] presents an integration model which discussed by Vandevelde and Dierdonck (2003). The model expresses the managerial actions by which a smooth production start-up can be ensured.

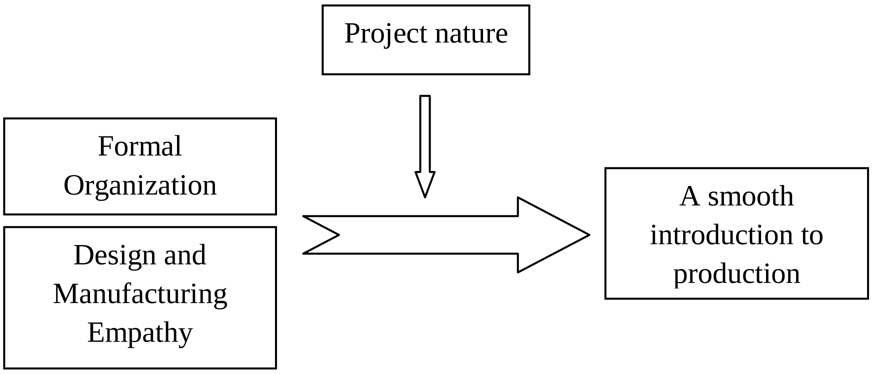

Figure 7; the "integration model", modified from (Vandevelde and Dierdonck (2003))

Clawson (1985) had explained critical issues that lead to operational risk of upper management decisions regarding the competence of real operational systems. A manufacturing start-up program has more ambiguous characteristics than a normal manufacturing process, which has been done for several times and all staff and different departments are used to handling the situation. Owning to this fact, managers should consider the reason for disturbances and going out of control within a manufacturing start-up program. A designer wants to create an elegant and perfect product whilst a manufacturing engineer is interested in simple producible products. Both of them should cooperate together in material selection and process planning. (Clawson, 1985)

3.2.2.3 Project Management

Project management is consisted of the project activity planning and project control. A project management is the heart of decision making during a development project. Hence, the decisions related to project management are controlling the performance of the entire project in every single phase. (Ulrich and Krishnan, 2001)

Wheelwright (1985) has addressed project management as the driving force for directing a development project. Ireland, (2006), has defined project management as a discipline of planning, organizing and controlling the activity of a project. In order to control, to measure and to evaluate the progress of pre-planned activities, a set of metrics should be implemented. For instance the activities related to product design and tool making should be overlapped. Otherwise, a problem creates when design is changed due to the effects on tool making process. Hence, the project needs more flexible management style (Clawson, 1985). Due to unpredictable circumstances within a start-up program, a well-defined plan must be flexible in different situations. Having not mature and well-established program from the beginning as well as evaluating improper performance criteria can lead to a huge project risk. The examples of immature program issues are: wrong estimation of the demands based on Bill-of-Material (BOM), wrong estimation of what is needed and when, not considering the effects of changes on the antecedence of parts and on the suppliers performance. Moreover, the examples of improper performance metrics can be: Having high rate of rejects due to inappropriate quality standards targets, and resource utilization purposes are incompatible with the actual demands. A well-defined schedule must consider monitoring and tracking the action throughout a critical path. It is suggested to have critical path and detailed scheduled program for each process. Normally tools should be available before stating the production and most of the tools and equipment should be modified based on the start-up program requirements. It must be considered that any change in design would lead to the changes in tooling. An effective product design can decrease the demands for new tooling. (Clawson, 1985)

Implementing unnecessary quality oriented constraints would generate unnecessary high reject rate. The production ramp-up target setting such as production rate and quality targets are more unrealistic since they are established at the early phases of product development phases supported by uncertain and approximate information. (Clawson 1985)

3.2.2.4 Human Resource Management

All factors concerning the mobilization and development of personnel as human resources are classifying as a human resource management. The personnel training, motivating approaches, reward and compensation systems should be established by human resource management. (Langowitz 1988) has argued that having good atmosphere of coordination and communication is influential on production start-up. To have good atmosphere of coordination it is necessary to establish predefined roles and responsibilities across team members.

During a start-up program, it is more effective to employ the more experienced, hard-worker and more knowledgeable labors. The knowledgeable workers can learn and being adopted with changes much more easily and rapidly. (Clawson, 1985)

Almgren (1999a) has deliberated a workforce policy as an approaches based on which project tasks are assigned to labors. It is suggested that the skilled and dedicated workforces would concentrate on critical processes during manufacturing start-up. Also, work rotation must be abolished during full-speed testing of start-up phase. The policies should increase the work motivation; it is in turn proposed to affect task performance. (Almgren, 1999a)

3.2.2.5 Supply Chain Management

The supply chain defined as “inbound and outbound flow of materials, as well as the supply of intellectual property and services to the firm” (Krishnan and Ulrich, 2001, pp.8). Supply china design decisions include supplier selection and the issues associated with production and distribution system design such as the configuration of physical supply chain which is directly related to the product design.

The result of a survey, accomplished by Johanson and Karlsson, (1998), expressed that the supply of material, product design, and flow of material within manufacturing processes were the most important sources of the problem within a production ramp-up. The problems concerning the supply of material had mostly happened due to uncertain delivery times, while lack of flexibility in design and uncertain technical specifications had been generating the problems concerning product design.

Planning the material demand and controlling the material flow is one of essential steps in production planning. Implementing a common material requirements planning (MRP) system during a manufacturing start-up program can add cost and chaos to the system. A computerized system to control the inventory level would revise the material flow. Clawson (1985) has suggested implementing a secondary inventory control system for start-up. This secondary system is not separated from the main inventory control system, but controlling just start-up inventory (Clawson, 1985).

A supplier must be informed and understand the changes within start-up phase. In order to alleviate potential purchasing difficulties, the manager can give the procurement agency technical support, develop detailed process schedule for parts, and identify the products critical path. (Clawson, 1985)

The proper material supply can avoid losses generated due to the lack of quality specifications as well as the lack of on time delivery. Hence, the idle time would be reduced; consequently the net operating time of machines can be increased. (Almgren, 1999a)

3.2.2.6 Strategy Alignment within different functions

The conductive structure of organization would reduce the uncertainty in decision making; consequently, the alignment would be achieved among product development program and other strategic management areas. The purpose is to institute an objective strategic management of such functions as Research and Development (R&D), pricing and marketing. The best approach is a more horizontal cut with less R&D in each new product development project and a better balance in the team from all functions. The R&D department should more focus on critical technology and inventions. (Wheelwright, 1985)

The comprehensive strategic thinking must govern the products requirements and factory learning and required skills, new product introduction, and managing the radical and incremental product development process. (Langowitz, 1988)

Within a start-up phase, the firm starts commercial production at a relatively low level of volume; as the organization develops confidence of the abilities of the organization (as well as the abilities of its suppliers) would consistently improve to execute production; moreover, the abilities of marketing can motivate more production by means of increasing the sell, capturing feedbacks from customer and interpreting them into production language, and forecasting the market demand , and consequently to increase the production volume. At the closure of the ramp-up phase, the production system has achieved its target levels of volume, cost, and quality. (Wheelwright and Clark 1992, p. 8)

It is discussed by (Wheelwright, 1985), (Langowitz, 1988) and (Berg and Säfsten, 2006) that there must be existent of the involvement of the objective strategic management not only within a product development process, but also within a production start-up management. The strategic alignment would encompass the strategies of the essential functions such as Research and Development (R&D), manufacturing strategy, pricing and marketing strategy. This alignment is not possible unless there created a strategic alignment among all resources and functions of enterprise organization.

The priority of projects portfolio is determining according to the product development strategy of the company. Johanson and Karlson (1998) have indicated that the priority of product development project as an affecting factor on production ramp-up performance since when the project is most prioritized, the companies are looking at the problems more seriously than less prioritized projects. Langowitz (1988) has pointed out that the smoothness of manufacturing increased as priority given to manufacturability increased.

[Figure 8] expresses the graphical presentation of discussed alignment between different strategies. Berg and Säfsten (2006) have argued the impact of manufacturing strategy directly on ramp-up performance. The suggested framework by Berg and Säfsten (2006), illustrated via [Figure 9], constitutes of three dimensions which are interfacing with overall manufacturing strategy of enterprises:

1- The changes needed in manufacturing strategy content
2- Critical factors affecting the production ramp up
3- Previous production ramp-up evaluation

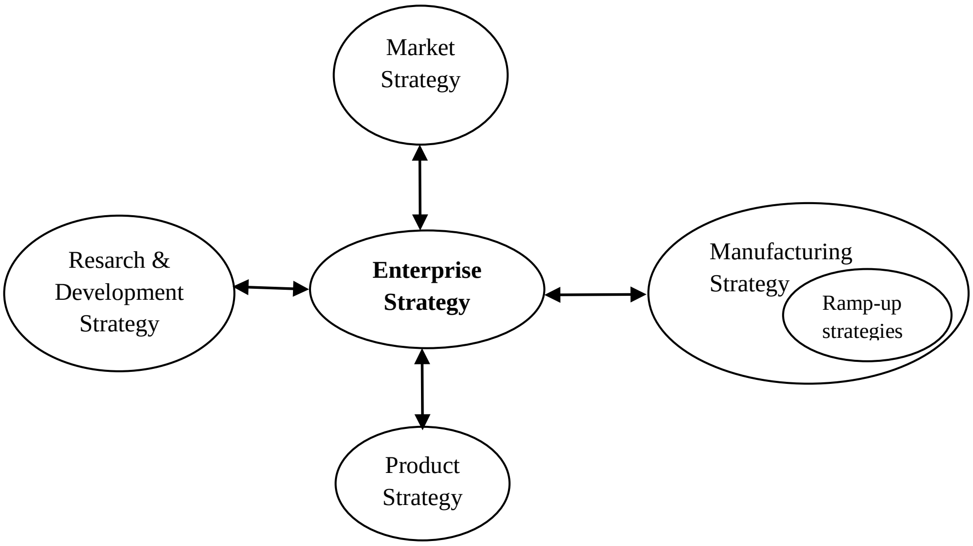

Figure 8; the alignment between product strategy and overall ramp-up strategy

One determining factor for the manufacturers to be flexible and reconfigurable in order to respond to volatile market is being capable of introducing new product across new or existing production system successfully at the shortest possible time window.

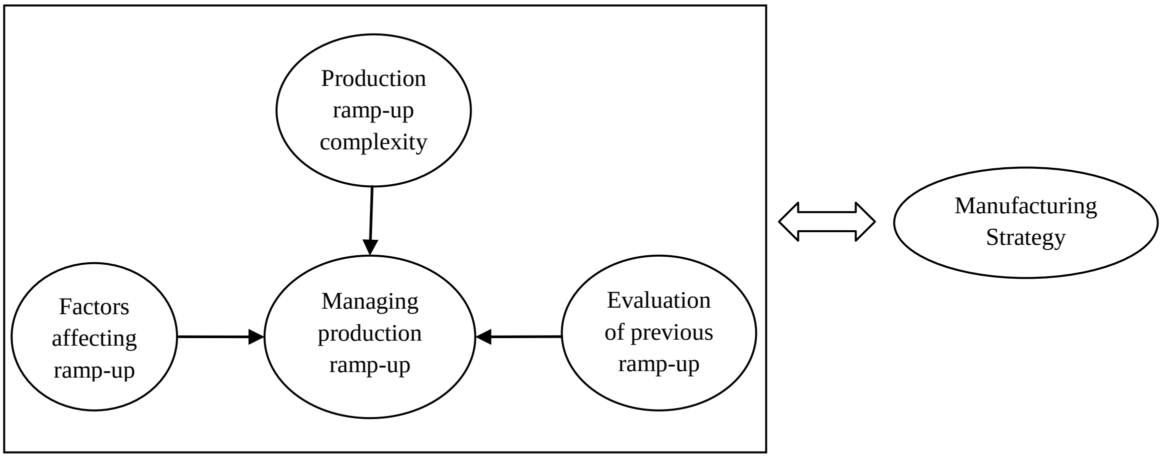

Figure 9; the interfacing of manufacturing strategy with ramp-up management (modified from (Berg and Säfesten, 2006)

3.2.2.7 Information Management and Learning organization

It is essential to institute a system which would enable the organization to achieve continual learning across a series of projects and to collect the experiences of each project, and learn from experiences across a series of projects. (Wheelwright, 1985)

Full-speed testing is an empirical experience that indicates the necessarily of information sharing across production ramp-up phase. The methodology and means which are used to handle a full-speed testing process must be communicated to the workforces. (Almgren, 1999a)

Merwe (2004) has introduced a framework, [Figure 10], for ramp-up compromising of three dimensions by which the body of production ramp-up management is forming. These three dimensions are novelty, learning, and ramp-up performance. A categorization of factors affecting the production ramp up is useful pattern to the fact that it can give important input how to manage training in connection to production start up. According to (Merwe, 2004) the production start-up performance can be seen as a result of providing or enabling the proper learning for a production start up with a certain level of novelty in four different categories; process, product, suppliers, and personnel. The background concept of the conceptual framework is that novelty in various aspects drives the performance improvement during the initial introduction of new products into manufacturing. The management of the introduction of both new process technology and new products into manufacturing presents a serious challenge to companies. Merwe (2004) is developing a framework using the concept of learning to link novelty to this performance curve drawing on the literature and also on various case studies. The conceptual framework is continually being refined as information about the mechanism through which novelty impacts manufacturing is gleaned from the case study data. The problems introduced through the five novelty dimensions are listed in the novelty column, thereafter the learning response of the organization and finally the impact on the start-up performance. (Merwe, 2004)

Fjällström et al (2009) have addressed the role of information enabling and supporting information during production start-up in the manufacturing industry. They have classified the events emerging during start-up into six events: suppliers/supply, product/quality, equipment/technique, process, personnel/education, and organization; and then, for each class of events the type of requested information and the source of information have been studied. The questions posed in (Fjällström et al, 2009) track the information types and sources relating to the different categories of critical events during start-up. However, considering the analysis and discussion in the previous sections, both type of information and information sources found useful when handling critical events were overall similar among the event categories. Information type and information source are not dependent on certain event categories which allows a general information strategy enabling production start-up. [Table 4] summarizes the type of information and their sources for each classified event.

The information flow during a start-up phase can be categorized into three type of information: “the problem information (e.g. type of error, what, where, and how do the problem occur), domain information (e.g. aspects of delivery, equipment and environment, functionality of machines and systems, how to assemble), and problem-solving information (e.g. how to solve the event)”. (Fjällström et al, 2009, p. 186) The domain information has essential role for assembly operators to know how to perform in different situations and for avoiding disturbances in the assembly line. Domain information consists of known facts, concepts, and theories in the domain of the problem in order to recognize the cause of the problem.

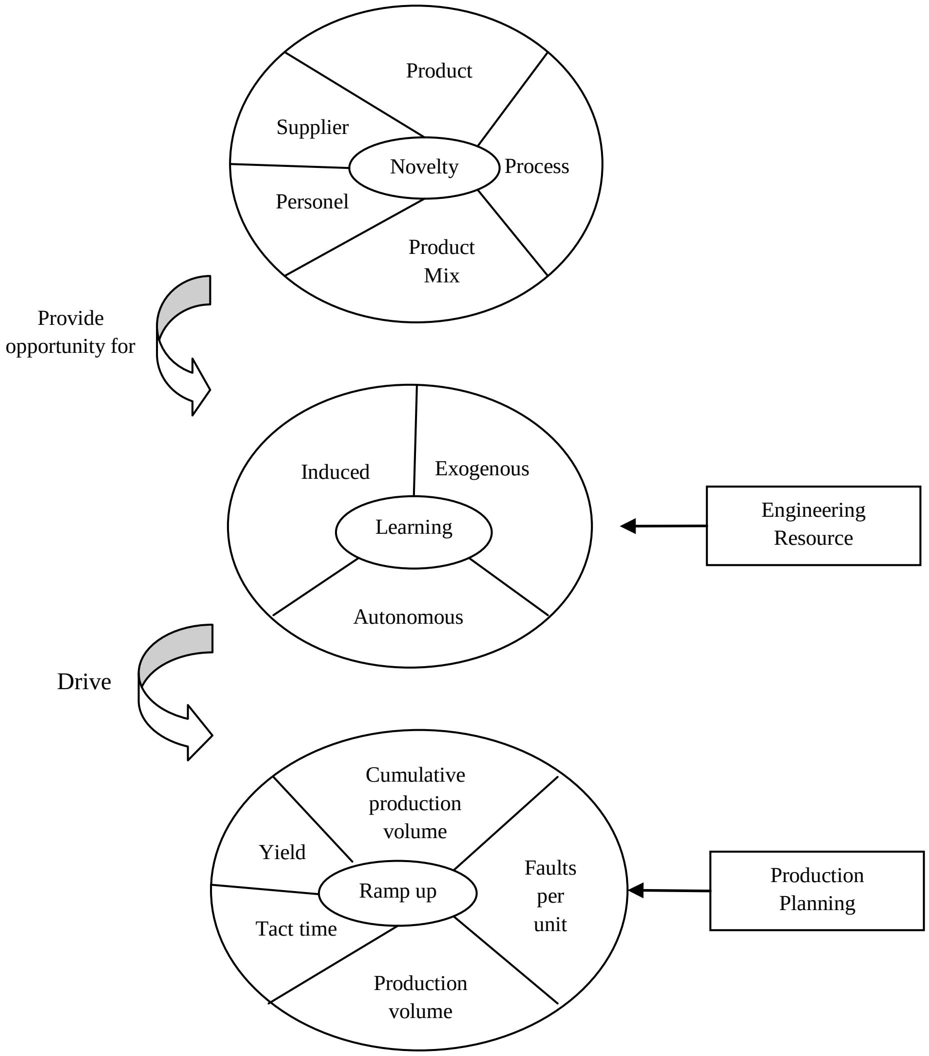

Figure 10; a production Start-up framework considering novelty and learning (adapted from Merwe, 2004)

3.2.2.8 Product Development Organization

The result of a survey, accomplished by Johanson and Karlsson, (1998), expressed that the organizations which are operating based on the light weight project matrix organization lead to more serious problems during production start-up. According to (Krishnan and Ulrich, 2001), the decisions associated with organizational structure are made via a decision area titled as "product development organization". Product development organization refer to a social system where design and development work is accomplished A particular product development organization is depended upon the organizational structure and organizational culture of the entire enterprises since a development project is a part of it. (Ulrich and Krishnan, 2001)

Having formal organization of the project should be considered as organizing and planning a new product start-up phase. According to (Langowitz, 1988) there can be three forms of design organization; 1) A sample design team compromised of only design professionals, 2) A team compromised of the central personnel of engineering department, and 3) A team that is a combination of manufacturing and design. Whatsoever, more emphasize on one function (design or manufacturing) can dominate the context of decision making throughout a project. Analysis of the research by (Langowitz, 1988) experiment that non-routine change increases as manufacturing receives greater emphasis in development. However, the manufacturability changes should be done in order to fit the designed product with current manufacturing competence when the development process is design intensive through realization process.

Critical events	**Type of information**	**information source**
Suppliers/ Supply	- Type of error, together with delivery ((status of material and quality of material being delivered to the line), environment, and economic aspects, were mentioned as important problem information -The rest of the information was categorized as domain information.	- Quality group -Documentary sources, information boards -Visual inspections of the material.
Product/ quality	-The functionality of machines, how to assembly for best result, and what measures are taken; these are categorized as domain information.	-Documentation - personnel
Equipment/ Technique	- For implementation of the new steering equipment in the production process the functionality of the system or as a domain information - How to solve it in the best way or problem-solving information was unknown and therefore discussed and decided at an initial meeting	-Personnel (reporting current situations and their experience) -Inspections
Process	- Information important for handling of process-related critical events were problem-related, such as what is the problem, where does the problem emerge, how do the problems occur; this information was categorized as problem information - The domain information was required in two events information about quality, equipment and reasons behind present process design.	- Contact with other people, - Documentation, - Inspection - Personnel experience.

Table 4; events, information and the information sources emerging in each event during start-up (based on (Fjällström et al, 2009)

The result of a survey, accomplished by Johanson and Karlsson, (1998), expressed that the organizations which are operating based on the light weight project matrix organization lead to more serious problems during production start-up.

The architecture of organization must be able to identify the problems and find out the solution as soon as possible. Owning this fact, Almgren (1999a) has suggested increasing the individual and organizational learning to ensure efficient operation and effective problem solving. Almgren (1999c) has argued that, in studied cases some decision had been made without analyzing the particular situation, hence, the personnel has relied on their previous experiences and intuitions that on analysis and prognosis when making a decision. This issue is interpreted as revealing the lack of clear-cut procedure or directive planning and controlling procedure in designing the organizational structure. (Almgren, 1999c)

Approved organizational structures, procedures, and policies may work well in normal periods of production, but they are often too ineffective and inefficient to generate the type of information that is needed for making decisions during pilot production and manufacturing start-up due to dynamic and unpredictable attitudes of these phases. (Almgren, 2000)

Formalization is defined as “the variety of mechanism that contributes to a structure and clear innovation management approach. It includes clear and structured implementation of co-ordination mechanisms belonging to the generic categories such as standards and rules, plans and schedule, formal mutual adjustment, and dedicated teams” Vandevelde and Dierdonck (2003, p.1332) The formalization of the product development project and the formalization of a product development organization are interdependent; that is, the establishment of each project team and structure inherent the attitudes of the organizational structure as well as the organizational culture. (Vandevelde and Dierdonck, 2003)

Schloz-R et al (2007) has more focused on organizational concepts and structures for technical product changes during production start-up. They pointed out that the essential goals for the ramp-up phase of new model ranges in automobile industry are costs, quality, efficiency of production system, availability of raw material, and the realization of production quantities at the specific points in time. These goals would be influenced by logistics, production and assembly process, the organization and staff, production networks and co-operations, product developments, instrument, tools and methods employed for production start-up.

3.2.2.9 Project Architecture

Project definition may be thought of as a mechanism through which project control is exerted, the involvement of other functions in development process is determined and defined, the stages and milestones are recognized, and also each task and responsibilities are instituted. Defining the milestone of the project and determining the required tasks would be helpful through project planning and control. Lack of the proper definition of milestones may rebate a barrier to the involvement of the functions, in addition to design, in development process. (Langowitz, 1988)

The importance of *Project Definition* is also discussed in other research of same researcher. The reader can refer to (Langowitz, 1989)

Project ownership is the distribution of responsibility for development tasks and decisions making concerning make-or-buy decision making, material decision-making, supplier selection, and transferring of the product from development into manufacturing.

The project nature affects the level of needed integration between design and manufacturing. Vandevelde and Dierdonck (2003) have addressed project nature as a situational variable by which the effectiveness of integration mechanisms is determined.

3.2.2.10 Ramp-up Strategy and Ramp-up Planning

The plan for market testing and launch include determining the degree to which test marketing should be done, the sequence in which product are introduced in different markets, launch timing, and the rate of production ramp-up. (Krishnan and Ulrich 2001)
Launch timing includes a set of decisions which are discussed through marketing concepts such as the threat of competitor entry and the completeness of development. Thus, the discussion related to launch timing is beyond the scope of this thesis.

The companies employing gradual replacing of new developed product and gratually increasing the ramp-up speed have been faced with the most ramp-up problems (Johanson and Karlsson, 1998). (Clark and Fujimoto 1991) has divided the ramp-up strategy and planning approaches into three choices:

1- Choice of ramp-up curve
2- Choice of operation patterns (e.g. line speed, mixed production planning, and mixed model assembly leveling plan)
3- Choice of workforce policy

The ***choice of ramp-up curve*** can be categorized in three models. The first one named **shut down model** indicating completely shutting down the producing of old model and replacing it with new developed model. The second one, **block introduction** express cutting off small block of old model and replacing each block by new model during a ramp-up time. The last curve is presenting gradual replacing of new developed product, **step-by-step** over ramp-up time. Choosing the ramp-up curve depend up the market strategy as well. (Clark and Fujimoto 1991)

The *choice of operating patterns* is limited into three options: adjusted line speed, empty hanger, and adjusted operating time. The operating patterns deal with shop floor activities such as material flow planning, job shop work-plan, production control and determine the production rate. (Clark and Fujimoto, 1991)

The ***workforce policies*** are classified into three groups: layoff/call in, stable workforce, and temporary addition. The first approach is releasing temporary employment and calling them in again after achieving the target point where the continuous production should be started. The second approach is keeping the stable number of employment before and during ramp-up. The last approach is adding new number of employment after inaugurating the new developed product in ramp-up phase. The workforce policy deals with the complexity of task assignment, human resource planning and labor scheduling. Implementing each one of strategies depend upon the company’s approach in introducing and rolling over the new product. (Clark and Fujimoto, 1991)

The more increasing ramp-up speed the more complex planning of material handling, workforce training, and job allocation. Thereby, the need for more training for operators and having skillful workers in order to achieve normal productivity is unavoidable (Clark and Fujimoto, 1991).

(Clark and Fujimoto, 1991) is comparing Japanese product development procedure with Americans and Europeans automakers. The conclusion of the survey is expressing that rapid organizational learning during ramp-up in Japanese assembly plants is depend upon effective real time communication, continuity of production system, exposure to the product during pilot run, and skill at working-level problem solving.

Increasing sale would indirectly boost start-up production. Within a ramp-up phase, the firm starts commercial production at a relatively low level of volume; as the organization develops confidence of the abilities of the organization (as well as the abilities of its suppliers) would consistently improve to execute production; moreover, the abilities of marketing can motivate more production by means of increasing the sell, capturing feedbacks from customer and interpreting them into production language, and forecasting the market demand , and consequently to increase the production volume. At the closure of the ramp-up phase, the production system has achieved its target levels of volume, cost, and quality. (Wheelwright and Clark 1992, p. 8)

Terwiesch et al, (1999) did touch upon financial advantageous of shorter ramp-up phase. Achieving a fast pay-back of investments in new product designs and production facilities require a short development time i.e. time-to-market. In addition to the time it takes to achieve acceptable manufacturing volume, cost, and quality, time-to-volume must be diminished as well. Time-to-market ends with the beginning of commercial production whereas time-to-volume explicitly encompass the period of production start-up. Given that at the beginning of a new product start-up, almost all of the investments for research, product development, manufacturing tools and equipment have already been made, delays in reaching production at the targeted volume and quality will postpone earning the eagerly awaited revenues. Ramp-up is substantially influences the acceptance of a market of a new product. Early, high volume, high quality production will expedite market penetration so that potentially subsequent market share will rise and deter competitors. The financial accounting measures such as return on investment as well as return on assets will be improved by shorter start-up. (Terwiesch et al, 1999)

The *supplier's quality conformance* and having *appropriate ramp-up targets level* such as production yield level are mentioned as two significant parameters affecting ramp-up performances by (Terwiesch et al, 1999). Low yields caused a substantial amount of scrap, and reduce output. However, yields are not a sufficient description of the plant's performance. (Terwiesch et al, 1999)

The short product life cycle means the smaller time window to prepare new generation of product; and consequently, the more time pressure. Thereupon, depending on particular product life cycle for different products in different markets, the ramp-up planning and product introduction should be varied. (Terwiesch et al, 1999)

Terwisch and Yi, (2004) defined production ramp-up as "the period of time following the introduction of a new process into a production facility with the objective to scale up production output from the small batches used in laboratory environments to the large volumes requested by the market" (Terwisch and Yi, 2004, p.72). By means of mathematical modeling approaches, Terwisch and Yi (2004) have formalized the inter-temporal trade-off between learning and process change in form of a dynamic optimization problem. They explained that the idea of a "copy-exactly" ramp-up, which freezes the process for some time period and does not allow for any change in the process. The results express when a firm should avoid any process change during the start-up; such copy-exactly ramps are beneficial if the initial understanding of the process at transfer into production is low, if the process is difficult to improve, if small modifications can have a large effect, and if the overall lifecycle is short. The yield is the indicator for ***process maturity*** and sooner achieving to ***process stability*** will diminish the start-up time.

(Schuh et al, 2005) has addressed three ramp-up strategies; see [Table 5] – slow motion strategy, dedication strategy, and step-by-step strategy. *Slow motion strategy* is carrying out the ramp-up phase by creating the overlap between old and new processes; a.k.a. parallel ramp-up. (Schuh et al, 2005) has suggested employing slow motion strategy for highly automated manufacturing systems, high variety product launch, and unproved process. *Dedication Strategy* is based on the sequential ramp-up of a new developed product. Dedication strategy would be employed for high variety series, prioritized variety allocation, manageable logistic. Moreover, by means of this strategy the final assembly requirements are taking into account to support the ramp-up quality management. *Step-by-Step strategy* would be useful when having enormous technical complexity such as dynamic and complex logistics, and variety specific technology.

Schuh et al, (2005) have noted that the start-up planning phase should follow simultaneously with product development process. Planning phase along with product development phases bring about a reliable forecasting of market demand and an alignment between market demand and process capabilities. As a result, the planning will be more stable. Schuh et al, (2005) comments that "As a basic for the realization of the ramp-up strategy, in the planning of the production, new and innovative design concepts for production equipment are necessary; These concepts have to fulfill the requirements in terms of volume flexibility, product mix flexibility and changeover flexibility" (Schuh et al, 2005, p. 264). Not only the production start-up planning deal with unplanned change in product and production, but also it should be integrated and coordinated with internal and external suppliers.

Ramp-up strategy	**Aim at**	**Production system**	**Attitude**
Slow motion	Parallel ramp-up	highly automated manufacturing process, high variety product launch	unproved process; creating the overlapping of old and new process
Dedication	Sequential ramp-up	high variety series, suitable for final assembly requirements to support quality performance	prioritized variety allocation, manageable logistic
Step-by-Step	Gradual ramp-up	having enormous technical complexity, variety specific technology	complex logistic

Table 5, a classification of ramp-up strategy (modified from (Schuh et al, 2005))

Although a start-up phase is part of overall manufacturing system, but there must be a specific strategy and plan to run it efficiently. Therefore, the operative strategies and operational planning can be established particularly for a ramp-up phase. Ramp-up strategy and planning determines the predefined action plan throughout a ramp-up phase. The strategies and plans would line up with marketing and manufacturing plans. The action plan constitutes of three elements: a) ramp-up curve; determining how the progress of production processes should be during ramp-up phase), b) operation patterns; determining how the lien speed and production rate can differ, and c) workforce policy; determining the human resource allocation during ramp-up phase. The most comprehensive discussions related to the ramp-up strategy and planning is explained by (Clark and Fujimoto 1991)

Schuh et al, (2005) have written about a conceptual ramp-up approach made up of three dimensions: ramp-up strategy, ramp-up planning, and ramp-up evaluation. Ramp-up Strategy considers the ramp-up preparation with coherent objective among different functionalities. Firstly it focuses on controlling the variety and volume of production, lowering the complexity (e.g. managing the highly integrated partner networks in automotive industry), and aligning the production with customer needs. (Schuh et al, 2005) argues that the complexity would be determined based on the attitude of products and process. Thereby, the variances for diversity of volume, the combination of various types of product as well as the employed technology would boost the complexity of ramp-up management due to increasing number of parameters that must be considered in decision making.

Schuh et al, (2005) have claimed that classical production planning parameters are insufficient because of frequent production run-ups and shutdowns. However the primitive acquired learnt knowledge in similar ramp-up phases would prepare a constellation of various productions attributes such as early bill of material and production plan. Hence, ramp-up evaluation based on benchmarking can help to identify any sort of operational deviation, optimization potentials, and remedial opportunities. The benchmark can be done within other partners and similar industries. [Figure 11] present the conceptual framework discussed by (Schuh et al, 2005).

The ramp-up benchmarking would be employed as an evaluation pattern to compare the result of other similar cases with ongoing ramp-up performance. (Schuh et al, 2005)

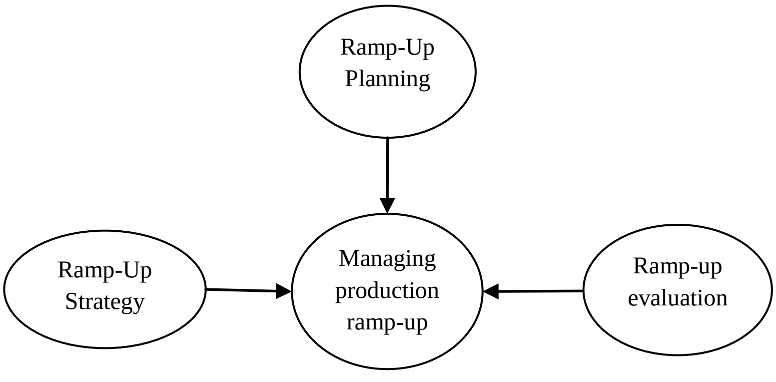

Figure 11; Production Ramp-Up management framework [Schuh et al 2005]

3.2.2.11 Manufacturing system capability

A survey result, accomplished by Johanson and Karlsson, (1998), has pointed out that high flexibility of manufacturing system can increase the capacity flexibility of production line. Hence, the start-up can be performed through flexible planning situation.

Choosing a tailored ***automation level*** can increase the manufacturing capability in dealing with start-up problems. (Johanson and Karlsson, 1998)

(Almgren, 1999a) has empirically experienced the concept of full-speed testing during a start-up phase based on a longitudinal case study in an advanced manufacturing system.

Full-speed testing is "a methodology for detecting potential problems and limitations in technology and organization and for increasing the rate of direct labor learning of operators as well as the rate of cognitive learning of other personnel. The goal of full-speed testing is to attain a level of steady-state manufacturing performance as rapidly and efficiently as possible". (Almgren, 1999a, p.130)

It is practiced that running production system, during manufacturing start-up phase, at the speed (rate) as equal and rapid as ***balanced capacity of production system*** will cause rapid and early detection of problem and disturbances, because, full-speed running would increase the direct learning of labor and improve the technical functionality of machines and equipments. In addition, depending upon whether manufacturing system is labor or machine intensive, the level of automation would influence the manufacturing system capabilities, so consequently the start-up performance. (Almgren, 1999a)

The speed losses during a manufacturing start-up can be the result of machine breakdowns and minor stoppages. (Almgren, 1999a), (Almgren, 1999b)

The work methods determine how a task should be done by an operator. Work methods are kind of methodology and instructions created according to standard operating procedures. (Almgren, 1999b)

Work Pace is defined it as "the intensity by which the activities that make up the work cycle are performed" (Almgren, 1999b, p. 85).

Process Disturbances can be generated internally and externally e.g. delivery performance of supplier, the competence of operators, and the status of machinery and equipment. (Almgren, 1999b)

The *conformance* is defined as "the degree to which a product's or a component' design and operating characteristics meet the established predefined standards such as product design conformance, the competence of operators, supplier conformance and equipment conformance. A deviation of product conformances usually results in a need of off-line correction" (Almgren, 1999b, p.85). The results of the case study in Almgren H., (1999c) explore that product conformance was affected mainly by two factors: 1) ***Material supply*** depended upon the status of materials and quality of the material being delivered to the line and 2) Product concept depended upon ***late engineering changes***.

(Almgren, 1999b), based on a longitudinal case study in automotive producer, has introduced a causal model of factors affecting output and efficiency during manufacturing start-up. First two performance indices are calculated in order to quantify the functionality of manufacturing system during production start-up. These two performance indices are: the capacity performance index and the quality performance index. The capacity performance index defined as a measure of the ratio between number of produced cars and number of planned cars. The quality performance index defined as a measure of the ratio between the number of failed cars and the number of produced cars. Thus, first step of the case study has helped to identify the production disturbances and losses during manufacturing start-up. (Almgren, 1999b)

Almgren, (1999c) has pointed out that product “quality measured as the number of products produced without known comments in relation to the overall number of produced products at the end of the line, was mainly affected by personnel missing parts, misaligned parts, scratches, and leaks were examples of the types of disturbances affecting product quality” (Almgren , 1999c, p. 164).

The cause for capacity losses are ***malfunction of machinery and equipment***, ***personnel absent***, and ***unsuitable material supply***. The causes for quality losses are ***unsuitable incoming material***, ***operator’s skill and competence***, and ***product design***. (Almgren, 1999b)

(Terwisch and Bohn, 2001) is analyzing the interaction among capacity utilization, yields and learning during a start-up phase. The learning curve is employed as a fundamental mathematical model for analysis. The basic mindset is that yield improvement is depending upon learning and knowledge earning process. Subsequently, the outputs of the manufacturing system can increase when the learning and experiment is increasing. Here, the result of quantified analysis is summarized:

Both ***high yields*** and a ***high level of utilization*** should be considered in order to achieve a rapid start-up. (Terwisch and Bohn, 2001)

There is a paradox at the beginning of start-up phase that managers should deal with. Even though the costs are in the highest extent and output at their lowest, it is nonetheless still the moment to further reduce the output in order to run engineering validation trials and work on yields and speed improvements. (Terwisch and Bohn, 2001)

A start-up environment is characterized by high degree of variability and uncertainty which are affecting the production start-up. The variability in terms of product, processes, equipments and peoples should be controlled will impact the material flow and by that the cycle time. Moreover, the uncertainty exists in qualification dates of tools, actual process speeds and the reliability of machines and equipments. (Haller et al, 2003)

Haller et al (2003) have been introducing a methodology by which the cycle time of processes can be controlled based on limiting the work-in-process (WIP) inventory. By doing so, the capacity of processes can be increased, the bottlenecks can be managed, yield will be stabilized, and consequently the throughput time will be increased. Therefore, the better ***managing the cycle times*** the better performance during production start-up.

3.2.2.12 Complexity of Product/Production system

The concept of *complexity* is not well-defined among reviewed literatures cf. the review for (Almgren, 1999c), (Berg and Säfsten, 2006), (Krishnan and Ulrich, 2001), (Johansson and Karlsson, 1998) and (Schuh et al 2005). The complexity of product and production system is pointed out as an effective parameter on the performance of production start-up, but there is no convergence concept.

Among different stages in generic product development process, concept development and product design have the most critical role in creating the complexity of product and production. The complexity can be generated due to two factors: complicated technology as well as an intricate component and material relationship. These two factors can be managed by appropriated configuration of bill-of-material, product architecture, suitable logistics approaches, and determining tailored product variety.

Through concept development phase the target value of the attributes of products is decided. The attributes are involving the customer requirements, engineering characteristics and technical performances. In addition the decision of which technological approach to pursue is made by two focused activities: concept generation, and concept selection. (Krishnan and Ulrich, 2001)

The level of shared components between products would alter the level of complexity in product design. The capability of sharing components across products is determined by the product architecture (Krishnan and Ulrich, 2001). Product architecture is the scheme by which the product functionality (functional elements) is partitioned among components (physical elements); whilst, the decisions regarding physical form and appearance of the product are included in industrial design (Ulrich, 1995). Nevertheless, Berg and Säfsten (2006) has noted that the more ***product mix***, the more material handling and machining set up, so consequently the more complicated production start-up.

(Johanson and Karlsson, 1998) has classified the mix of change in product-process dyad ***(****[New] Product- [New] Process mix)* into four groups. The most problem has reported in the mix of new product-new process where there is higher degree of complexity. The most common status is new product-modified process which has reported as a less problem status. Similarly the mix of a modified product-new process as well as a modified product-modified process has been reported as a status with fewer problems.

The ***complexity*** would determine according to the attitude of product and process. Thereby, the diversity of volume and product mix in terms of various models and technology would be increased the system’s complexity. (Almgren, 1999a)
Product variety is defined as “the diversity of products that a production system provides to the marketplace” (Ulrich, 1995, p. 428). Product variety must balance different customer

preferences and also economics of standardization in design and production. (Krishnan and Ulrich, 2001)

Vandevelde and Dierdonck (2003) have argued that ***the complexity and newness of product*** and technology hinder a smoothness production start-up. In fact, the complex is interpreted as a newness of product.

(Schuh et al, 2005) indicates that one of problem of start-up phase is raising ***the complexity of product and technology (process) which*** influence start-up effectiveness. This complexity can be managed if the product planning aligned with technological and manufacturing engineering capability.

Berg and Säfesten (2006) commented that the differences between the necessary manufacturing approaches before and after start-up phase would be seen as the production start-up complexity. They remark that it would be beneficial if the differences can be identified at the early stage of the product realization process.

3.2.2.13 Late Engineering Changes

In one side, the commitment of suppliers for providing required parts and subassemblies is one of the important factors which are affecting the performance of a start-up phase. The inability of suppliers in updating the tools and their production system at the right time leads to establishing the engineering changes which are happening at the late phases of product development process. These changes are usually time-consuming since changing a part of a designed product/process will touch upon other sub-related parts; therefore, the functionality of the whole system should be considered after each change. As a consequence, the suppliers are not able to supply right quantity and quality of material. In the other side, the ability of company in designing appropriate product concept in terms of involving the right requirements of the customer, and implementing the mature technology can avoid later engineering changes. (Almgren 2000)

Prototypes can reduce the risk of late engineering changes, costly iteration, and restructure task dependencies. The design is being prototyped while detailed design decisions are being made in order to test and validate the fitness of customer requirements and products performance (Krishnan and Ulrich 2001). Product performance is defined as how well the product can perform its assigned functional elements (Ulrich, 1995).

Ulrich and Eppinger (2009) have enumerated different sort of prototypes which are generated throughout the various phases across product development process for different usages. Preproduction prototypes, a.k.a. pilot-production prototypes, are those which producing within production start-up process. At this point the production process is not operating at its full capacity but is making limited quantities of the product. These prototypes are used to verify the production process capabilities due to further testing.

4 Theoretical Exposition; Part Two

4.1 Why Concurrent Engineering

There are various approaches that can generate an integrated and a unique body of product development system. For instance, Concurrent Engineering (CE), System Engineering (SE), Design for X abilities (DFX), Product Life Cycle Management (PLM), and Lean Product Development (LPD) are considered as system-wide approaches that, in a systematic and structured way, take the entire development process into account.

System Engineering (SE) is defined as an interdisciplinary approach which enables the realization of successful systems. It integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. It considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE)

Design for X-abilities (DSX) is focused on different life-cycle functions, metrics, methods and guidelines to apply in the development process supporting the endeavor to enhance the different life-cycle functions.

Product Lifecycle Management (PLM) is defined as a strategic business approach that applies a consistent set of business solutions through which support the collaborative creation, management, support the extended enterprise (customers, design and supply partners, etc.) support the spanning from concept to end of life of a product or plant, support the integration of people, processes, business systems, and information. (CIMdata)

Lean Product Development (LPD) approaches make improvements across the organization. Lean approaches affect both product development and production systems when these systems have to become developed quite rapidly, with the objective of achieving lower cost through the reduction of waste material, inefficient or unused processes (Michelletti, 1994). The techniques of LPD based on (Karlsson and Åhlström, 1996) are: supplier involvement, simultaneous engineering, cross-functional teams, heavy-weight team structure, and strategically managing a project. The techniques of LPD are similar to the principles of other approach which has been implemented in product development processes earlier than LPD; so called Concurrent Engineering (CE). Lean product development has been structured since middle of 21 century, but CE has been implemented since late 1980s (Hines, et al 2006).

Hines et al., (2006) have also commented that “the influence of CE school emerges in the body of recent works which are titled as Lean new product development (LNPD)” (Hines et al, 2006, p. 870). The most distinguishable influence of CE is applying set-based concurrent engineering, along with knowledge management and delayed decision makings policies are key elements of Toyota NPD system as an initial lean NPD approach. (Hines et al, 2006)

Concurrent engineering (simultaneous engineering) is a workflow that carries out a number of tasks in parallel, instead of working sequentially through different stages. For instance, tool design may start before finishing the detailed designs of the product, or detail design of solid models may start before completing the concept design of surfaces models. Although this rearrangement does not necessarily reduce the amount of manpower required for a project, it does drastically reduce lead times, thus reduce the time to market. Concurrent engineering also has the added benefit of providing better and more immediate communication between departments, and reducing the chance of costly late design changes. It adopts a problem prevention method as compared to the problem solving and re-designing method of traditional sequential engineering. Billington et al., (1998) have addressed CE as an opportunity to deal with technology changes risks. Lee-Mortimer, (1990) by exemplifying an instance of production start-up phase has explained how a concurrent engineering program can be beneficial. Pilot build production often do not help to identify the problem of volume production. But, within pre-production stage first time production concerns become clear; for example, the assembly cannot possible in current assembly condition (Lee-Mortimer, 1990). And here the concurrent engineering approaches would make a fertile way out over contriving a system-wide approach among all functions specifically design and manufacturing in production start-up phase.

There are two basic managerial initiatives for implementing a concurrent engineering program. First one is improving cross-functional integration and communication. The latter is improving methods for design analysis and decision making so that designers can cultivate design excellence. (Swink, 1998)

Concurrent Engineering is “a widely recognized approach to improve product introduction” (Brookes and Backhouse, 1998, p. 3035). The research presents a result of a case study comprised of nine companies in UK that have been implementing concurrent engineering approach in their product development processes. A perceived benefit of concurrent engineering is its ability in reducing product development lead time more than reducing development costs and quality improvements. The obstacles for applying a CE program in an organization are: the natural resistance of organization to change, the difficulty in obtaining the information, and lack of effective communication way. (Brookes and Backhouse 1998)

A result of a survey, among 1400 British engineering companies that belonged to key industrial section, accomplished by Ainscough and Yazdani, (2000) presents that CE has been considered as a strategic philosophy within British companies so as to support the company to achieve its objectives in systematic way. This research express that the objective of 67 % of companies in UK is being customer focus, 60 % is focusing on quality, and 40% is achieving competitive time-to-market level. These companies described their goal of choosing concurrent engineering as a philosophy that can satisfy their requirements when focusing on customer, allowing a right first time philosophy to be practice, and shortening time for introducing a product to market. (Ainscough and Yazdani, 2000)

Therefore, the reason for selecting CE is (1) to use a specific approach which is famous in the field of product introduction improvement, (2) CE can improve cross functional integration and communication, hence, it can cover majority of problems in start-up phase which are generated due to lack of empathy between design and manufacturing, (3) CE employ a set of comprehensive methods for design analysis so that designers can select the most optimal design solution which is not only considering the design constraints, but also taking the constraints of production system, logistics and distribution into account.

4.1.1 Concurrent Engineering Definition

Most of the scholars referred to Winner's definition of concurrent engineering; he defined it as "a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life-cycle from conception through disposal, including quality, cost, schedule, and user requirements" (Winner et. al., 1988 in [(Parasad, 1996, p. 164)]) However, there are other definitions that explore Concurrent Engineering in different viewpoint. [Table 6] summarizes reviewed concurrent engineering definitions.

The complex of activities dealing with the design and manufacturing of products in an industrial environment. The basic objective of CE is the installation, organization, and control of the manufacturing process as a whole, and in such a way that all decisions to be taken in the course of the product realization process can be executed in coherence with each other yielding the best possible solution for design and manufacturing and regarding life cycle aspects such as maintenance and disposal at the end of product life.	(Michelletti, 1994)
The parallel execution of different development tasks in multidisciplinary teams with the aim of obtaining in minimum time and with minimum costs an optimal product with respect to functionality, quality and producability	(Rolstads, 1995)
Integrated product development due to minimizing the cycle time and paralleling of lifecycle functions.	(Parasad, 1996)
The synchronization and integration of product design and development activities as well as its related support functions such as manufacturing. This approach causes product developers to consider all effective aspects across product life cycle from product concept through product disposal.	(Stahl et al, 1997)
A systematic approach towards the design of products and the way they are manufactured, assembled, stocked, transported, distributed, and recycled, which aims to optimize product designs in terms of both external demands (e.g. price, quality, delivery time, delivery reliability, range, recyclability) and internal demands (e.g. cost, lead time, manufacturability, assemble-ability)	(Paashuis and Boer, 1997)
As the simultaneous design and development of all the process and information which are needed to manufacture a product, to sell it, to distribute it, and to service it.	(Swink , 1998)
The 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 lifecycle from conception through disposal, including quality, cost, schedule and user requirements.	(Trygg, 1993) modified from IDA
Concurrent engineering is the synchronization and integration of product design and development activities as well as its related support functions such as manufacturing. This approach causes product developers to consider all effective aspects across product life cycle from product concept through product disposal	(Stahl et al, 1997)
A term that has been applied since the 1980's to the product development process where, typically, a product design and its manufacturing process are developed simultaneously, cross-functional groups are used to accomplish integration, and the voice of the customer is included in the product development process.	(Smith, 1997)

Table 6; reviewed concurrent engineering definitions

The apprehensible and transparent definition must explain the nature of the subject as well as its goal and scopes. One of the key fining in this thesis can shed the light on a comprehensive and structured definition through compiling the main concepts of reviewed definitions. Hence, in this thesis CE is defined as following:

- Concurrent Engineering is a systematic approach for integrated and simultaneous product design and production planning in the course of product realization process by means of organizing, installation, execution, and controlling the standard work procedures of design and manufacturing functions; this is subject to considering the requirements of internal and external customers as well as the lifecycle aspects of a product. The ultimate goal is to achieve cost and time effective product realization process and high quality product.

4.2 Concurrent Engineering Principles

The core principle of concurrent engineering is addressed throughout reviewed articles using different terminologies. Some of the referred terms, for instance, are: generic elements, main components, key dimensions, fundamental principles, or concurrent engineering subject domains. [See (Elshennawy et al, 1993), (Trygg, 1993), (Dowlatshahi, 1994), (Parasad, 1996), (Ainscough and Yazdani, 2000), (Landeghem, 2000), (Koufteros et al, 2001)]

The core principles of concurrent engineering are the foundations of a formal product introduction as well as formal project management activities (Ainscough and Yazdani, 2000). Therefore, the successful implementation of a CE program, which would ascertain a successful product introduction, depends upon how much an organization may apprehend the main principles and planned based on them.

The main aim of the survey accomplished by Ainscough and Yazdani, (2000), is to question the components of CE programs and analyze statistically the implementation fashion of each components among different industry sectors; considered components are a) A formal new product introduction process, b) Multi-functional team works, c) Continuous engineering tools and techniques, d) Process enabling information technologies, e) Project Management activities. A formal new product introduction consider a systematic way of carrying out the new product development and product introduction processes, such as formal and systematic generation of blue prints, road maps and templates, while injecting the concurrency into the process. Multifunctional team works within concurrent engineering environment requires to establish a cross-functional communication ability within team members in order to achieve quick decision making and undertaking a set of activities which along with every functional efforts should take account the requirements of other downstream sub-processes. The project management responsibility is predicting and recognizing the potential risks and dangers across product development activities. A project planning must consider the dependency relations of activities, the feasibility of parallel and overlapped execution, and resource allocation constraints. (Ainscough and Yazdani, 2000)

Nowadays the enterprises look for an alternative organizational solution and new work methods through which providing rapid availability of information may be possible. The organizational solution aims at reducing the slack time and unnecessary reworks so as to facilitate the earliest possible start of the various development sub-tasks. A CE program is an example of organizational solutions. A pattern of generic elements for implementing a concurrent engineering program can be listed as following: (Trygg, 1993)

1- Employing multifunctional teams to integrate the design and manufacturing processes. The team can also involve customer and suppliers.
2- Employing computer integrated design-manufacturing and engineering methods and tools such as CAD, CAE/CAM
3- Using a variety of analytical methods to optimize a product’s design and its manufacturing and support processes. Design experiment, Taguchi methods, DFMA, and QFD can be example of these analytical methods.

(Dowlatshahi, 1994) and (Parasad, 1996) have enumerated various approaches for successful implementation of a concurrent engineering program are discussed. These approaches have been classified into five groups:

1- Information systems, software design and artificial intelligent – the information system must gather the design data as well as the feedback data after the design is placed in service,
2- Integration of computer-aided design and computer-aided manufacturing – the objective is to design both product and process simultaneously,
3- Life cycle engineering (LCE) or unified life cycle engineering (ULCE) – the underlying focus is considering the entire life cycle of the product in the early stage of the design process,
4- Design for manufacturability (DFM) and design for assembly (DFA),
5- Organizational and cultural changes – are focusing on the effective communication between designers and other functionalities.

Early problem discovery in design process would save time and cost. Early decision making would freeze the decisions at a specific point; consequently, the design becomes mature as faster as possible. Work structuring defines and allocates the tasks of a project such that they can be accomplished independently of each other either by a human being, machine or computer. A team of people working in separate groups and different functions generate a design of a product. Hence, a team affinity creates an optimal result upon condition that people trust each other and cooperate together rather than work in isolation. Moreover, common understanding is about to bring sympathy in team work; how different functions working as a team should encounter when certain parameters will change. And more important, teams should be empowered to make decisions and given ownership of what they create. Due to broad domain of product design and its complicated nature, it is difficult to create general purpose and automated knowledge based systems. However, interlink between computerized knowledge-driven tools will support human to make ultimate decisions. (Parasad, 1996)

The principle of concurrent engineering are increased role of manufacturing processes design in product design decisions, combining of people with different functional backgrounds into a design team is a fruitful way to combine the different knowledge and experiences (cross-functional teams), taking the customer preferences into account during the design process, time-to-market (process lead-times) is an important determinant of competitive advantageous. (Smith, 1997)

In this thesis, the core principles are first enumerated, and then each one of them is explained and supported by comments of reviewed literatures:

- Comprehensive deployment of constituents
- Early involvement of internal and external constituents
- Cross-functional team and project organization
- Dynamic information management system
- Concurrency
- Integrated product realization process/tools

It would be remarked that the relationship of core principles to each other is complementary; that is, for instance having the cross-functional team make involvement of all constituents possible. Or, an appropriate information management system enables an organization to implement a tailored computerized tool which make possible to carry out product design and manufacturing activities concurrently.

4.2.1 Comprehensive deployment of constituents

In a simple meaning, a CE program does enable to encompass each and every single constituent of a product development process. The reviewed literatures in sub-section 4.2.1 express the comprehensive extension of a CE program’s borders. The CE program determines the path for a product from *planning*, the starting point of generic product development process, to *production start-up* to *market* and to *product disposal*. Therefore, a CE program is able to establish a set of strategic and systematic foundation for various processes throughout the whole life cycle of a product. The strategic foundations can align the macro strategies of an enterprise and would become a guideline for determining a strategic vision for functions; hence, the global optimization would achieve when the strategy and performance of each function is align with downstream and upstream function.

The basic feasible approach via CE is the installation, organization, and control of the product system as a whole, and in such a way that all departments to be acted in the course of the product realization process and to be executed in coherence and in constancy with each other yielding the best possible solution for the whole system. The purpose of *constancy* is to determine overall cooperated goals such that every department makes sufficient effort to meet a common set of consistent goals rather than make their departments look good (Parasad, 1996).

The scope of a CE program, in the course of design integration and concurrency, starts from design for assembly (assembly issues) where the organizational breadth, complexity in tradeoffs, and need for tailored approach are in the lowest intensity. Then the focus is respectively going through design for manufacturing (fabrication and supplier issues), design for excellence (testability, reliability, maintainability, reparability, and robustness), design for competitiveness (customer needs, competitive strategies), and finally design for environment (environmental and social cost issues) where the organizational breadth, complexity in trade-offs, and need for tailored approach are in the highest intensity . It is managerial decision to determine which scope is suitable for implementing a concurrent engineering program. A manager would consider such criteria as the importance of new product development program, the complexity and newness of the product, and the intended uses of the market for the product. (Swink, 1998)

The strategy of CE implementation should be considered as a top-down implementation strategy to get the commitment of top management and his/her involvement. Top managerial level of organization must sustain the changes throughout the organizational structure as well as the organizational culture. Most importantly, the strategic vision of the company should be announced to entire employees. The strategy vision can include the expectation of concurrent engineering program, schedule and timing for project. Regarding the strategic viewpoint, a concurrent engineering can lead the development process in a way to achieve quality, cost reduction, and shorter time-to-market. The strategy for employing a concurrent engineering approach can be what company is planning to make of it; that is, for implementing a concurrent engineering program there is no need to apply every single tool of concurrent engineering approaches. Concurrent engineering program can involve the best practice which is more suitable for each company's specific process and conditions; its concentration can be on a local issue. In the other word, concurrent engineering can be deployed to achieve a specific goal; it can for example, just focus on decreasing the product part count. (Pawar and Riedel, 1994)

"Life cycle engineering (LCE) is also referred to as the *total quality management* approach to concurrent engineering. […]. The underlying principle in LCE focuses on the consideration of the entire life of the product in the early stage of the design process" (Dowlatshahi, 1994, p.110)

(Elshennawy et al, 1993) has introduced a conceptual framework so called "Concurrent Engineering Deployment". It established a concurrent engineering program can across an organization. The conceptual framework consists of four key dimensions (See [Table 7]), five functional resources, and five forces of change. "Concurrent Engineering Deployment" is a procedure comprised of selected practices in concurrent engineering environment. The key dimensions included in CE deployment are: organization, communication infrastructure, requirements for decision making, product development process, quality functional deployment, reverse engineering, and virtual reality. They are associated with organizational culture and matching the authority areas to the required responsibilities in order to run a concurrent engineering program within an organization.

Key dimensions of CE Deployment	Concept
organization	It would impact the functions such as design, manufacturing, marketing, sales, and finance. Moreover, the consequence of impact depends upon the forces of change which are the ability of organization to make changes happen. The forces of change are technology, tools, tasks, talent, and time.
communication	The communication infrastructure facilitates gathering, analyzing, and organizing the information, so that the knowledge and understanding of product and process development can be shared among various functions. The more product complexity, the more complex infrastructure needed. A tailored Information technology to the concurrent engineering program would support fundamental requirements of the program. Not supporting the concurrent engineering program with proper IT facilities would lead to losing control on process of collaboration, loss of product functionality, problem in testability, delays in manufacturing, and finally loss of customer.
requirements	The requirements dimension focuses on determining and adopting customer requirements. In addition, the requirement dimensions must identify essential decision making areas and determine the conditions which must be reviewed before making decision.
product development	The product development dimension involves all the activities through which design process can link to manufacturing processes and transfer the requirements into an expected reality.
Quality Functional Deployment (QFD)	Quality Functional Deployment (QFD) has three steps for interpreting the customer voices: First recognizing what the customer requirements are. Secondly, QFD should evaluate how to translate the customer requirements into specification of production parameters. And finally it should determine how well the product development process could respond the voice of the customer. “House of Quality” is an interior tool which is used in QFD process. The house of quality is a matrix based analysis of customer needs within which marketing, manufacturing, and design engineer can express their ideas so as to the best comparable design solution would be brought up.
Reverse Engineering	It prioritizes the process planning and manufacturing procedures rather than product design.
Virtual reality	It involve a computer graphics technology that is enable to generate real-time computer images as if a virtual model as good as a solid model. A head-mounted audiovisual display, 6-D position sensor, tactile interface devices are some example of virtual reality’s equipments. CAD/CAM tools are also mentioned as significant tools that are more flexible and more rapid than solid modeling.

Table 7; the key dimensions of Concurrent Engineering Deployment, (Elshennawy et al, 1993)

Brookes and Backhouse, (1998), have explained the scope of CE in three levels: a tactical level, at a strategic level, and at an objective level. At the tactical level, concurrent engineering is considered as a series of tools, techniques and organizational structure. The elements that are creating concurrent engineering at a tactical level encompass of planning parallel tasks, establishing cross-functional development teams, inter-disciplinary workgroups, use of quality engineering methods (e.g. QFD, Taguchi, and statistical process control (SPC)), establishing an integrated computer aided engineering environment, using design-for-manufacturing techniques. At the strategic level, all functions associated with product introduction (such as manufacturing, customers, cost, material, quality control, scheduling, supplier safety, and maintainability) must be considered simultaneously and in parallel. The final level, objective level, attempts to improve the performance of product introduction, and hence improving the overall business performance. The borders of third level include the technology management or better selection of ideas. (Brookes and Backhouse, 1998)

Through considering the concept of “system thinking”, the product introduction has seen as a system in where “people” and “tools” are as transforming elements within the system whereas “the process of product introduction” is the interaction of transforming and transformed elements. People and tools are responsible for introducing the product and the organizational relationship among people determines the structure of transforming elements of the system. Hence, five different aspects of concurrent engineering can be considered as the elements of the system which are people, tools, structure, processes, and control. Depending upon the product complexity and company type, the arrangement of mentioned elements would differ. [Table 8] summarized the concept of each element of the system. (Brookes and Backhouse, 1998)

System thinking's element	Concept of the element
People	who are performing product introduction would be classified in different skill groups The skill grouping of the people and combining the most critical skill and knowledge level is the most important phase of establishing a product development and introduction teams.
Tools	Instruments and approaches that are used in product introduction by people.
Structure	The structure of the system indicates the architecture of peoples and their relationships, participated functions in product introduction. That which functions/teams should be co-work together is generating the "structure" of model. For instance, the functions that would involved in the team structure are such as: sale, marketing, contract manager, procurement, test system engineer, mechanical design, electrical design, industrial design, software design, hardware design, manufacturing and production engineer.
Process	The activities by which the people and tools create the product introduction. The product development and introduction process can differ from one product to other.
Control	The mechanism by which the introduction of new products is controlled. "Planning and monitoring mechanism specifically developed for product introduction were mostly found at the individual project level"

Table 8; the concept of a system's elements (modified from (Brookes and Backhouse, 1998))

(Kinacade et al, 2007) and (Holt and Barnes, 2009) have presented the result of a case study within three apparel industries. The most common scope of concurrent engineering are classified as summarized in [Table 9].

By getting help from literatures, Kinacade et al, (2007) have gathered operational statement corresponded to each conceptual area (See [Table 10]). Then, through a survey, the authors investigate which activity in apparel industry can be rearranged according to the operational statement. Discussing about the final result of this article is beyond the scope of this thesis since it is purely related to the manufacturing processes of the apparel industry. However, the conceptual areas of concurrent engineering as well as operational statement of them can help to understand the potentiality of concurrent engineering program.

4.2.2 Early involvement of internal and external constituents

Internal constituent addresses the functions which are directly or indirectly influenced by product realization process such as engineering, manufacturing, purchasing, sale, accounting, distribution, and quality. The external constituents are the participant of target market as well as suppliers and sub-contractors. The most important point is that the involvement must be conducted as early as possible so that the engagement of various participants can be more beneficial due to recognizing the constraint and resolve them as early as possible.

Design for xxx	Considered concept by (Kinacade et al, 2007)
Design for cost (DFC)	An aproach to achieve a specific cost/price target point. In the other words, design and cost issues take into account at the same time from the beginning of design processes.
Design for enabling technology (DFET)	Involves the integration of computer-oriented technologies for the design of the product and for communicating them with production system as well as trade partners.
Design for lifecycle use – inspect ability, maintainability, reliability (DFLC – I, DFLC – M, DFLC – R);	These three concepts are focusing on a set of desired attitudes of product rather than fashion and style of products which is taking most degree of concentration in apparel products. Design for maintainability involves the form of guidelines or tools for predicting maintenance costs and reliability of product. Related to maintainability is the reliability of a product which defined as "the ability of a product to perform its functions over a period of time without failing" (Holt and Barnes, 2009, p. 6).
Design for manufacturability (DFM)	For setting up a product development process in a way that the design not only is feasible for a company's production system but also is cost effective. Design for manufacture and disassembly (DFM/DFA) is similar to Design for Analysis. it helps a designer to determiner feasible disassembly sequence for a product. DFM is more concerned the component level of design, whilst DFA is more concerned about product structure. DFM concerning the cost efficient design from the beginning stage of design through, for example, avoiding needless design iteration.
Design for quality (DFQ)	A tool for ensuring that the customer's requirement will be met. DFQ consists of a set of tools such as quality functional deployment (QFD), Taguchi methods, and benchmarking through which the customer requirements will be met. Taguchi methods are used as a way of quantifying the cost of deviation from an idealized parameter value via providing metric that can be optimized.
Design for Environment (DFE)	It includes environment friendly products design. Its tools are providing a set of metrics through which a designer can evaluate the environmental impact of a design solution and make an appropriate green design decision.

Table 9; the most common scope of concurrent engineering in apparel industry, (Kinacade et al, 2007) and (Holt and Barnes, 2009)

Design for xxx	Operational Statement
Cost	Lifecycle costing, Target cost for product, Tracking system that monitors cost targets
Enabling Technology	2D/3D CAD systems, Accumulated design knowledge to be used repeatedly, Avoid paper drawings, CAD solid modeling, Digital data processing systems, Electronic data exchange (EDI), Product data exchange using STEP , Data Storing systems, Tools and fixture design
Lifecycle use – Inspect ability	Automated equipment compatibility, Built in test diagnostic capability, Early involvement of quality assurance, Geometric dimensioning and tolerance, Having ability to test and diagnosis, Specification of product parameters, Standard connections
Lifecycle use – maintainability	Analyzing mean time to replace, Available inexpensive parts, Designing products for easy maintenance, repair and replacement, Modular design replacement, Tradeoff considerations
Lifecycle use – Reliability	Computer-aided engineering tools to test, Building prototypes and test iteration, Provide standard parts, Reliability engineering, Taguchi quality engineering, Vendor/partner relationship
Manufacturability	Design for ease of assembly, Design for ease of fabrication, Ergonomic factors requirements, Group technology, Inspection or measurement at the source Shop floor team organizations, Minimal Handling, Minimizing design-manufacturing variations, Reducing job-machine set up time, Reducing the number of parts, Using standard components and material
Quality	Acceptable tolerance, Benchmarking, Designing a robust product, Quality functional deployment, Selecting high quality components/suppliers

Table 10; the conceptual areas of concurrent engineering and their operation statements, (Kinacade et al, 2007)

That is, the early feedback of participant will lead to early problem solving and early decision making. Hence, time-consuming reworks can be avoided.

Lee-Mortimer, (1990) has pointed out that the complexity and the quality assurance of a product can be controlled by involving procurement department enables gaining the inputs from supplier and subcontractor abilities. Dowlatshahi, (1993) has discussed that in order to achieve the greatest beneficial of integration, all activities related to the development of a product should be focused in the early stage of product design; consequently, the impacts and constraints associated with various functional requirements should be known to the designer on a timely, accurate, and relevant basis. Koufteros et al, (2001), has commented that the involvement of various constitutes as early as possible can generate the match among different functions through avoiding misperceptions and understanding the capability of other functions. Therefore, late engineering changes can be avoided; besides, purchasing can order long lead times in advance and track the material availability much better.

Koufteros et al, (2001) have pointed out that “the most cited reason for delays in product development projects in manufacturing system is engineering change orders. These occur when materials are unavailable and/or parameters about the product do not match manufacturing capabilities and/or customer expectations” (Koufteros et al, 2001, p. 100).The involvement of various constitutes as early as possible can generate the match among different functions through avoiding misperceptions and understanding the capability of other functions.

In order to facilitate the involvement of suppliers earlier in the product development process, three approaches are discussed in (Parasad, 1996) to share product’s life cycle responsibilities with subcontractors and suppliers: specification and formal purchasing contract, two-phase contractual agreement (between supplier-manufacturer), partnership and mutual learning (between, subcontractor-supplier-manufacturer). Trygg, (1993) has mentioned that the early involvement of suppliers would help them to reduce their preliminary design and production tasks based on preliminary information; likewise, the early involvement of the customer can help to recognize the critical requirements of the customer as early as possible.

4.2.3 Cross-functional team and Project organization

Cross-functional team is the most essential factors of a CE program. Almost all of the reviewed literatures have explained the importance of cross-functional teams to help the progress of concurrent engineering program. [See e.g. (Trygg, 1993), (Swink et al, 1996), (Stahl et al, 1997), (Huak et al., 1997), (Ainscough and Yazdani, 2000), (Landeghem, 2000), (Koufteros et al, 2001)]

Cross-functional team means a work team consisted of multidisciplinary experts who can belong to various functions such as designer, manufacturing process planner, mechanical engineer, software programmer, and etc. Trygg, (1993) has argued that the dominating element of concurrent engineering is the use of multifunctional project teams, often including customer and supplier as well. The purpose of the multifunctional teams is to facilitate the communication channels between participating functions so as to all of them can provide their inputs before finalizing the design. (Trygg, 1993)

The appropriate organizational and cultural changes are the prerequisite for successful implementation of a CE program. Communication is one of the key elements of changing the organizational culture. The degree of involvement and the extent of interaction between design and manufacturing are mostly determined through the organizational structure, the management philosophy/style, and the organizational culture. The organizational culture must provide a new mode of operation so that make product innovative, make production flexible, and make the integration between manufacturing and other functions possible. (Dowlatshahi, 1994) and (Huak et al., 1997)

Koufteros et al, (2001) have argued that cross-functional product development teams enable easier communication and smooth flow of information; the easier communication will lead to innovation followed by a search for information about a technical solution to meet the need. Trygg, (1993) has indicated that the smooth information flow, which is facilitated through communication channels among cross-functional team members, enables participated functions to provide their inputs before finalizing the design. It is discussed in (Ainscough and Yazdani, 2000) that cross-functional teams help to achieve quick decision making and undertaking a set of activities which should take the requirements of other downstream sub-processes into account, in addition to normal responsibilities of each function.

In reality gathering different persons from different backgrounds with different standards of communication, and with different cultures and attitudes is not simple exercise. It would require restructuring the form of an organization. Other reason for changing the structure of a project organization is due to altering the work procedures that should be accomplished simultaneously rather than sequential order. That how much an organization can become successful in changing the work procedures and adopting new fashions depend on the “forces of change” or “change agents”. The forces of change are the ability of organization to make changes happen. The forces of change are known as 7Ts included technology, tools, tasks, time, teamwork, talents, and techniques (Elshennawy et al, 1993), and (Parasad, 1996).

But the significant decision, which would affect the whole CE program, is that what should be change? Dowlatshahi, (1994) has discussed that organizational and cultural changes are focusing on the effective communication between designers and other functionalities. The successful implementation of a concurrent engineering program requires: the great deal of coordination and planning, fluid and flexible organizational structure, institutional culture that can encourage innovation. Pawar and Riedel (1994) have classified the organizational changes when applying a concurrent engineering program into three groups: organizational structure, personnel practice, business practices and procedures.

Regarding concurrent engineering program structure, Swink et al, (1996) have pointed out eight major functional group that play important roles in product development process; These groups are: design engineering, marketing, customers, partners, regulators, product support, manufacturing, and suppliers. Design engineering should integrate the design activity related to electrical and mechanical systems in terms of both software and hardware aspects. The design should be planned according to a certain time intervals and financial considerations. Customer is the main source by who the required performance and requested product features can be recognized. Marketing department is responsible to gather the customer requirements as well as information regarding competitors' available product in the market. Suppliers, partners, and regulating groups must provide substantial support for engineering design especially when the major components are new or has been subcontracted. Manufacturing and support engineering can evaluate the design in terms of manufacturability and upcoming production and maintainability issue of product. (Swink et al., 1996)

Depending on the integration of project manager and functions, every concurrent engineering program can set up in different *organizational structure,* depending on the integration of project manager and functions, such as: functional structure, lightweight product manager structure, balanced matrix structure, heavyweight product manager structure, and separate project team structure. In the *functional structure* the authority rests with the functional manager, and there is no top coordinator like a project management to make overall supervision of project. In the *lightweight product manager structure*, there exists a product manager or a team leader who does not have complete authority on project activities; rather than, the *heavyweight product manager structure* in which a product manager is the clear responsible for planning and authoring the tasks and members of different team and functions. In the *balanced matrix structure* the authority is shared between the functional manager and the product manager. The *separate project team structure* lead team members to tie to the functional departments. (Pawar and Riedel, 1994)

The characteristics of a new product development program encompass the critical issue such as design quality, product cost, introduction speed, complexity, level of innovation, and technical risk. If there is high priority on product introduction speed, the objective of the project would be reducing development times as well as reducing design reworks. Hence, the concurrent engineering program should be consider establishing heavy interaction between internal and external technical product design experts, creating less formalized teams and task forces, establishing high project phase and design concurrencies. (Swink et al (1996)

Regarding the *personnel practice*, commitment to developing more qualified workforce is important. In concurrent engineering environment reward system is more focused on team performance rather than individual performance (Pawar and Riedel, 1994). Moreover, personal practice requires changes in relations, norms, cultures, and attitudes on management, white collars and blue collars (Dowlatshahi, 1994).

Change to *business practice* would include the general aspects of business procedures such as establishing long term relationship with customer, establishing long term relationship with supplier and eliminating counterproductive competition policies, working procedures e.g. new accounting systems, or project management procedures (Pawar and Riedel, 1994) and (Parasad, 1996).

The organizational culture must provide a new mode of operation so that make product innovative, make production flexible, and make the integration between manufacturing and other functions possible (Dowlatshahi, 1994).

Work structuring defines and allocates the tasks of a project such that they can be accomplished independently of each other either by a human being, machine or computer. A team of people working in a separate groups and different functions generate a design of a product. Hence, a team affinity would create optimal result upon condition that people trust each other and cooperate rather than work in isolation. Moreover, common understanding is brining sympathy in team work, how different functions working as a team should encounter when certain parameters will change. And more important, teams should be empowered to make decisions and given ownership of what they produce.

Ainscough and Yazdani, (2000) have commented that project management is the critical role that would be affected by exercise of a concurrent engineering program. The project management responsibility is predicting and recognizing the potential risks and dangers across product development activities. Considering the dependency relations of activities, they must execute parallel and overlapped with each other; hence, the project planning and controlling must fulfill accuracy in resource utilization.

Selecting appropriate integration mechanism would affect some critical factors of concurrent engineering program such as differentiation and linkages between departments, cross-functionality requirements, uncertainty of information, and complexity of tasks. The enumerated integration mechanisms by Pawar and Riedel (1994) which are listed in next section

4.2.4 Dynamic information management system

The *communication* infrastructure facilitates gathering, analyzing, and organizing the information, so that the knowledge and understanding of product and process development can be shared among employees. The more product complexity needs more complex infrastructure. A tailored Information technology to the CE program would support fundamental requirements of the program. Not supporting the concurrent engineering program with proper IT facilities would lead to losing control on process of collaboration, loss of product functionality, problem in testability, delays in manufacturing, and finally loss of customer. (Elshennawy et al, 1993)

Elshennawy et al, (1993) have commented about the necessity of appropriate information technology for a CE program; they argued that the lack of support via proper information technology facilities would halt the process of collaboration, loss the product functionality, make problems in testability, and consequently cause delay in manufacturing processes. Salzberg and Watkins, (1990) have indicated that the information system must be able to manage the complexity of relationship among information sources along with the creation of more volume of information. Moreover, the information system must generate the integrated display of data supplied through various source of information and functions.

An information management system may be implemented to not only do save the engineering and technical data but also it would enable to combine the data coming from different resources and make automated analysis possible. For instance, when having numerous and complex information which must be analyzed through failure mode and effect analysis (FMEA) tools, an automated FMEA procedure can help researcher to manage the information rapidly (Salzberg and Watkins, 1990) and (Wilson and Wilson, 1994).

In this thesis the information management system is defined as:

- A system that can facilitate gathering, saving, summarizing, analyzing, and organizing the data coming from different sources by means of hardware and software infrastructure in a dynamic concurrent engineering environment. This system must enable and manage the flow of information across an organization and make transparent communication possible. The ultimate goal of the information management system is to provide manageable knowledge sharing among users and to get feedback from users in order to establish unified comprehension of product and process development processes.

The information system structure explained in this paper remark that the critical issue is the transfer of relevancy between the specific functional areas while the ultimate purpose is unifying the product concept. Wilson and Wilson (1994) have pointed out that the overall purpose of a CE program is to merge the organizational functions via a parallel and synchronized working relationship. The example of organizational function would be marketing, design, manufacturing, quality control, procurement, and accounting. For instance, the information linkage between organization, its supplier and customers can be supported by Electronic Data Interchange (EDI) to transfer of business data. (Wilson and Wilson, 1994)

It is important to determine which data should being generated, what the data source is, where the data should go, and, how the procedure of data analyzing is. The information systems consist of the information database served as a network within which there is a connecting link of various functions and departments participated in a CE environment. Dowlatshahi, (1994), has suggested that in order to utilize the information management systems for design of mechanical systems, two types of data are required: Design data and Performance data. Design data refer to identification and documentation of work procedures, behaviors, product testing, design validation, design review, and product reliability records. The performance data provide feedback to design after placing the design in service across actual operative systems. Salzberg and Watkins, (1990) have exemplified other sort of data that would involved component drawings, assembly drawings, factory and process layout, product testing information, customer feedback (marketing feedback containing the complaints and suggestion from customer), repair records, plant reliability and process capability records and problem histories. Paashuis and Boer, (1997), have commented that one of the problems in redesigning a new product development process is the lack of tools for mapping the process. There exist a few structured tools, listed by (Paashuis and Boer, 1997, p.84), such as PRISMA, trigger-modeling, Petri nets, technology and organizational analysis, and IDEF0.

These tools are employed for modeling an information management system throughout a product development process (Paashuis and Boer, 1997).

Terwiesch et al, (2002) have addressed the information stability and information precision issues when functions have to start their operation based on preliminary information coming from other precedence or antecedence functions. Information precision refers to “the accuracy of the information exchanged” while information stability refers to “the likelihood of changing a piece of information later in the project” (Terwiesch et al, 2002, p. 402). The framework addresses two alternative strategies, iterative coordination and set-based coordination, which guide a manger to match the organizations’ problem solving strategy with interdependencies among functions and activities in an organization. Three factors should be considered when evaluation the trade-offs for choosing coordination strategy. First factor is the format of the information as transferred by upstream, the downstream adjustment costs to changes, and possible substitutes for preliminary information. (Terwiesch et al, 2002)

Iterative strategy is formed as realizing high precision preliminary information by upstream functions based on what “it views as the most likely outcome at the current state of knowledge. The final outcome is likely to be different (low stability) and downstream has to adapt in form of rework” (Terwiesch et al, 2002, p. 416). Set-based strategy would be classified into two different approaches: starvation and duplication. In starvation approach, “upstream release only that information that will be part of the final information with a degree of certainty (high stability). This can lead to starvation downstream which may have too little information to proceed” (Terwiesch et al, 2002, p. 416). Duplication approach is when “upstream release all possible outcomes of its problem solving, which makes the preliminary information very stable. Starvation is avoided (precision is high), as downstream pursues multiple scenarios” (Terwiesch et al, 2002, p. 416).

However, the implementation of an information system in an organization would not become into practice unless the barriers can be identified and resolved. Salzberg and Watkins, (1990) have enumerated a list of implementation barriers as following:

- Existing information are inadequate or in an unusable form
- Inter-functional barriers for establishing an information flow; e.g. the lack of standard communication symbols between product design and process design groups, and then between process design groups and manufacturing engineers.
- Having more effective way of disseminating many types of information from different functional within organization
- Technical barriers such as insufficient type of computer, improper network infrastructure, integrating data from various databases, establishing dynamic and flexible information after changes and updating, data classification and aggregation, data storage requirements.
- Organizational barriers (such as motivating the engineers to contribute to the system, achieving the critical mass of data so as to the system become users first source of information, existing performance assessment systems, keeping information as secret source bring about a power in organization (inappropriate organizational culture).

4.2.5 Concurrency

The concurrency in concurrent engineering program would be employed in: (Parasad, 1996) and (Swink et al, 1996).

- Parallel product decomposition
- Resource allocation
- Concurrent processing
- Concurrent project phases
- Design concurrency
- Product concurrency

In an enterprise where there are different product development project is carrying out, the *parallel product decomposition* means establishing an aggregated plan to take multiple characteristic of a product life cycle and develop them in parallel for various product development program (Parasad, 1996). *Product concurrency* has interfered by Swink, (1996) as "the overlap of separate but related new products requiring coordination between new product development programs. Product concurrency exists either in the concurrent development of first-generation and next-generation products or in the development of separate product variants" (Swink et al, (1996), p.240).

Concurrent resource allocation means planning, scheduling, and putting a same source of resources such as labor, or a machine into action for different product development programs simultaneously, rather than waiting to finish with one activity and then going towards the next one sequentially. (Parasad, 1996)

Concurrent processing means simultaneously developing different phase of a product development program such as market concepts, product design, manufacturing processes, product support structure simultaneously. (Swink et al, 1996)

Design concurrency involves "the overlaps of design disciplines (e.g. system, software, electrical, and mechanical engineering) so that system level and component level designs are produced concurrently" (Swink et al, (1996), p.239).

In this thesis concurrency is defined as:

- Planning and accomplishing the activities involved in the product realization process simultaneously by means of computerized tools and project management techniques.

With simultaneous work of different functions, the information will release earlier within teams. Hence, time-consuming reworks can be avoided by early detection of failures; besides, purchasing can order long lead times in advance and track the material availability much better. (Koufteros et al, 2001)

Establishing an effective and efficient concurrency is not always possible. Hoedmaker et al, (1999) have mentioned that counterproductive subdividing the work into modules of activities, resource limitation and not allocating proper resource for each activity, and determining the optimal overlapping of activates to reduce the lead time of each stage can be important barriers of concurrency. The factors which have the critical impact on concurrency effectiveness would be summarized as following: (Hoedmaker et al, 1999)

- Task subdivisions which can generate the complexity of project planning and controlling. The more complexity of the project avoids the project plan to achieve more concurrency.
- Team effort and the way of communication among team members
- The correlation between team size and development speed as well as between team size and design productivity. The larger group, the harder to communicate, and the longer cycle times.

(Wei, 2007) has introduced a quantitative model that can optimize concurrent process development time through identifying the loop among design project activities. This methodology would help to analyze and optimize the concurrent engineering process in order to find out more rational and optimal concurrent operation orders. As it is indicated in this article "the objective of concurrent design process modeling and optimization is to improve parallel degree of operation and reduce whole execution time by eliminating iteration and loop time caused by improper operation order" (Wei, 2007. p. 661). Managing the design process involves four steps (1) model the information and dependency structure of the design process, (2) provide a design plan indicating the order of execution for the design tasks, (3) reduce the risk and magnitude of iteration between design tasks, (4) explore opportunities for reducing the project cycle time. Design structure matrix and graph theory are two scientific methods to explore the dependency of tasks systematically. Moreover, managing the interaction between activities of development process needs to deal with an intricate interdependency and information feedback among tasks. Hence, the type of relationship between two tasks should be recognized. . (Wei, 2007)

Several management tools developed to model the interface and dependencies among tasks of design process such as PERT, CPM, and IDEF0. PERT is the project evaluation and review techniques that can be applied to illustrate a diagraph of project's tasks. PERT is using the probabilistic time of accomplishing for each task in order to estimate a timing plan of entire project in which the start and finish time for each tasks is planned. CPM is stand for the critical path method which assumes the time-cost tradeoffs among tasks rather than a probabilistic duration time. Both PERT and CPM do not consider the possibility of concurrency and overlapping of design tasks. And also, the iteration probability of tasks cannot be modeled based on PERT and CPM. IDEF0 is invented to investigate the information management process; the standardized IDEF0 modeling techniques can be implemented. However, IDEF0 is inefficient for modeling concurrency and iteration between activities. (Wei, 2007)

4.2.6 Integrated Product Realization Process and Tools

The term, "integration", is interpreted differently in literatures. Paashuis and Boer, (1997) have gathered some interpretations such as: A cross-functional and a sense of collective responsibility, Unity of effort, Establishing a reciprocal information flow in order to facilitate the earliest possible start of development subtasks, Interaction through formalized co-ordinate actions and collaboration.

In this thesis, an integrated product realization process is defined as:

- An aggregated system of functions which are accommodated throughout a product lifecycle from the concept design to production and from production to after sale services.

In concurrent engineering environment, the outcomes of integrated product realization process would integrate managerial and operational departments, and would make parallel and concurrent development among functions, a.k.a organizational integration. These purposes are exemplified by Trygg, (1993), Wilson and Wilson, (1994). They have mentioned that Just-In-Time (JIT) systems generate a link between manufacturing operations and suppliers, and the rapid flow of information among different sources can make possible a parallel and simultaneously analysis among designers and manufacturer. The organizational integration refers to a suitable work practice for coordinating tasks across an organization (Paashuis and Boer, 1997) and (Swink, 1998). Market-oriented attitudes of concurrent engineering approach aim to focus on integrating customer needs and marketing strategies into design decisions, emphasizing the roles of marketing and R&D departments in boosting the information transfer among both departments (Swink et al., 1996).

An appropriate integration of different functions requires an approval by other functions, using liaison personnel, meeting between representatives of different functions, and using cross-functional teams to accomplish integration. Having the approval of other departments, a.k.a. sign-off cooperation, is not a strength form of cooperation because there is no mechanism to ascertain that all functions would consult at the early stage of product development process. Liaison personnel are capable to address issues that span functional boundaries even though they are not members of any function of an organization. Meeting between the representatives of different functions would maintain the functional structure by means of discussing boundary-spanning issues or general interest items. Using cross-functional teams means encompassing various experts as a unique team from design, manufacturing, procurement, marketing, sale and etc in order to work on a specific project and stay together throughout the development process. (Smith, 1997)

The strategy of an organization, the level of implemented technology, the structure of an organization and integrating processes are determinant factors based on which the integration would be generated within an organization. [Table 11] summarizes the concept of each mentioned factors. (Paashuis and Boer, 1997)

The efficient integration of computer aided design and manufacturing area would help to combine the activities of production engineering and product design, so that both areas can be developed in parallel. For example, the design of tools and fixtures and NC-programming can carry out synchronously with design; thus, NC codes will changes concurrently as changes happen in design. The integration of computer-aided design and manufacturing tools, analytical work methods, production planning, and other engineering support systems would be beneficial for customized design and decreasing the number of physical prototypes. (Trygg, 1993)

Approach to generate integration in CE program	concept
Integration by strategy	The enterprise strategy determines the principle for organizations and its constituents e.g. design and manufacturing. In particular, the configuration of product-market strategies determine which role an enterprise wants to play in the market, and which product must be implement so as to create an integrated strategy. The integrated strategy must ascertain the market qualifier and market winner features of a product; moreover, the strategy must define these attitudes as early as possible in product concept. The integrated strategy would remark the organizational goal for middle level managers who should make decisions based on the general strategies of enterprise.
Process integration	The activities of new product development process should be re-structured in order to eliminate non-value adding activities.
Integration by technology	Applied technologies in an organization can be classified into three categories: human-ware, software, hardware. Human-ware comprises of the knowledge level of workforces, their experience as well as technical managerial skills. The integration, counted on human affairs, include the workers ability in that how they accomplish the activities by which upstream and downstream activities are linked together, how the workers implement their social and managerial skills, and how their attitudes formed towards cross-functional co-operation and communication. Formal training period, training-on-the-job, and job rotation can also help to improve the cross functional communication. Software technologies are work practices in the form of computer software e.g. computer aided process planning (CAPP), engineering database (EDB), and electronic data interchanges (EDI). Hardware technologies are machines and physical tools which enable integration in the form of computer and communication instruments.
Integration by organization	Organizational integration refers to a tailored work practice for coordinating tasks across an organization. These work practices can defined as a standardized paper work, liaison roles, formal tasks forces and project teams, matrix structure, secondment, co-location, and role combination.

Table 11; approaches to generate integration in CE program (Paashuis and Boer, 1997)

However, achieving those outcomes require overcoming to some obstacles. The interaction between functions is the most critical barrier; the intensity of interactions determine by organizational structure, organizational culture, and management style (Dowlatshahi, 1994) and (Elshennawy et al, 1993). Information infrastructure is the other obstacles that can dominant the successful implementation of a concurrent engineering program (Salzberg and Watkins, 1990) and (Swink et al., 1996). Pawar and Riedel (1994) have noted those issues in terms of implementation strategy, organizational changes and structure, integration mechanism and team forming.

The significant beneficial of integrations in concurrent engineering environment are the integration of design-marketing, design-manufacturing, design-logistics. That the design is one stable part of mentioned integration dyads would remark the importance of design as a function by which the foundation of product is created. Most of the literatures indicate the integration between design and manufacturing as the essential components of a concurrent engineering program, e.g. See (Dowlatshahi, 1994), (Smith, 1997), (Kinacade et al, 2007), (Holt and Barnes, 2009). The integration between design and marketing aims at focusing on aggregating the customer requirements and marketing strategies into overall design decisions

(Swink et al, 1996). Knowing the dominant role of logistics in various performances of product lifecycle, Dowlatshahi (1996) has classified a list of attributes that would involve from the beginning of concept development into three groups of requirements. The requirement groups include the interfaces between design and logistics. For instance, Fine et al, (2005), have demonstrates a debate of integrality versus modularity between product design and supply chain design in concurrent engineering environment. Product architecture is the concept, linked to the domain of product development, which defines how the functions of a product are allocated to its constituent components. Integrality and modularity of a product is determined as product architecture forms. The product architecture and the architecture of supply chain network must be aligned along the integrality-modularity spectrum. The model proposed in this article indicates that supply chain design would be according to the product design; that is, if product design is more modular (or integral) the supply chain design must be modular (or integral). The integral supply chain encompass of the members (suppliers and subcontractors) which are in close proximity with each other in terms of geographic, organizational, cultural, or electronic connectivity. Whereas, modular supply chain consist of highly dispersed members geographically and culturally, but few organizational ties and electronic connectivity support their functionality. (Fine et al, 2005)

(Dowlatshahi, 1996) has discussed the integration between design and logistics, their interfaces and collaboration area. Product design in concurrent engineering environment is the center of attention; hence, in the early stages of the design process various product design attributes are considered from the beginning of concept development (such as aesthetic, durability, ergonomics, interchangeability, logistics, maintainability, marketability, manufacturability, capability of procurement planning, reliability, re-manufacturability, safety, capability of production planning and scheduling , serviceability, simplicity, testability, and transportability). These attributes is classified into three groups of requirements: business requirements, production requirements, and support requirements. Design for marketability, design for purchase-ability, and design for cost take the business requirements into account. Besides, production requirements include design for schedule-ability, process design, design for manufacturing planning and control, design for manufacturability. And the last group consisted of design for reliability, design for maintainability, and design for logistics fulfill the support requirements. (Dowlatshahi, 1996)

In a hierarchical decomposition, the concept of design for logistics in concurrent engineering environment is divided into four elements (logistic engineering, manufacturing logistic, design for packaging, and design for transportability). And each element divided into four modules. First element, logistic engineering, is defined as “a field of logistics that deals with the supportability of product and systems throughout their life cycle. Logistic engineering is concerned with the design process in that it establishes requirements to which the ultimate design configuration must comply” (Dowlatshahi, 1996, p.191). The concept of the modules of first two elements are summarized in [Table 12] and [Table 13]. Manufacturing process and manufacturing logistics are two major determinant of logistics system design. Manufacturing characteristics involve set-up time and lead time evaluations, and providing faster throughput time. Logistics attributes is compromised of on-time scheduling for material delivery, economical use of transportation systems, reducing inventory levels, and optimized space utilization, warehousing and storage management, physical distribution system, order fulfillment, managing seasonal inventory and seasonal demand, outsourcing or in-house production decision making. An instance for cooperating design and manufacturing logistics, which can be considered in design for manufacturing categorization, would be focusing on minimizing the use of critical materials, critical processes, and especial manufacturing tooling. (Dowlatshahi, 1996)

Third element, design for packaging, is associated with packaging requirements in the product design process. Design for packaging consists of four modules: functional packaging requirements, packaging material, packaging testing, packaging design features. All of mentioned modules address the issues related to proper and speedy order filling, inventory control, warehouse space saving, lower transportation rate, material selection for packaging, testing the reliability of package, interior and exterior marketing aspects.

Forth element, design for transportability, addresses the issues associated with transportation costs, transportation modes and standards. Design for transportability consists of transportability requirements, shipping/handling/storing, transportation mode, and transportability design criteria. (Dowlatshahi, 1996)

4.2.6.1 Integrating tools and methodologies

In order to bring about the integration, in concurrent engineering environment, two approaches are implemented:

- Computerized design and manufacturing tools
- Analytical and formalized work procedure
- Cross-functional rearrangement

The common frame of outlook over both approaches is system-wide thinking while deploying best practices to achieve a specific goal. Selecting an appropriate integration mechanism would affect such critical factors of concurrent engineering program as the differentiation and linkages between departments, cross-functionality requirements, uncertainty of information, and complexity of tasks. (Pawar and Riedel, 1994)

Computerized design and manufacturing tools are software oriented applications that enable designers and process engineers to provide artificial prototypes and models before implementing decisions in reality. The computerized design and manufacturing tools can streamline design and manufacturing process, draft design documentations, facilitate design generation, and help to optimize both design and manufacturing outcomes. In next section of thesis in [Table 14] and [Table 15], the computer-aided design and manufacturing tools, exemplified within literatures, is summarized.

Analytical and formalized work procedures are a set of well-defined and structured work methods which are established based on an identical technical standard or the experts' work experience. The analytical work procedures would implement to optimize a design of a product, employ as an algorithm for starting a new product design process, use for being proactive and foreseen potential failure modes. A formal new product introduction consider a systematic way of carrying out the new product development and product introduction processes, such as formal and systematic generation of blue prints, road maps and templates, while injecting the concurrency into the process (Ainscough and Yazdani, 2000). In next section of thesis in [Table 16] and [Table 17] the analytical and formalized procedures, exemplified within literatures, is summarized.

Cross-functional rearrangement is a set of methodology to prepare the structure of work teams, to redefine the way of goal establishment, and to encourage communication within team members with the purpose of improving cross-functional integration so that the design analysis and decision making process can be facilitated.

Modules for logistic engineering	**concept**
Design for supportability	The inputs of logistical support are data from storage and material movement system, needed equipment, choice of carriers, and product's physical dimensions. A group of designers and logistician engineers should decide how, where, and when the various required items should be delivered to support end-item product.
Design for manufacturing-distribution pipelines	The design and logistician engineer should cooperate in design process so as to consider the competency of manufacturing/distribution system; consequently, the engineering change orders as well as the number of product variation would be reduced in manufacturing-distribution system. Furthermore, a design team should meet the requirements of demand chain management; for instance, demand variability, forecast errors, and product seasonality should be taken into account. The issues related to demand management concepts are more important when facing with turbulent market and unpredictable consume patterns. Three approaches would take into account when designing for manufacturability. First approach is "part standardization" or using "off-the-shelf parts". The second approach remark diminishing the number of parts. The third approach is focusing on the usage of interchangeable parts.
Product lines	"Major changes in a firm's product line must be evaluated for their implication upon the entire logistics system. The nature of the product (e.g. the weight, value, bulk, and market characteristics) influences the logistics system design. […] Demand variability, forecast error, and product seasonality should also be considered when designing products in terms of design lead times and product time to market." (Dolatshahi, 1996, p.194)
Design attributes	This module is providing the significant logistics inputs to the design process. It is important to specify design criteria quantitatively and qualitatively. The product and part specifications should be recognized in terms of performance, application, dimensions, and weight

Table 12; the concept of logistics engineering in "design for logistics", (Dowlatshahi, 1996)

Modules for manufacturing logistics	**concept**
Manufacturing process	This module includes the manufacturing operations, their efficiency and robustness as well as the flow of material. Manufacturing characteristics involve set-up time and lead time evaluations, and providing faster throughput time.
Production planning and control	It is considering the impact of the length and size of the "production cycles" runs as well as planning the production system for efficient seasonal demand and seasonal inventory.
Material	Logistics should ensure a sufficient and adequate material planning to meet the production requirements and design specifications.
Plant location	There are two general considerations through the decisions of plant location. First, logistics considerations are such as availability of transportation modes, transportation costs, and distribution channels and policies. Second, plant capacity, flexibility, and demand schedule as the important factors affecting the performance of logistics system.

Table 13; the concept of manufacturing logistic in "design for logistics", (Dowlatshahi, 1996)

4.2.6.2 Concurrent Engineering Tools and Techniques

In previous section, the commitment and significant role of concurrent engineering tools in establishing an integrated product development process is discussed. This section is categorizing and summarizing different tools of concurrent engineering.

Within scientific literatures, any attempts for computerizing a process of design and manufacturing is referred as an approach that is using the components of concurrent engineering philosophy. However, it does not mean that every computerized process and any engineering software can be used or even would be beneficial in a concurrent engineering environment. The reason for this claim is related to the characteristic of a concurrent engineering program such as:

- Due to broad domain of product design and its complexity, it is difficult to create a general-purpose and an automated knowledge-based system. (Parasad, 1996)
- Due to specific attitudes of design and manufacturing, it is difficult to create a united body of CAD/CAM systems. (Dowlatshahi, 1994)
- Applied technology must be able to gather, analysis, synchronize, and document huge mass of data from different resources. (Ainscough and Yazdani, 2000)
- Applied technology must be able to minimize the interfaces between design and manufacturing. (Parasad, 1996)

Paashuis and Boer, (1997), have commented that one of the problems in re-designing a new product development process is the lack of tools for mapping the process. There exist a few structured tools, listed by (Paashuis and Boer, 1997, p.84), such as PRISMA, trigger-modeling, Petri nets, technology and organizational analysis, and IDEF0. These tools are employed for modeling an information management system throughout a product development process. However, none of named methods support the mapping of dynamic process encompassing unpredictable loops and pulse. (Paashuis and Boer, 1997)

Giving above aspects in mind, a series of computerized design and manufacturing tools which are specifically for the concurrent engineering is summarized in [Table 14] and [Table 15]

The analytical and formalized work procedures do not have to pursuit mentioned characteristics above. A formulized work procedure supports an innovative solution for solving a problem or forecasting potential failures; e.g. TRIZ is a methodology to find out an innovative engineering solution for technical problems during product development process (Buyukozkan et al, 2004). A simple well-established work procedure can be automated via using an appropriate information technology and information databases. For instance, Salzberg and Watkins, (1990), have discussed the application of information management systems in creating an automated FMEA procedure. The analytical and formalized work procedure in concurrent engineering program are summarized in [Table 16] and [Table 17]

As commented by (Huak et al., 1997), the success of a concurrent engineering program depends on the interaction between the cross-functional team members; hence, applied methodologies must consider multidisciplinary concepts belonged to organizational behaviors, performance measurement and award systems, business process reengineering. A good example of such exercises is described by (Haque et al, 2003). The methodologies for cross-functional rearrangements are classified into three groups (Swink, 1998): first set of methods can be implemented for setting and analyzing goals within team members. The second group of methods can direct and control the integration via organizational rules, training, or specific project planning. The last group of methods is the way of communication and encouraging the awareness within team members. [Table 18] summarizes these tools.

Tool	Description	Reference
Quantitative Intelligent system	a software oriented tool for gathering information required in the concurrent engineering design process and the task integration from different parts of product development lifecycle	(Xue and Cong, 1994)
EDI (Electronic Data Interchange)	The information linkage between organization, its supplier and customers to transfer of business data.	(Wilson and Wilson, 1994), (Paashuis and Boer, 1997), (Buyukozkan et al, 2004),
Reference model	A methodology for integration of design and process planning activities through computerized and hierarchical models.	(Eversheim et al, 1995)
Concurrent engineering tool for semiconductors (CETS).	The software working based on a semantic network, which is created via artificial intelligence-based models, and support CE program through documentation the knowledge so that the long verbal inquires for sharing the knowledge between design and process planning teams will reduce.	(Rogers et al, 1995)
Computer-aided process planning (CAPP)	To make concurrent arrangement of design and process planning as well as production capacities	(Paashuis and Boer, 1997), (Bonney, et al (2003)
Aggregate product and process planning	A computerized model to establish an equilibrium between the requirements of detail design and the competence of process planning	Maropoulos, (1999)
Automated Concurrent Engineering Software (ACES).	This tool is a knowledge based software that incorporate both product and manufacturability knowledge elements. The system follows "axiomatic method" in which the quality of design is based upon systematically analyze the transformation of customer needs into functional requirements as design axioms, design parameters, and process variables.	(Esche et al, 2001)
The Design Co-ordinate System	A system is working based on intelligent agent oriented method. Deployed in CE implementation process especially for make-to-order approach of large complex products.	(Coates et al, 2000)
Computer aided design (CAD), and interactive CAD	A software based tools for drafting and documenting the design process, or process scheme using graphic and three dimensional displays. Interactive CAD used interactively between different departments during design.	(Ainscough and Yazdani, 2000), (Jiang et al, 2002), (Buyukozkan et al, 2004),
Computer-aided design (CAM), and interactive CAM	A software based tools for controlling the machine tools, machinery processes, and generating numerical code for CNC machines. Interactive CAM can use interactively between different departments during manufacturing process design.	(Ainscough and Yazdani, 2000), (Jiang et al, 2002), (Buyukozkan et al, 2004),
Boothroyd-Dewhurst DFA method	Computer-based implementation of assembly design guidelines which includes a design efficiency rating system	(Swink, 1998)
Knowledge based system (KBS)	Artificial intelligence that can facilitate defining a rule for effective product and process integration.	(Ainscough and Yazdani, 2000), (Buyukozkan et al, 2004),
Finite Element Analysis (FEA)	A computerized analysis tools to verify the integrity of a structural design, fits, or clearances	(Parasad, 1996)
Variation Simulation Analysis(VSM)	A computerized analyzing of design according to required tolerance and dimensioning	(Parasad, 1996)
The integrated approach of DFMA-FEA	The systematic analysis based on four different concurrent engineering tools: CAD model analysis, DFA toll application, FEA tool application, and DFM tool application	(Giudice et al, 2009)
Template-based integrated system	A design template-based system that can foreseen manufacturing constraints during concept generation phase of product design.	(Kamrani and Vijayan, 2006)

Table 14; computerized design and manufacturing tools

Tool	Description	Reference
Groupware and Collaborative computing	They are computer software that can support groups of people engaged in a common task. It can provider synchronized interface to a shared environment.	(Buyukozkan et al, 2004),
Designer's toolkit	CAD based aides to process instructions concerning a specialized manufacturing facilities	(Swink, 1998)
Computer-aided DFM	Computer-aided engineering tools which integrate parametric, featured-based design with access to manufacturing process attitudes	(Swink, 1998)
Manufacturing process simulation	Computer based facilitate which simulate the variation of manufacturing outputs for given design parameters	(Swink, 1998)
PERT, CPM, IDEF0	management tools developed to model the interface and dependencies among tasks of design process	(Wei, 2007)
Product Data Management (PDM)	A software framework that enables manufacturing to manage and control the engineering information within a new product development process.	(Buyukozkan et al, 2004),
Computer Aided Manufacturability Analysis (CAMA),	It can capture the knowledge in a structured form, modified them, implement and incorporates the captured knowledge within the product design tools such as CAD systems. The main responsibility of CAMA is representing the proof of concept and set up a tangible prototype of an adoptive and open DFX tools.	(Molcho G. et al 2008)

Table 15; continue of table [24]

Methodology	Description	Reference
JIT	To support the link between manufacturing operations and supplier partnership.	(Wilson and Wilson, 1994)
Up-front ending the design process	Early consideration of all elements of the product life cycle	(Pawar and Riedel, 1994)
Conjoint analysis	Versatile marketing research technique that can provide valuable information for market segmentation and pricing decisions	(Buyukozkan et al, 2004),
Quality Functional Deployment (QFD)	For setting and analyzing the goals, fulfill the customer's requirements. QFD's foal is to develop a proper design and then interpret the characteristics of design comparing with market needs and the ability of competitors.	(Swink, 1998), (Ainscough and Yazdani, 2000), (Holt and Barnes, 2009), (Buyukozkan et al, 2004),
DFM/DFMA guidelines	There are specific processes for these methods which are including procedures for identifying parts that can be eliminated or combined and for estimating assembly lines and costs based on components characteristics.	(Ainscough and Yazdani, 2000), (Holt and Barnes, 2009), (Swink, 1998)
FMEA	Detail analysis of product and process design to identify the potential failure modes and the cause and source of failures.	(Pawar and Riedel, 1994), (Swink, 1998) , (Ainscough and Yazdani, 2000)
Cause/Effet analysis	Systematic methods to identify the key issues and their cause e.g. fishbone, pareto analysis, block diagram	(Swink, 1998),
DFQ/Taguchi	The way of quantifying the cost of deviations from an idealized parameter value, providing metric that can be optimized. It comprises parameter and tolerance design.	(Ainscough and Yazdani, 2000), (Holt and Barnes, 2009), (Buyukozkan et al, 2004), (Swink, 1998)
Design for Excellence	Design approaches that incorporate more that performance or feature of a product. It involves techniques such as DFM, design for logistics, design for green, and etc.	(Buyukozkan et al, 2004),
DFQ/Benchmarking	A quantifying tool to find out how well a product carry out its main required functions compared to the competitors.	(Holt and Barnes, 2009)
Design freeze	Without it changes can occur right up to launch and hence delay the launch	(Pawar and Riedel, 1994)
Value (analysis) Engineering	Analysis to identify non-value added component and processes	(Parasad, 1996), (Swink, 1998), (Buyukozkan et al, 2004),

Table 16; analytical and formulized work procedures

Tool	**Description**	**Reference**
Rapid Prototyping	Building the production oriented prototypes	(Pawar and Riedel, 1994), (Swink, 1998), (Buyukozkan et al, 2004),
Concurrent scheduling	A mathematical based decision making support model for scheduling the activates of project concurrently	(Nicoletti and Nicolo, 1998)
Variety control	classical industrial methods such as process standardization, Pareto analysis, and classification in order to avoid deviation from designed processes	(Landeghem, 2000),
Standardization	Defining the standard procedures, processes, materials, and parts for design and manufacturing a product. Or even standardize paper work.	(Buyukozkan et al, 2004), (Paashuis and Boer, 1997)
Cellular manufacturing	a manufacturing strategy in which machines/tools are grouped into physical or logical cells in order to minimize the cellular interactions	(Dereli and Bayakasoglu, 2004), (Buyukozkan et al, 2004), (Swink, 1998)
Group technology	Classification approach for parts based on geometric or production process similarities	(Swink, 1998), (Dereli and Bayakasoglu, 2004), (Buyukozkan et al, 2004),
TQM	Catalyst for increasing interdepartmental communication, it is focused on more integration with shop-floor	(Pawar and Riedel, 1994)
Controlling the engineering changes	Internal sources, external (supplier) sources	(Pawar and Riedel, 1994)
Axiomatic Design	A way of systematic analysis that can facilitate identifying customer needs and transferring them into design parameters, functional requirements, and process variables	(Swink, 1998), (Buyukozkan et al, 2004),
Functional Build	Using flexible criteria when producing sub-assemblies and components may actually lead to a more efficient manufacturing validation process	(Hammett et al 1999)
Process Design rules	Highly specialized instructions for specific processes e.g. instruction for material selection in sand casting	(Swink, 1998)
DFP	methods that determine if a manufacturing system has sufficient capacity to achieve the desire throughput and approaches to estimate the manufacturing cycle time	(Wong et al, 2004), (Hermann and Chincholkar, 2002)
Design-to-cost methodology	Systematic approach for allocating production or product life cycle cost target to sub system elements	(Swink, 1998)
TRIZ	Theory of invention problem solving; can employed for finding innovative solution to technical problems	(Buyukozkan et al, 2004),
Design for Environment (DFE), Design for end-of-.life (DFEOL), Design for disassembly (DFD), and Design for recycling (DFR).	tools are providing a set of metrics through which a designer can evaluate the environmental impact of a design solution and make an appropriate green design decision	(Holt and Barnes, 2009)
Desing for maintainability (DfMt), design for reliability	Concerns with the form of guidelines or tools for predicting maintenance costs. Related to maintainability is the reliability of a product defined as “the ability of a product to perform its functions over a period of time without failing”	(Holt and Barnes, 2009)

Tabell 17; continue of table [16]

Tool	**Description**	**Reference**
Tools for setting and analyzing goals (establishing a unique and common goal for the group)		
Customer service	For both internal and external customer; data gathering mechanism employ direct interview, surveys, focus groups, steering committee,	(Swink, 1998)
Product benchmarking	Determining the goals based on competitors capability or existing products in the market	(Swink, 1998)
Super-ordinate project goals	Establishing group oriented approach for achieving a goal on which the whole or majority of group should be involved	(Swink, 1998)
Return map	Graphical representation of product cost and revenue forecast over time	(Swink, 1998)
Direct and controlling integration (designing and planning the procedure to control an interaction)		
Organizational rules	Standard operating procedure aimed at controlling the cross functional integration e.g. outlined approach for concurrent engineering	(Swink, 1998)
Project specific rules	Documented standard procedure that can apply for a specific project	(Swink, 1998), (Paashuis and Boer, 1997)
Pre-project training	Training the specific project activities and key responsibilities which demand more integration	(Swink, 1998)
Organizational analysis	A methodology for comprehensive organizational analysis as implementing a CE program. The methodology is founded based on concepts of organization science, performance measurement, process and organizational modeling methods and tools, and also business process re-engineering. Hence, it combines traditional organizational theory with the most recent business process reengineering approaches in order to analysis of organizational issue in concurrent engineering environment.	(Haque et al, 2003)
Encouraging communication and awareness		
Cross functional teams	The team can involve different managerial level, various technician from different functions, lead customers	(Pawar and Riedel, 1994), (Swink, 1998), (Paashuis and Boer, 1997)
Team incentives	Monetary or other compensation and rewards for motivate individual or team participation	(Swink, 1998)
Liaison roles	A special person who can lead two-way communication between two different functions	(Swink, 1998), (Paashuis and Boer, 1997)
Secondment	Movement of personnel from one function to another in order to inject the experience of one function to others	(Swink, 1998), (Paashuis and Boer, 1997)
Role combination	Combining the tasks which had been used to execute by different functions (groups) and assigning them into one group of people	(Swink, 1998), (Paashuis and Boer, 1997)
Co-locating	Placing most related functions close together physically	(Pawar and Riedel, 1994), (Swink, 1998), (Paashuis and Boer, 1997)
Open-door policies	Improve the flow of information and communication throughout organization	(Swink, 1998)
Review Meetings	Periodic review meetings as well as milestone review meetings (in order to review key design issues and factors)	(Swink, 1998)
War room	Special meeting for reviewing the critical objectives by means of specific charts and presentation forms	(Swink, 1998)
Design database	Shared design and knowledge data base	(Swink, 1998)
Electronic communication	Electronic oriented tools of communication such as mail or telephone conferences	(Swink, 1998)

Table 18; methodologies for cross-functional rearrangement (based on Swink's classification in (Swink, 1998))

5 Analysis and Result

The fifth stage of "literature review model", introduced in section *2.2 Research Design*, is critical part of research at where the various concepts should be synthesized in order to answer the research question appropriately. The fifth section of this thesis will analyze the conceptual findings throughout literatures and answer the research questions.

5.1 Structuring parameters that affect a production start-up performance

In order to identifying the significant parameters, in this thesis, the previous researches reviewed. However, having the list of parameters was not sufficient to structure a managerial conception by which a manager or a production planner may recognize the necessary elements for managing and planning a production start-up phase. The main reason for this insufficiency was due to not pursuing an identical and reliable pattern that can determine what a manager or a planner needs to manage or plan a start-up phase. Therefore, the decision areas of product development process considered to understand the area on which a manager or a planner should concentrate and construct each and every single phase of a new product introduction project.

In the following tables, [Table 19] and [Table 20], all effective parameters in production start-up performance is listed. The parameters first ordered based on chronological order of references, and then similar items are combined together. In the other words, each reference can discuss different aspects of a parameter, but since they all are discussing the effects of one common parameter they grouped together.

5.1.1 A Conceptual Framework for Managing the Start-up Phase

In order to set up a product development process through which the requirements and constraints of the start-up phase can be considered from the beginning of the project, this thesis is introducing a managerial framework that structure the significant parameters on a production start-up phase. The framework, illustrated in [Figure 12] would help managers to understand and improve the performance of production start-up phase as well as production start-up process, rather than providing them a tutorial of practical mechanisms. The framework is encompassed of 13 modules. The first five modules are needed to ensure the optimized setting up for a product development project.

The purpose is to manage the effective parameters which are associated with foundation of a project. The rest of the modules are part of the product realization process and are determined based on required the decision areas across product development process, according to (Krishnan and Ulrich, 2001), and required functions in product and process development procedure, according to (Ulrich and Eppinger, 2008) e.g. quality control, engineering validation, production planning. The modules are enumerated as following:

1- An Organization
2- Product Development Organization
3- Project Architecture (Project definition, Project Management)
4- Suppliers/Stockholders/Customer Relationship Management
5- Information Flow and Knowledge Management

6- Concept Development
7- Product Design
8- Reconfiguration Management
9- Inbound and Outbound Supply Chain
10- Ramp-up Strategy and Planning
11- Process Planning
12- Manufacturing System Design
13- Shop floor scheduling and control

Effective Parameter	Reference
Management in the department level	(Clawson, 1985)
Project management	(Clawson, 1985), (Wheelwright, 1985)
Predefined performance metric	(Clawson, 1985)
Coordinated product design and tool making	(Clawson, 1985)
Human Resource Management (staffing plan)	(Clawson, 1985), (Langowitz, 1988), Schloz-R et al (2007)
Procurement plan for start-up phase	(Clawson, 1985)
Coordinated design and manufacturing	(Clawson, 1985), (Wheelwright,1985), (Langowitz, 1989), (Vandevelde and Dierdonck, 2003),
Inventory control system	(Clawson, 1985), (Billington et al, 1998)
Quality and volume target setting	(Clawson, 1985)
Strategic management of the functions	(Wheelwright, 1985), (Langowitz, 1988)
Continued learning across a series of projects (benchmarking)	(Wheelwright, 1985), (Schuh et al, 2005), (Berg and Säfesten, 2006)
Formal organization of the project	(Langowitz, 1988), (Vandevelde and Dierdonck, 2003)
Project Definition (Project nature)	(Langowitz, 1988), (Langowitz, 1989), (Vandevelde and Dierdonck, 2003)
Project Ownership (A formal organization)	(Langowitz, 1988), (Vandevelde and Dierdonck, 2003),
Increasing demand and sales rate	(Wheelwright and Clark 1992)
Ramp-up strategy and planning	(Clark and Fujimoto 1991), (Johansson and Karlsson, 1998), (Schuh et al, 2005)
Technological and technical capability of manufacturing system (e.g. automation level)	(Billington et al, 1998), (Johansson and Karlsson, 1998), (Almgren, 1999c) and (Almgren, 2000)
Timing for announcing a new product and overly optimistic sale forecasting	(Billington et al, 1998)
Supply of material	(Johansson and Karlsson, 1998), (Terwiesch et al, 1999), (Almgren, 1999a), (Almgren, 1999b), (Almgren, 1999c) (Almgren, 2000)
Product design	(Johansson and Karlsson, 1998), (Almgren, 1999b)
Flow of material across manufacturing processes	(Johansson and Karlsson, 1998),
Organizational structure	(Johansson and Karlsson, 1998), (Almgren, 1999a), (Almgren, 1999c), (Schloz-R et al, 2007)
Product and Production Complexity	(Johansson and Karlsson, 1998), (Almgren, 1999a), (Vandevelde and Dierdonck, 2003), (Schuh et al, 2005), Berg and Säfesten (2006), (Juerging and Milling, 2006)
(New) Product- (New) Process mix	(Johansson and Karlsson, 1998),
Ramp-up targets leveling	(Terwiesch et al, 1999)
Product Life cycle	(Terwiesch et al, 1999)
Coordinated process planning and production planning	(Gindy et al, 1999)
Capacity of production system	(Almgren, 1999a)
Workforce Policy	(Almgren, 1999a)

Table 19; effective parameters in start-up performance

Information sharing, Information flow management	(Almgren, 1999a), (Fjällström et al, 2009)
Machine breakdowns and minor stoppages	(Almgren, 1999a), (Almgren, 1999b), Schloz-R et al (2007)
Personnel (operator performances, absenteeism, individual learning, and work performances)	(Almgren, 1999b), (Almgren, 1999c) and (Almgren, 2000), Schloz-R et al (2007)
Work Method	(Almgren, 1999b)
Work Pace	(Almgren, 1999b)
(Late) engineering changes	(Almgren, 1999b), (Almgren, 1999c), (Almgren, 2000)
High yields, Process maturity and stability	(Terwisch and Bohn, 2001), (Terwisch and Yi, 2004)
High level of utilization	(Terwisch and Bohn, 2001)
Learning (labor & machine)	(Merwe, 2004)
Managing the cycle times	(Haller et al, 2003)
Decisions made across product development process	(Juerging and Milling, 2006), Schloz-R et al (2007)
Degree of the Innovation of Product/Process	(Juerging and Milling, 2006)
Degree of Overlap among product development activities	(Juerging and Milling, 2006)
Manufacturing Process Standardization	(Juerging and Milling, 2006)
Manufacturing Strategy	Berg and Säfesten (2006)
Product mix	Berg and Säfesten (2006)
Logistics	Schloz-R et al (2007)
Production and assembly process	Schloz-R et al (2007)

Table 20; effective parameters in start-up performances (continue of table [19])

Module One: Organization

Findings of this thesis indicate that “the strategic alignment will make managers of different functions to prioritize the project which is the most important project strategically. Thereby, the resource allocation will create the smoothness of operations including production ramp-up”. Hence, the first module is considered the strategic management of an enterprise. The first module determines macro decisions through which all structures, functions, and processes are dominated. The wide-ranging policies and far-reaching organizational structure would influence the way of structuring, making decisions, identifying the weaknesses, and boosting the opportunities for each developed project. The strategic alignment will make managers of different functions to prioritize the project which is the most important project strategically. Thereby, the resource allocation will create the smoothness of operations including production start-up.

Module Two: Product Development Organization

The organization structure is defining the arrangement and coordination of different functions. The architecture of product development organization must determine what task and responsibility should be done by which functions (i.e. the ownership of tasks and responsibilities), and also it must establish the co-ordination mechanisms such as standards, rules, and the relations between organizational work procedures. Moreover, it must increase the possibility of individual and organizational learning to ensure efficient operation and effective problem solving.

Module Three: Project Architecture (Project definition, Project Management)
Project architecture is determining the scope of a project. It would be thought of as a mechanism through which the subsequent of the involvement of other functions in development process is defined an established, the stages and milestones of the project are recognized, the timing and sequence of tasks and responsibilities are instituted, and consequently a project can be planned and controlled.

Module Four: Suppliers/Stockholders/Customer Relationship Management
Instituting an smooth production start-up not only require the harmonic utilization of all internal resource and functions, but also the support and sustenance of external allies such as suppliers, stockholders, and even customers. Thereby, the long term relationship with external supporters can pay back in start-up phase as encountering with unpredicted and uncertain circumstances.

Module Five: Information Flow and Knowledge Management
For establishing a smooth start-up phase, the innovative ideas should be directed, and the novelties should provide opportunities for learning. The learning organization requires managing and classifying an appropriate level of knowledge based on which radical and incremental innovations can be structured. Moreover, the information flow among various functions must be directed in the way that can support the decision making processes. Having right information at the right time can decrease the complexity of product and production since the more prepared information the less uncertainty.

Module Six: Concept Development
Defining the target value of the product attributes and required specifications through concept Development module would determine the level of the complexity of product and production system. As discussed through the theoretical exposition, this module has essential role in making decision about the product architecture, the variants of the product that will be offered, the possible components that can share across the variants of product, the product mix, and physical appearance of product. Therefore, one reason of complexity be managed through this module.

Module Sven: Product Design
This module is involving the decisions related to the value of technical and engineering parameters, the configuration of the components and assembly precedence relations as well as the detailed level design. The detailed design is addressing the interactions between product design and production process. Product design (and concept development) is the other reason for product complexity.

Module Eight: Reconfiguration Management
Across the pilot production as well as start-up phase, via testing different production prototypes, lots of detail engineering and technical issues, various changes as well as new optimized design solutions are discovering; they must be validated and documented. In addition, the quality control and assurance processes find out the parameters causing performance losses, then, the corrective or preventive instructions must be introduced and

documented. Furthermore, late engineering changes must be coordinated with manufacturing processes since some of them should be re-planned. These activities are so called reconfiguration, in this thesis. This module manages the activities related to reconfiguration process.

Module Nine: Inbound and Outbound Supply Chain
As discussed in the fourth module, the long term relationship with suppliers is one of the most critical parameters that can ensure the success of start-up phase. In addition, an appropriate logistical infrastructure must assure a tailored delivery of material in terms of delivery time and quality. Having considerable level of non-conformity goods during start-up phase would paralyze start-up process. In this module, inbound supply chain indicates the material purchasing as well as internal logistics of material and subassemblies across the production line. Outbound supply chain indicates the planning and execution of outbound logistics from suppliers' site till delivery at the front of the factory's entrance dock.

Module Ten: Ramp-up Strategy and Planning
Inasmuch as significant role of production ramp-up phase in shrinking the product development process, there must be separated operational plan, but coordinated with executing plan of manufacturing. Ramp-up strategy and planning approaches determine the predefined action plan throughout a ramp-up phase. The operational strategies and plans would line up with executing plans of marketing and manufacturing. This module concerns determining an optimized ramp-up curve, an optimized operational patterns, and suitable workforce policy for ramp-up phase.
Ramp-up strategy and planning approaches determine the predefined action plan throughout a ramp-up phase. The operational strategies and plans would line up with executing marketing plan and manufacturing/distribution plan.

Module Eleven: Process Planning
This module is translating the design information into tooling instruction, manufacturing instruction, and technical manufacturing functions and processes.

Module Twelve: Manufacturing System Design
The manufacturing system must be able to fulfill required conditions which are planned and defined through process planning module. In the other words, the manufacturing system is the operational filed to carry out the actions, instructions, movements, and commands defined via process planning.

Manufacturing system design involves the parameters which are affecting the technical and technological competence of a production system. Employing distinct manufacturing systems brings about different capabilities associated with machining and tooling, jig and fixture design, auxiliary hardware, material selections, manufacturing methods, material handling, storage systems, layout, maintenance planning, quality control, inventory control, production planning, the level of production flexibility. For instance, Flexible Manufacturing System (FMS) and Reconfigurable Manufacturing System (RMS) are two kind of manufacturing systems which are designed to rapid adjustment of required production capacity and its functionality.

Module Thirteen: Shop-floor Scheduling and Control

The shop-floor activity control module includes all the daily activities and operations which are performing across the production line in order to execute all the master plans and bring the design and manufacturing’s plans into the action. The shop-floor activity control module should determine the required works during a start-up phase which should be performed across a production line. The shop-floor scheduling and control activities must be support through a suitable information technology since tracking the right information at the right time is the most significant factor to create an optimized production plan and control during a start-up phase. These works can be classified as following:

- Breaking down the master production plan into detailed daily-based plan
- Synchronizing the start-up planning with common production plan
- Defining which activities should be done based on a daily work plan
- Assessing and determining which work center/station can accomplish the work in terms of technical qualifications, capacity utilization, labor constraints, and etc.
- Allocating defined work plan into specific work centers/stations
- Work center/station scheduling
- Establishing maximum inventory level, minimum batch size levels, and order quantities across production line
- Planning the sequence of operations (common production and specific start-up operations) and line balancing
- Coping with bottleneck work centers/stations
- Instituting appropriate work methods
- Planning daily preventive and corrective maintenance

Start-up management Modules	Effective Parameters
Macro strategies of organization	Strategic management of the functions,
Product Development Organization	Management in the department level, Formal organization of the project, Project Ownership (A formal organization), Organizational structure, Degree of Overlap among product development activities
Project Architecture	Project management, Project Definition (Project nature), Decisions made across product development process
Suppliers/Stockholders/Customer Relationship Management	Supply of material, Procurement plan
Information Flow and Knowledge Management	Continued learning across a series of projects (benchmarking), Information sharing, Information flow management, Learning (labor & machine)
Concept Development	Product Life cycle, Degree of the Innovation of Product/Process, Product mix
Product Design	Product design, product architecture
Reconfiguration Management	Coordinated design and manufacturing, (Late) engineering changes
Inbound and Outbound Supply Chain	Procurement plan for start-up phase, Inventory control system, Supply of material, Flow of material across manufacturing processes, Logistics
Ramp-up Strategy and Planning	Predefined performance metric, staffing plan, Quality and volume target setting, Increasing demand and sales rate, Ramp-up strategy and planning, Timing for announcing a new product and overly optimistic sale forecasting, Ramp-up targets leveling, Workforce Policy, High yields, Process maturity and stability
Process Planning	Coordinated product design and tool making, Coordinated process planning and production planning
Manufacturing System Design	Technological and technical capability of manufacturing system (e.g. automation level), Capacity of production system, High yields, Process maturity and stability, Manufacturing Process Standardization, Manufacturing Strategy
Shop-floor Scheduling and Control	Machine breakdowns and minor stoppages, Work Method, Work Pace, High level of utilization, Production and assembly process, Personnel (operator performances, absenteeism, individual learning, and work performances), Managing the cycle times, Human Resource Management

Table 21; allocation of effective parameters into the modules and sub-processes of the proposed framework

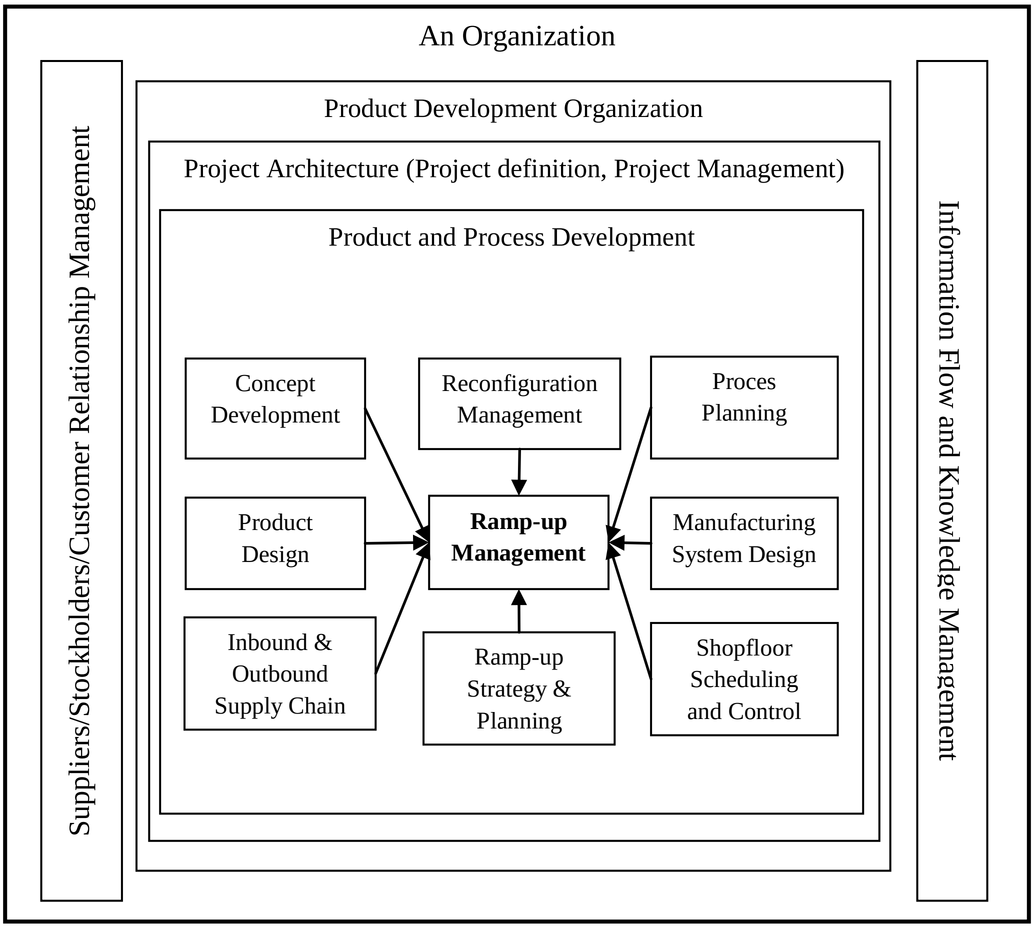

Figure 12; Start-up Management Framework, proposed framework for managing production start-up phase

As a summary of result, following issues must be taken into the account when managing a start-up phase:

1- The effective parameters would be brought about not only by operational level i.e. processes related to design and manufacturing, but also by strategic level decisions. The operational and executive plans of an organization must be aligned with strategic decisions of it. In accordance, the goals of each function/department must be aligned with the strategic goal of the organization.
2- The supplier and customer involvement would influence the start-up phase enormously
3- Putting together a group of people from various departments, with different background and different experienced is the most vital parameter
4- Flowing information among people and departments must take into consideration essentially
5- Implementing appropriate techniques of project management and project controls would become beneficial for optimal utilization of project resources
6- Late engineering changes are unavoidable and prevalent problems; a contemporaneous effort can involved such departments as design, manufacturing and even suppliers in order to diminish the negative effects of late engineering changes

7- The structure of an organization must have the capability of dealing with start-up phase requirements
8- A product development team must make use of specific tools and techniques by which optimal solution can be found to deal with such problems as the complexity of product/production, providing the proper work methods and instructions for operational stages, identifying the root of problem-making elements and etc.
9- There should be specific material requirement plans for start-up phase; correspondingly, a specific procurement plan must be prepared and suppliers must be informed in due course.
10- The inbound logistics is as critical as the outbound logistics. The flow of material as well as the level of inventory must be track-able and recordable.
11- The capability of manufacturing system must be balanced with the innovative design solutions. The capability of manufacturing system would depend upon the level of machine/human utilization as well as the employed technology.
12- The capability of human resource must be balanced with the requirements of a product development plan.
13- Determining appropriate performance indicators and establishing relevant start-up targets level would enable the product development team to focus on crucial priorities.
14- The requirements of customer/market/consumer must be balanced with the product design. In addition, the timing of launching a product into the market or a segmentation of a market must be analyzed. The outcome of such balance would set-up the product life cycle.

If a system-wide approach can be enabled to deal with following issues, it would facilitate a product realization process so as to achieve global optimization throughout the entire process. One of such system-wide approach is Concurrent Engineering which can be applied owing to being enable to choose the best practice to improve product introduction process, being capable to improve cross functional integration and communication, and being empowered to apply a set of comprehensive methods for design analysis so that designers can select the most optimal design solution which is not only considering the design constraints, but also taking the constraints of production system, logistics and distribution into account. Hence, it can cover majority of problems in start-up phase which are generated due to lack of empathy between design and manufacturing.

5.2 How CE's principle can support an efficient production start-up

The core principles of a concurrent engineering program are explored throughout literatures and enumerated as below:

- Comprehensive deployment of constituents
- Early involvement of internal and external constituents
- Cross-functional team and project organization
- Dynamic information management system
- Concurrency
- Integrated product realization process/tools

It should be remarked that the relationship of core principles to each other is complementary; that is, for instance having the cross-functional team make involvement of all constituents possible. Or, an appropriate information management system enables an organization to implement a tailored computerized tool which make possible to carry out product design and manufacturing activities concurrently.

The principles of a concurrent engineering program would establish a set of direct and indirect effects on a production start-up phase. Direct effects advocate the parameters which would be generated across a production start-up phase e.g. late engineering changes; that is, the reason for direct effects is not the phases before starting the start-up phase. For instance, these can be examples for such phases that should become accomplished before starting the start-up phase: choosing an appropriate supplier, evaluating current manufacturing system and determining required level of automation, the alignment between inter-departmental strategies, the reconciliation between developed concept and required human resources.

Moreover, throughout a product development process, a CE program does reconcile the cooperation between manufacturing/distribution system and customer (market) requirements; consequently, the outcome of reconciliation will have an indirect effect on the performance of a production start-up phase. For example, the process planning is a point where design and manufacturing team must reconcile their different ideas in order to determine the suitable tooling (jigs and fixtures). In case having a problem with tooling during a production start-up, late engineering changes would become unavoidable.

In this section, first the indirect effect of the principle of a concurrent engineering program is analyzed and enumerated via sub-sections 5.2.1/2/3/4/5/and 6. Then two explicit direct effects of CE's principle on a production start-up phase will explain.

5.2.1 Comprehensive Deployment of Constituents

CE program does enable to encompass each and every single constituent of a product development process. The reviewed literatures, in [Chapter 4], express the comprehensive extension of a CE program's borders. The CE program determines the path for a product from *planning,* the starting point of generic product development process, to *production start-up* to *market* and to *product disposal*. Therefore, a CE program is empowered to establish a set of strategic and systematic foundation for various processes throughout the whole life cycle of a product. The strategic foundations can align the macro strategies of an enterprise and would become a guideline for determining a strategic vision for functions; hence, the global optimization would achieve when the strategy and performance of each function is align with downstream and upstream function. Thus, the significant parameters which are linked to strategic decision making and related to establishing a basic structure of product development process can be managed through comprehensive deployment of constituents. For instance, a list of significant parameters that can assign to first principle can expressed as following (See [Table 22] project ownership, project definition, manufacturing strategy, staffing plan, planning a product life cycle, harmonizing the manufacturing plan with customer demand.

5.2.2 Early Involvement of Constituents

Internal constituent addresses the functions which are directly or indirectly influenced by product realization process such as engineering, manufacturing, purchasing, sale, accounting, distribution, and quality. The external constituents are the participant of target market as well as suppliers and sub-contractors. The most important point is that the involvement must be conducted as early as possible so that the engagement of various participants can be more beneficial due to recognizing and resolving the constraint as early as possible. That is, the early feedback of participant will lead to early problem solving and early decision making. The consequences of the early involvement of constituents are: appropriate communication and good understanding between enterprise and its suppliers/subcontractors, generating the smooth flow of information, rapid feedback and avoiding time-consuming reworks, recognizing the competence of constituents.

Thus, the significant parameters which are caused by the lack of suitable cooperation and coordination between constituents can be managed through second principle of CE. For instance, the negative effects of late engineering changes may be controlled when the supplier is informed that a new revision will be issued, or when the design department has informed of the lead-time for new tooling, that should be built by manufacturing department. The early information would enable a supplier to arrange a suitable decoupling point for its delivery plan; hence, a win-win relationship can bring about across a start-up phase where the engineering changes could be unavoidable. Nevertheless, the supplier is flexible enough to provide the requirements since her early involvement in the project allow the suppler to plan her production and delivery plan sufficiently.

A list of significant parameters that can assign to first principle can be enumerated as following, (See [Table 22]): coordinated product design and tool making, coordinated design and manufacturing, ramp-up strategy and planning, technological and technical capability of manufacturing system (e.g. automation level), supply of material, flow of material across manufacturing processes, product and production complexity, (new) product- (new) process mix, ramp-up targets leveling, (late) engineering changes, decisions made across product development process, logistics.

5.2.3 Cross Functional Teams

Cross-functional team building is the most significant approach of a CE program that can catalyst making the convergence opinions in a team encompassed of various functions. Cross-functional team means a work team encompassed of multidisciplinary experts who can belong to various functions such as designer, manufacturing process planner, mechanical engineer, software programmer, and etc. The purpose of the multifunctional teams is to facilitate the communication channels between participating functions so as to all of them can provide their inputs before finalizing the design. The arrangement and layout of a cross-functional team depends upon the structure of project organization as well as the staffing plan of an enterprise since the structure of an organization and the staffing plan must enable a human resource to play a versatile role across various functions so that a cross-functional team would be created. The cross functional team makes communication easier wherein there is need to cooperation and coordinating of various functions. As a result, the smooth flow of information leads to an innovative technical solution which provide the optimized design attitudes before finalizing the design. Thus, the significant parameters which are linked to the lack of coordination among various functions and the lack of team-work spiritual can be managed through third principle of CE. For instance, a list of significant parameters that can assign to third principle may be as following, (See [Table 22]): management in the department level, formal organization of the project, project definition, project ownership, organizational structure, product and production complexity, workforce policy, personnel (operator performances, absenteeism, individual learning, and work performances).

As a case in point, a cross functional team consisted of R&D expertise, designers, production engineers, logisticians, and marketing would control the complexity of product and production systems designed for a new product. The R&D expertise can introduce, for example, an innovative material/technology; the design team must improve the design solution based on new innovative solution; the production engineer may evaluate the new solution in terms of manufacturability and rapid start-up phase; the logistician would assess whether the supplier can provide the new request material and whether the distribution system needs new requirements concerning new solution; marketing department would investigate the customer/user interest regarding new solution in design. Now, the complexity may be generated if each department is going to apply new process since it means longer lead-time and a new start-up phase with new problems. Nevertheless, a cross functional team can solve the problem in the course of a multidisciplinary approach. The designer can replace the new solution in a versatile fashion with previously applied non-value added techniques; consequently, the production engineer will be able to keep previously built tooling and fixtures. Hence, there is no need to test new tooling or new assembly techniques; as a result, there is no need to spend more time on start-up phase. The new versatile solution may enable the logistician to think about the postponement of decoupling point more forward and become more flexible to meet the demand of customer/user.

5.2.4 Dynamic Information Management System

In this thesis the information management system is defined as a system that can facilitate gathering, saving, summarizing, analyzing, and organizing the data coming from different sources by means of hardware and software infrastructure in a dynamic concurrent engineering environment. This system must enable and manage the flow of information across an organization and make transparent communication possible. The ultimate goal of the information management system is to provide manageable knowledge sharing among users and to get feedback from users in order to establish unified comprehension of product and process development processes.

The dynamic information management systems applied in CE environment would definitely support required smooth information flow for start-up phase. The information technology employed by a CE program would facilitate the integration between design and manufacturing, and bring about easier communication tools. Hence, the primitive design information can be evaluated by processes planners, suppliers, marketing departments. Consequently, when developed product is approaching start-up phase, there is no need for essential changes.

It is in this parallel process of concurrent engineering where a potent computer-based-decision support-tool may offer further cost and benefit analysis. Such a system would tremendously empower the product design by early feedbacks on the conceptual design in terms of material choice, machine selection, manufacturing and costing in the initial stage of the design cycle.

The importance of information management in a production start-up phase would emerge when there is a need to communicate the status of start-up phase with designers in order to recognize the problems and identify a proper solution. The information is the basic element of learning curve. The operators should, hence, be informed at the right time with sufficient information to learn how to conduct the assigned activities throughout a production start-up phase. As a result, the predefined target values for a start-up phase can achieve more rapidly. A list of significant parameters that can assign to fourth principle may be as following, (See [Table 22]): continued learning across a series of projects (benchmarking), product and production complexity, information sharing, information flow management, learning (labor & machine), and degree of the innovation of product/process.

5.2.5 Concurrency

In this thesis concurrency is defined as planning and accomplishing the activities involved in the product realization process simultaneously by means of computerized tools or project management techniques.

The concurrency in concurrent engineering program would be employed in: (Parasad, 1996) and (Swink et al, 1996)

- Product concurrency or Parallel product decomposition: an aggregated plan to take multiple characteristic of a product life cycle and develop them in parallel for various product development program

- Resource allocation: planning, scheduling, and putting a same source of resources such as labor, or a machine into action for different product development programs simultaneously, rather than waiting to finish with one activity and then going towards the next one sequentially
- Concurrent processing: simultaneously developing different phase of a product development program such as market concepts, product design, manufacturing processes, product support structure simultaneously
- Concurrent project phases: simultaneously developing different phases of a project.
- Design concurrency: the overlaps between system level design disciplines and component level design discipline. The design disciplines are such as system, software, electrical, and mechanical engineering.

The parameters related to project architecture such as the involvement sequence of critical stages and milestone of the project, timing and the sequence of operational tasks. A CE approach implements formal project management tools to define the scope of the project concerning the entire life cycle of the product. In addition, the most significant mindset of a CE program is planning activities concurrently which can be accomplished in six fashions embracing not only detail design stages, but also parallel product pipelines. Therefore, the sequence of activities within a product development process can be optimized via CE's concurrency rules. [Figure 14] illustrates the relationship between different steps of a product development process when the CE program makes the concurrency rules across different project phases. Through implementing mentioned concurrency items in CE environment, the lead-time of activities would shorten via concurrent project phases. The product and production complexity can be controlled via overlapping and paralleling product decomposition. The cross functional team can be formed more easily via resource allocation. In addition, more experience operators can move into start-up phase whenever a bottleneck is starting or the workforce strategy over start-up phase is changing.

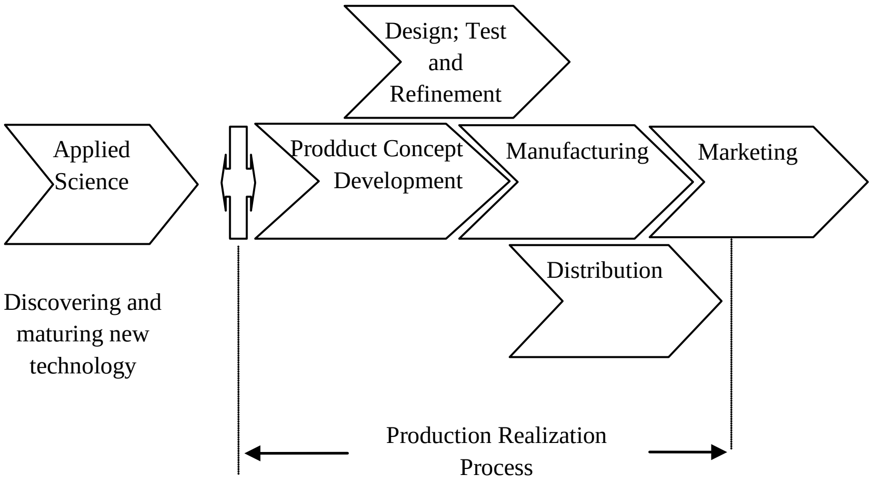

Figure 13; concurrency & significant parameters, overlapping among activities

5.2.6 Integrated Product Realization

In this thesis, an integrated product realization process is defined as an aggregated structure of functions which are accommodated throughout a product lifecycle from the concept design to production and from production to after sale services. In CE environment, the integration among three functions would be the most determinant factor to create a smooth and efficient start-up phase. The functions are: design, manufacturing and marketing. As an illustration, [Figure 15] expresses the status of start-up phase within the integration of mentioned factors.

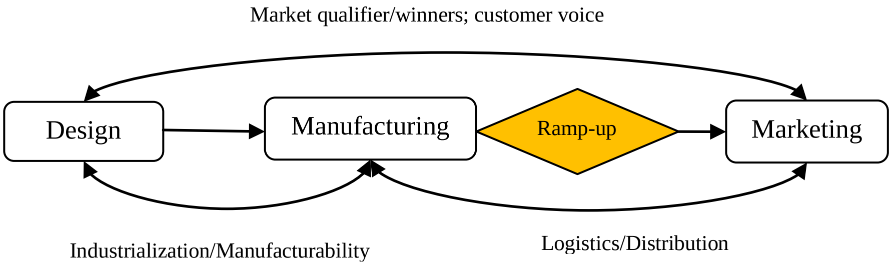

Figure 14; the integration between design, manufacturing, and marketing in CE environment

The ram-up phase, whereat the volume and quality targets much achieve, is performing as a bottleneck between production and market. The integration of each three function must consider the start-up phase circumstances. In a CE program, the integration within various functions can be achieved through four elements: strategy, processes, technology/tools, organization (Paashuis and Boer, 1997). The integrating tools and methodologies which are supported by dynamic information management would provide appropriate level of integration between such functions as design and manufacturing which have the most crucial effects on start-up phase performances. The integration of design, process planning, and tool making would support product development team to find out the tailored start-up strategy such that both product design and manufacturing requirements can be fulfilled. Moreover, the feasible ramp-up targets can be determined by design team members as they recognized the competency of production system. The integration between design and logistics would support a suitable procurement plan for start-up phase; Fine et al., (2005) demonstrates a debate of integrality versus modularity in product and supply chain design in concurrent engineering environment. A cross functional team would establish an appropriate work methods via implementing an integrated tools; consequently, the rapid work peace and the short start-up phase can be achievable. The integrated information technologies such as computer based DFM would support a design team to simulate the manufacturability of a design and recognize the obstacles that can happen throughout production start-up and production start-up phase.

Concurrent Engineering Principles	Significant Parameters affecting a production start-up phase
Comprehensive deployment of constituents	Project management, Predefined performance metric, Human Resource Management (staffing plan), Strategic management of the functions, Increasing demand and sales rate, Product Life cycle, Decisions made across product development process, Manufacturing Strategy
Early involvement of internal and external constituent	Coordinated product design and tool making, Coordinated design and manufacturing, Start-up strategy and planning, Technological and technical capability of manufacturing system (e.g. automation level), Supply of material, Flow of material across manufacturing processes, Product and Production Complexity, (New) Product- (New) Process mix, Start-up targets leveling, (Late) engineering changes, Decisions made across product development process, Logistics
Cross functional teams and project organization	Management in the department level, Formal organization of the project, Project Definition (Project nature), Project Ownership (A formal organization), Organizational structure, Product and Production Complexity, Workforce Policy, Personnel (operator performances, absenteeism, individual learning, and work performances)
Dynamic information management system	Continued learning across a series of projects (benchmarking), Product and Production Complexity, Information sharing, Information flow management, Learning (labor & machine), Degree of the Innovation of Product/Process
Concurrency	Timing for announcing a new product and overly optimistic sale forecasting, Supply of material, Product design, Degree of Overlap among product development activities, Logistics, Production and assembly process, High level of utilization , Machine breakdowns and minor stoppages, Managing the cycle times
Integrated product realization process and Tools	Coordinated product design and tool making, Procurement plan for start-up phase, Inventory control system, Quality and volume target setting, Coordinated process planning and production planning, Capacity of production system, Work Method, Work Pace, Manufacturing Process Standardization, Product mix, Production and assembly process, High yields, Process maturity and stability

Table 22; the relation between CE principles and significant parameters affecting production start-up phase

As a summary of result, a Concurrent Engineering program does enable to:

- Determine a path from *planning*, to *production start-up* to *marketing* and even to *product disposal*. Therefore, a CE program is empowered to establish a set of strategic and systematic foundation for various processes throughout the whole life cycle of a product. The strategic foundations can align the macro strategies of an enterprise and would become a guideline for determining a strategic vision for functions; hence, the global optimization would achieve when the strategy and performance of each function does align with other downstream and upstream functions.
- Involve both internal and external constituent as early as possible. This can help the product development team to recognize and resolve the constraints and get feedback from various constituents at the right time.
- Build cross-functional teams which can catalyst making a convergent decision in a team encompassed of various functions. The purpose of cross-functional team is to facilitate the communication channels between participating functions so as to all of them can provide their inputs before finalizing the design. The cross functional team makes communication easier when there is need to cooperation and coordinating of various functions. As a result, the smooth flow of information leads to an innovative technical solution which provide the optimized design attitudes before finalizing the design.

- Employ an information technology which can facilitate the integration between design and manufacturing, and bring about easier communication tools. Hence, the primitive design information can be evaluated by processes planners, suppliers, and marketing departments. Consequently, when developed product is approaching start-up phase, there is no need for essential changes.
- Arrange the parameters related to project architecture such as the involvement sequence of critical stages and milestones of a project, timing and the sequence of operational tasks. A CE approach implements formal project management tools to define the scope of the project concerning the entire life cycle of the product. In addition, a CE program can execute activities concurrently which can be accomplished in six fashions embracing not only detail design stages, but also parallel product pipelines. Therefore, the sequence of activities within a product development process can be optimized via CE's concurrency rules.
- Bring about a proper integration within various functions. This can be achieved through four elements: strategy, processes, technology/tools, organization. The integrating tools and methodologies which are supported by dynamic information management would provide appropriate level of integration between such functions as design and manufacturing which have the most crucial effects on start-up phase performances.

As a final consequence, analyzing the effective parameters would help to identify the requirements for managing a start-up phase. And also studying the capabilities of concurrent engineering approach would help to recognize which possibilities can be prepared for dealing with production start-up issues. Table 23 summarizes the indirect effects of principles of a concurrent engineering program on a production start-up phase.

The direct effects of principles of a CE program are explicitly associated with changes and planning within a start-up phase.

The changes might be needed to meet require engineering and operational changes. For instance, the necessary changes in tooling, tolerance, or quality control obligations. Late engineering changes are unavoidable problems; a contemporaneous effort can involved such departments as design, manufacturing and even suppliers in order to diminish the negative effects of late engineering changes. A concurrent engineering program would establish a preventive and corrective solution through cross functional teams and integrating tools in order to decrease the negative effect of changes on a production start-up phase.

The start-up planning and control involves the planning of a ramp-up phase as well as the planning of a set of tasks for shop-floor. An optimize plan must implicate the utilization of the resources e.g. skillful task forces, machine, and control an efficient supply of material. The resources and materials can be allocated from other product pipe lines into the production start-up for new designed product. A concurrent engineering program would establish preventive actions through concurrency rule as well as cross functional teams to generate a well-defined aggregated resource plan. Moreover, a concurrent engineering program would establish a dynamic information flow by using integrated tools and early involvement of constituents. Consequently, a well-established plan can optimized the resource utilization (man, machine, material) in a way that a start-up phase can take necessary reactions against common effective parameters such as machine break downs, complex work methods, work peace, and fulfilling the necessary cycle time.

Requirements for start-up management	Possible approaches based CE's core principles
The supplier and customer involvement would enormously influence the start-up phase Putting together a group of people from various departments, with different background and different experienced is the most vital parameter Smooth information flow among people and departments must take into consideration essentially Implementing techniques of project management and project controls would become beneficial for optimizing resource utilization The structure of an organization must have the capability of dealing with start-up phase requirements Specific tools and techniques must be used to find optimal solutions for dealing with such problems as the complexity of product/production, providing the proper work methods and instructions for operational stages, identifying the root of problem-making elements and etc. Certain material requirement plans for start-up phase must be developed; correspondingly, a specific procurement plan must be prepared and suppliers must be informed in due course. The inbound logistics is as critical as the outbound logistics. The flow of material and the level of inventory must be track-able and recordable. The capability of manufacturing system must be balanced with the innovative design solutions. The capability of human resource must be balanced with the requirements of a product development plan. Determining performance indicators and establishing relevant start-up targets level would enable the product development team to focus on crucial priorities. Market requirements must be balanced with the product design. In addition, the timing of launching a product into the market or a segmentation of a market must be analyzed. The outcome of such balance would set-up the product life cycle.	CE can determine a path from *planning*, to *production start-up* to *marketing* and even to *product disposal*. Therefore, a CE program is empowered to establish a set of strategic and systematic foundation for various processes throughout the whole life cycle of a product. The strategic foundations can align the macro strategies of an enterprise and would become a guideline for determining a strategic vision for functions; hence, the global optimization would achieve when the strategy and performance of each function does align with other downstream and upstream functions. CE can involve both internal and external constituent as early as possible. This can help the product development team to recognize and resolve the constraints and get feedback from various constituents at the right time. CE can build cross-functional teams which can catalyst making a convergent decision in a team encompassed of various functions. The purpose of cross-functional team is to facilitate the communication channels between participating functions so as to all of them can provide their inputs before finalizing the design. The cross functional team makes communication easier when there is need to cooperation and coordinating of various functions. As a result, the smooth flow of information leads to an innovative technical solution which provide the optimized design attitudes before finalizing the design. CE can employ an information technology which can facilitate the integration between design and manufacturing, and bring about easier communication tools. Hence, the primitive design information can be evaluated by processes planners, suppliers, and marketing departments. Consequently, when developed product is approaching start-up phase, there is no need for essential changes. CE can arrange the parameters related to project architecture such as the involvement sequence of critical stages and milestones of a project, timing and the sequence of operational tasks. A CE approach implements formal project management tools to define the scope of the project concerning the entire life cycle of the product. In addition, a CE program can execute activities concurrently which can be accomplished in six fashions embracing not only detail design stages, but also parallel product pipelines. Therefore, the sequence of activities within a product development process can be optimized via CE's concurrency rules. CE can bring about a proper integration within various functions. This can be achieved through four elements: strategy, processes, technology/tools, organization. The integrating tools and methodologies which are supported by dynamic information management would provide appropriate level of integration between such functions as design and manufacturing which have the most crucial effects on start-up phase performances.

Table 23; comparison between critical requirements for managing start-up phase and the indirect effects of principles of a concurrent engineering program on a production start-up phase

6 Discussion and Conclusion

This research, as a master thesis, studied the significant parameters which affect a production start-up phase. Then, it investigated whether the principle of concurrent engineering would support an efficient start-up phase. The selected research methodology is based on a conceptual and supportive review of current scholars in the field. The research design is according to a three-step process which is applied to catch most relevant literatures. The outcomes of the three-step process are statistically presented in table [1], sub-section 2.3.1. As a result of the research, the significant parameters are identified. In addition, a framework is structured that can present the requirements to manage an efficient start-up phase. The research, through the comparison between principles of a CE program and significant parameters, indicates how a concurrent engineering program would support a start-up phase. This comparison is summarized in [Table 23].

However the influence of parameters related to marketing such as product launching time into the market must be investigated more. Launch timing includes a set of decisions which are discussed through marketing concepts such as the threat of competitor entry and the completeness of development. Thus, the discussion related to launch timing is beyond the scope of this thesis.

In comparison with former presented frameworks such as (Langowitz, 1988), (Merwe, 2004), (Schuh et al, 2005), (Berg and Säfsten, 2006), (Vandevelde and Dierdonck, 2003), the introduced framework, in this thesis, is more comprehensive. It expresses required elements that should be considered in a production start-up planning. However, it may not be generalized since each product development process would have various characteristics which may demand new elements to be considered in the framework. Nevertheless, the introduced framework can construct the fundamental skeleton of a production start-up plan. Likewise, this issue can be indicated about significant parameters; each product system and production system can bring about new obstacles related to production start-up which are not listed in this thesis.

The decisions made by managers would generally influence the overall procedure of development process; hence, it is necessary to identify the decisions which are essential and significant for a start-up success. This discussion is also proved by (Juerging and Milling, 2006) via modeling the interdependencies of product development decisions the production start-up performances. Ulrich and Krishnan (2001) have pointed out that poor product-design decisions can slow the rate of production start-up. (Clawson, 1985) has remarked that the decisions coming from significant functions, such as purchasing, quality assurance, engineering, manufacturing, and suppliers are affecting the manufacturing start-up phase.

It has claimed that concurrent engineering is a “widely recognized approach to improve product introduction” (Brookes and Backhouse, 1998, p. 3035). The analysis of this thesis also indicates that the principle of concurrent engineering approach support the significant parameters which affect production start-up phase. However, there is a lack of dedicated practical or theoretical research that would investigate the effects of a concurrent engineering program directly on start-up phase. For instance, most of the researches, such as (Ainscough and Yazdani, 2000), are focusing on the effects of concurrent engineering on product introduction phase. There is a lack of researches that help to evaluate whether the concurrent engineering program does have a certain approach to plan and control the shop floor activities. Most of the concurrent engineering methodologies are concentrating on the design process and the integration of design and manufacturing.

It should be remarked that the relationship of core principles is a complementary relation to one another; that is, for instance, having the cross-functional team make involvement of all constituents possible. Or, an appropriate information management system enables an organization to implement a tailored computerized tool which make possible to carry out product design and manufacturing activities concurrently.

A CE program can be a set of selected best practices and methods. It has indicated that "managers have found that different projects, company, and industry context often necessitate customized approaches to concurrent engineering" (Swink, 1998, p. 103). Therefore, a CE program can focus either on a simple local issue, such as start-up phase management, or overall organizational changes. It is up to the company find out how a CE program should be planed and controlled. However, it has experienced that only relying on computer and automated processes cannot optimize the process of product realization. Lee-Moritimer (1990) has claimed that "too many companies find that investment in computer aided engineering (CAE) and CNC machines, or new manufacturing systems (e.g. MRP, JIT) do not solve all of the problems associated with the introduction of new products. The consequences are continued excessive lead times and difficulty in manufacturing new product cost effectively" (Lee-Mortimer A. 1990, p.11). Therefore, a CE program must consider both automated and on-the-paper tools to deal with start-up phase and potential parameters which can affect the performance of a start-up phase.

7 Further Research

For further research two areas would be interested. First, the proposed framework for managing and controlling a start-up phase can be examined through more empirical case studies in order to find out more detail aspects of product and production system which affecting start-up performance. As a case in point, the supplier relationship can be divided into specific area (e.g. procurement, external logistics, regulations, and monetary commitments) and for each area the effects of managerial decisions on start-up phase can be investigated more specifically. Moreover, a set of case studies can help to identify which one of CE tools and methodologies are the best practice in terms of start-up phase circumstances.

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