CHAPTER - II
REVIEW OF LITERATURE

2.1 INTRODUCTION

In this chapter, a review of the various works carried out in the areas of Lean Manufacturing, implementation of Lean principles in Product Design and Development, Analytical Hierarchical Process, Data Envelopment Analysis, and fuzzy logic approaches in product design are presented. Also, two other topics viz., Team formation and modularization are discussed. A major objective of the literature review is to trace the limitations of existing methods of customer preference evaluation methods and difficulties with conventional methods of analyzing homogeneous products that exist in the market. Such a review, hopefully, paves the way for not only understanding the current state of the art but also providing guidelines for further research.

The organization of this chapter is divided into eight sections. Introduction and objective of this study is presented in section 2.1. Section 2.2 discusses about various stages from conventional manufacturing to Lean manufacturing. Review on Product design methods are discussed in Section 2.3. Section 2.4 deals with customer integration for Lean product design and development. The Data Envelopment Analysis review is presented in section 2.5. Section 2.6 deals with Fuzzy logic approach in product design. Team formation methods from simple assignment model to Multi assignment model and integration of Linear Programming is presented in section 2.6. Section 2.7 reviews about modularization methods for Lean Product Design and Section 2.8 of this chapter includes brief summary and conclusions.

2.2 LEAN MANUFACTURING

In the past, mass production was the method that a majority of manufacturers adopted for maximum profit at the highest machine efficiency. This involved expensive equipment, a large amount of money tied up in work in process (WIP), and excess finished goods inventory (Sanchez & Nagi, 2001). Anything that does not add value to the product can be considered as waste, Lean manufacturing aims to eliminate waste (John M. Nicholas, 2001). In order to stay competitive, companies
now adopt manufacturing principles in which lead times and cycle times are shortened, Quality levels are increased and excess inventory and other waste are decreased. The basic underlying idea of this system is to minimize the consumption of resources that add no value to a product (Hines & Taylor, 2000).

Lean thinking began roughly 50 years ago with introduction of the Toyota Production System (TPS) used by Toyota Motor Company (TMC) in Japan to the US automotive industry (Womack & Jones, 1994).

A study that was done at the Massachusetts Institute of Technology of the movement from production toward lean manufacturing as explained in the book “The Machine That Changed the World” (Womack, Jones and Ross, 1990). The study understood the great success of Toyota at NUMMI (New United Motor Manufacturing Inc.) and brought out the huge gap that existed between the Japanese and Western automotive industry. The ideas came to be adopted in the United States of America because the Japanese companies developed, produced and distributed products with half or less human effort, capital investment, floor space, tools, materials, time, and overall expense (Womack et al., 1990).

Kosonen et al., (1995), discusses customer focused lean production development. Their research concerns changing a factory into a lean organization. The main issues treated are as follows: To increase productivity by means of decreasing total lead-time and increasing flexibility in processes. One part of the project was to develop a production system for a new product group through customer involvement.

In order to compete in today’s fiercely competitive market, Indian manufacturers have come to realize the traditional mass production concept has to be adopted to the new ideas of lean manufacturing (Lucas T.V.S, 2001).

Lean manufacturing is not only the implementation of tools and techniques. It involves an adaptation at all levels of the company’s workforce to the lean philosophy. Lean must involve a culture change and a new way of thinking, often referred to as lean thinking explained through five principles (Womack & Jones, 1994).
Specify Value:

The first lean principle is to precisely specify value. Womack and Jones (1996) define value as “a capability provided to a customer at the right time at an appropriate price as defined in each case by the customer”. The definition is useful for application where the final product production is explicitly defined. For product development, however, it is less helpful. In practice, lean assessment of product development tends to fall back on unplanned characterizations concerning which activities add value.

Identify Value Stream:

The value of a product is determined through a sequence of actions that eventually delivers the product to the customer. This sequence forms the value stream, and is defined as “the sum of specific actions performed on a product to carry it from raw material state into the hands of the customer as a product” (Womack and Jones, 1996). Mcmanus (2004) describes value stream analysis and mapping (VSA/M) as the understanding and improvement of business process using illustrations to show the product flow towards a final outcome.

Create Continuous Flow:

Once the value stream has been identified, the process of continuous flow can be introduced. Continuous flow is “the progressive achievement of tasks that transform (with no stoppages, backflows or unnecessary work) relatively raw material or information into a customer desired product or service”. The concept of continuous flow may be applied in all phases of the product life cycle. Unfortunately, this concept has not yet been introduced in many areas of industry. For example, McManus (2004) have reported that 62% of the product development tasks they examined were found to be idle at any given time in a detailed member study. This stat is in line with the other findings from kaizen events that show 50% to 90% idle time.
Let Customer Pull:

The fourth principle, “Let Customers Pull” deals with the scheduling aspects of lean manufacturing (McManus, 2004). A true lean manufacturing environment runs on a pull system where the customer sets the speed and no product is made until the customer places an order for it. The pull system is a key element of lean manufacturing which allows only the necessary amounts of inventory in process to satisfy customer demand. In Product development, Kanban cards are sometimes used to signal the need for specific information.

Pursue Perfection:

The final step in achieving a lean enterprise is pursuing perfection. Pursuing perfection implies process improvement is never done increase in efficiency can be achieved repeatedly. For example, industry has successfully increased efficiency in some processes by upwards of 30% each time they revisit a process (Womack and Jones, 1996). Womack and Jones also presents that transparency, or unrestrained access to data, is the most important aid to perfection and it creates an environment where it is easy to discover better ways to minimize the waste in product development.

Lean techniques may be applied to any stage of the supply chain, although results are often more easily seen in the manufacturing stage. This is due to the visibility of flowing or stationary product as well as the quantifiable nature of the activities in the manufacturing stage, such as inventory counts and cycle times. Lean office, lean product development, lean design, lean accounting and lean warehousing are all lean processes that are becoming more widely spread.

The use of the term “Lean” in a business or the manufacturing environment describes a philosophy that incorporates a collection of tools and techniques used into the business or in an organization to optimize human resource, assets and productivity simultaneously improving the quality level of products and services to their customer (Zoe et al., 2004).

Many different terms, such as agile or flow, are used synonymously with lean however, they are all quite different. In order to become lean, various tools and
techniques must be implemented in addition to the adoption of the lean philosophy such as

- Value Stream Mapping
- 5S Method
- Visual Management
- Single piece flow
- Kanban
- Poka-yoke
- Changeover reduction
- Kaizen
- Continuous Flow

**Seven Types of waste**

Muda, the Japanese term referring waste, is any activity that consumes resources but no value (Santos et al. 2006). The goal of lean manufacturing is to reduce all types of waste in order to improve production and satisfy customers. Shingo (1997) from the Toyota Production System identified seven types of waste that are most common to manufacturing factories are as below.

1. Overproduction
2. Waiting
3. Transportation
4. Processing
5. Inventory
6. Motion
7. Making defective products (Japan Management Association, 1989; Santos et al., 2006)

According to Yuliang et al. (2004), the rapid changes in many manufacturing industries, and the global competitive pressures in those industries, designers have fallen more out of touch with the manufacturing terms than they were in the past. As a result, there has been a large increase in the amount of attention given to practices that can aid in design for manufacture. The importance of these practices has been highlighted, and claims that 70% of the manufacturing costs of a product (costs of materials, assembly etc.) are determined by design decisions, while the same applies to only 20% of production decisions (process planning etc.).
Sylvain et al., (2007) discusses about “From manufacturing to Design: An Essay on the Work of Kim B. Clark” made the case that product development could be managed in new ways that would lead to significant competitive advantage for firms and Product and Process design at the center of his explanation of how innovation determines the structure and evolution of industries.

2.3 LEAN PRODUCT DESIGN AND DEVELOPMENT

EL food. Buffa.S (1983), Modern production, operation management a text book mainly describes the technology and the design of products and services. It also helps to know the various inventory replenishment policies, material requirements planning, also given various models for improving customer based selective models on linear programming line model, work measurement model etc.

Kenneth B. Kann’s (2001), New Product Planning is a concise, comprehensive book on New Product Development and Product Management and the book mainly discusses the important product planning issues, such as, defining customer needs, translating the needs into technical specifications, generating concept, evaluating results, developing marketing plans and marketing testing, product launch, and brand management, etc.

David Rowe & Ivan Alexander (1970), selling Industrial products, a text book details about the work of industrial sales managers and industrial salesperson. He opines that expenditure on the upgrading of sales forces could for many firm represent the quickest way of improving performance and profits, because good aggressive salesman can start a chain reaction back into other parts of the organisation forcing decision upon design and production departments. This book suggests a framework within which the industrial selling role can be meaningfully analysed and also offers some practical guidance on the conduct of the job and new product development. The selling process is mainly depended upon the consumer’s satisfaction. The author quoted many ease studies from the various industries like steel, chemical and plastics raw material, machine tools, ship building, cement building material, textile spinning and heaving, heavy electrical and mechanical engineering etc.

Tony carter (2003), Sales force management a contemporary approach, a book mainly helps the industrial entrepreneurs to strengthen their through creating a automation and sales force management. This book mainly helps to understand how to quantify a sales force technology investment and determine return on investment.
based on augmented sales and enhanced customer service levels. It also helps to know
the strategic issues for an international sales effort etc

Smith and Reinsertion (1991) identified the application process of JIT (Just-in-
Time) manufacturing philosophy in the new product introduction process. JIT is the
manufacturing analogy of the kind of improvement that the NPI process is trying to
achieve. As per their opinion, in a manufacturing pull system, the downstream process
calls for the parts when they are ready for them. They also state that if the information
is pulled it will go faster to the entity requiring it and will be done in the form of small
batches. This will also be more applicable and more recipient oriented and will
compress the whole development cycle. The “pull” approach is established in a
development team by making it clear that it is the responsibility of the downstream
person to ask for whatever information they need

Milkulina (1998), identified the key elements of demand flow manufacturing
can be applied to new product introduction in the area of relationship with suppliers or
vendors. Supplier partners are responsible for the management of component supply.
This supply process is based on the demand basis when this process flows freely, the
whole process of the particular company can work effectively. The process of
information supply should not only be based on price and but to the local cost,
including impact on production, operating cost, quality, delivery and inspection.

The book on “The design of things to come: How ordinary people create
extraordinary products” written by Craig M. Vogel et al., (2006) reveals a new
generation of products that feel perfect, fulfill deep unmet desires, and transform
consumer lifestyles. It also profiles a new generation of innovators, revealing exactly
how they are inspiring people and directing their visions to profitable reality. Many
articles of this book mainly discusses, how a company can avoid the chain of mistakes
that can destroy the organization.

business success”, this book is written by using the unique customer in center
concept. This book explain how investing in customer value can increase the market
share and profitability of a company. It shows companies how they can be driven by
customer and their needs, and how sustained business success can be achieved
through customer value investment. Each chapter of this book explains key terms and
basic concept, and insightfully illustrated with caselets, tables, graphs and key points.
The book explains how companies can move beyond customer management and satisfaction to loyalty, how companies can become market leaders and improve business results.

John E. Hunt (1997), Business and Commercial Aspects of Engineering, this book is written to provide the material necessary for the commercial and engineering functionaries. The aim is to introduce entrepreneurs of engineering related business. It also discusses the emphasis to the roles and relationship of various departments of organizations. It also covers the commercial function in detail marketing, sales, purchasing and distribution activities that are shown to be related to the product flow. It also examines the interfaces and information flows between the engineering and commercial functions. It explains cost elements, types and behavior within a business.

According to Karlson and Ahlstrom (1996), the conceptualized Lean Product Development is mainly based on supplier involvement, cross-functional teams, simultaneous engineering. This lean product development process also follows an integration of activities instead of coordination activities. It also has a peculiar strategic management vision and objectives instead of detailed specifications. It also based on block box engineering whereby demands on the “Functions” of the product replace the “detailed guidelines on specific measurements and features. The authors also emphasis that successful move towards lean product development requires approaching these interrelated techniques as elements of a coherent whole. The authors had not explicitly looked at the identification of “value” in product development.

According to John et al., (2000), Quality Function Deployment is a tool for bringing the voice of the customer into the product development process from conceptual design through to manufacturing. It begins with a matrix that links customer desires to product engineering requirements, along with complex benchmarking information and further matrices can be used to ultimately link this to design of the manufacturing system.

Garry Conner (2001), collection of waste types within product development on a case study that contrasts product development processes of companies in North America with those performed by the Toyota Company. Thus his work is practically oriented and enriched with “Toyota thinking” at the same time. Conner concentrates on “Process waste” and suggests a good number of new and useful aspects that were
not concentrated by other approaches and re-interpretations of the lean seven types of waste.

Mcmanus (2004), reinterpretation of the lean seven types of waste focus on the actual product of product development, which is information, and provides a very concentrated in this important aspect. His work includes a comprehensive list of appropriate information waste examples also suggests a number of possible causes for each example.

**Differences between Manufacturing and Product Development**

Applying lean manufacturing principles to the area of product development is not that easy and has to be developed systematically. In product development, value addition consists in the creation of new and useful information in order to develop new product data, specifications and directions, or some kind of 'product instructions' which then can be realized by manufacturing.

According to Negele et al. (1999) product development process itself can be understood as multi dimensional process nets where processes and process chains are highly interconnected between feedback loops and interactions cross multiple hierarchical levels. Further, product development process can be characterized by the following set of attributes (Negele et al., 1999): namely creative and innovative, dynamic, interdisciplinary, strongly interrelated, parallel, iterative, communication intensive, anticipatory, planning intensive, uncertain and risk.

Even if there can be seen some parallels between manufacturing and product development like the idea flow, there still exist a lot of differences which might mean some more or less big hinders for the application of lean manufacturing principles and tools to product development at this point of time.
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<th>Attributes</th>
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<th>Manufacturing</th>
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<td>Character of work</td>
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<td>Focus on</td>
<td>Time on Critical path</td>
<td>Costs and expenses as measure of waste</td>
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### Table 2.1 Differences between Product development and Manufacturing

2.3.1 The Product Development Process

New product development (NPD) can originate from new technology or new market opportunities. But irrespective of where opportunities originate, when
it comes to successful new products, it is the consumer who is the ultimate judge. Hence, in order to develop successful new products, companies should gain a deep understanding of 'the voice of the consumer'. Consumer research can be carried out during each of the basic stages of the NPD process: (a) opportunity identification, (b) development, (c) testing, and (d) launch (Urban et al., 1997). It is most widely applied during the development, testing and launch stages. Even the most technologically oriented companies use consumer research to verify that consumers will accept a new product when it will be launched at the market. Despite the importance of the later stages, it is increasingly recognized that successful NPD strongly depends on the quality of the opportunity identification stage. The goal of this stage is to search for new areas of opportunities, which typically involve the unmet needs and wants of consumers.

Traditionally, the Product Development Process (PDP) includes numerous steps. Different authors describe these steps, or phases, in a product's development somewhat differently. Even companies have their own view of how to proceed in the process, although they all have great similarities. In this section, the product development process will be described in brief, mainly based on Ulrich and Eppinger (1995). They suggest that the generic product development process should be divided into following six phases (Fig.-2.1).

![Fig.2.1 The generic product development process (Ulrich and Eppinger, 1995)](image)

2.3.2 Customer integration for Lean Product Development

The involvement of customers in new product development is considered as a victorious strategy and tactic to improve new product success (Li Pheng Khoo et al., 2002). In the present work, the customers' perspective is taken. It is first shown that the locus of initiative for product development involvement is of relevance for
identifying different types of involvement. It is then argued that the degree of involvement needs to be measured. Furthermore, since customers have different expertise, they should be chosen according to their ability to appreciate the degree of newness of the future product as well as their potential stage-specific contributions. The degree of involvement can be as far as to make the customer involved in the development of the product, experience and delivery. Within customer-integrated design, the product is regarded to be a subset in what meets the customers' need of identification, problem solving and consumption. The possibility to influence the design and the consumption itself is assumed to be of great importance for the customers buying decision and loyalty (Anthony and Harvard, 2002).

Understanding and fulfilling each individual customer's requirements have been recognized as a pressing challenge for companies across industries. Apart from offering market-focused products, which corresponds to an average satisfaction of customer requirements, companies are pursuing a strategy of offering customer focused products with a large degree of individuality (Ulwick, 2002). Poor understanding of customer requirements and inaccurate assumptions made during the elicitation and analysis of requirement information have significant negative implications on design and manufacturing of product in terms of quality, lead time and cost.

Transformation of customer needs to product specifications implies a time consuming and error-prone effort. Despite much advance in computer aided design and engineering, there is relatively little progress in providing analogous support for requirement management (Yuliang et al., 2004).

2.3.3 Difficulties in Customer requirements evaluation

Tseng and Jiao (1998), point out the difficulties inherent in the customer requirements evaluation process. First, customer requirements are normally qualitative and tend to be imprecise and ambiguous due to their linguistic origins. In most cases, requirements are transferable and may be inconsistent with one another, and thus tradeoffs are often necessary. Frequently, customers, marketing people and designers employ different sets of perspective to express the requirements. Differences in customer feelings and expressions always impair the ability to convey requirement information effectively from customers to designers.
Second, there rarely exists any perfect structure of requirement information. Variables used to describe requirements are often poorly understood and expressed in abstract, fuzzy, or conceptual terms, leading to work on the basis of vague assumptions and implicit inference (Tseng et al., 1998).

Third, the mapping relation between customer needs and Engineering characteristics are often not clearly available at stage of design. Customers' are often not aware of underlying coupling and interrelation among various requirements with regard to product performance. It is difficult, if not impossible, to estimate the consequences of specifying different requirements (Clausing, 1994).

Fourth, the specifications of requirements result from not only the transformation of customer requirements from those end users, but also considerations of many engineering concerns (Madeleine E et al., 2002). In practice product development teams must keep track of myriad of requirement information derived from different perspectives of the product life cycle, such as product technologies, manufacturability, reliability, maintainability, and environmental safety.

2.3.4 Understanding Market and customer Needs

A number of customer-related marketing approaches have been reported to the increasing importance of customers in today's business environment. These approaches include, for instance, customer satisfaction, customer marketing, customer-lead method, customer-driven evolutionary systems, and customer loyalty. Customer relationship management has become a focus in today's product development research (Bailetti, 1995).

Anthony W et al., (2002) advocate a customer marketing strategy for identifying, acquiring, keeping and developing customers through formulating a customer pyramid. While a clear understanding of customers and markets through market research is of paramount importance, there are other factors to consider as well for managing customer requirements in product development (Lancaster et al., 1994).

Bennett (1996) presents that customer group segmentation should be emphasized under the intensifying competition pressures. Barness points out the necessity of quantitative customer preferences evaluation and argues that individual customers should be put in more direct contact with manufacturer or organizations via
a channel using information technologies. In this regard Li Pheng Khoo et al. (2002) developed a customer-oriented information system to establish a closer link between product re-innovation and customer involvement in product conceptualization.

Guinard (2001) proposes the micro and macro perspectives to explain the different ways in which customer preferences are evaluated. From the micro perspective the functional correlation between customer requirements and design specifications is largely influenced by engineering considerations.

Flavio S (2003) analyses multicultural customer factors to support organizations to recognize individual customer needs better and to interact with customers directly.

A decision support system for product design presented by Lida Xu et al., (2007) compared with the traditional sequential design method and concurrent engineering. Concurrent Engineering is a systematic approach to integrate concurrent design of products and their related processes. One of the key factors to successfully implement concurrent engineering is information technology. In order to design a product and its manufacturing process simultaneously, information on product features, manufacturing requirements, and customer demands must be processed while the design is concurrently going on.

2.3.5 Information Technology

With the ever-improving ease, adaptability and speed of computers and programmable software, it is highly unlikely that any major operation does not use some type of information technology (IT). IT is a popular method for operations to assist in planning and scheduling as well as improve their processes (McClellan, 1997). Some lean leaders have once said that lean and IT are incompatible and should not coexist (Crabtree, 2005). Various methods of IT are used in manufacturing industry, for example, the internet, computer Aided Process Planning, Management Information systems, Automated Material Handling, Flexible Manufacturing Systems, and Computer Automated Manufacturing.

The internet has greatly helped all industries through the use of web-based technologies, By utilizing the internet and web based technologies, companies are
able to quickly respond to customers and suppliers, link or integrate automated systems with customers and suppliers and also provide access of information around the clock. With information and access so readily available to customers, companies need to be able to react quickly in order to meet the customers’ requirements. Manufacturers are choosing to adopt lean concepts into their manufacturing practices and they require systems that can handle the flexibility, complexity, and urgency needed to satisfy the customer demands.

Russell & Taylor (2003), addresses Computer Aided Process Planning (CAPP) as a specialized process planning software that can be modified by an engineer when necessary for the production of new parts. A variant or generative system may be used, where the variant systems allow for modification of the programme and generative systems are created from scratch. Management Information System (MIS) and Manufacturing Intelligence (MI) are used to move all types of information throughout organization (Aberdeen Group, 2006, Russell, 2003).

Bartholomew, (2005) recommended, IT is able to help in lean manufacturing by aiding in sequence control, calculating and recalculating the supermarkets and kanban containers and sizes. Creating direct links or integrating between sales, production and supply resources, and shipping responding to changes in demand, implementing schedules and providing visual information, which aids in decision making. Some software vendors has added lean modules into their existing packages and have created lean-specific applications.

2.3.6 Customer Needs Evaluation

The importance of understanding the consumer has increased over time. In the past, many companies succeeded without relying on knowledge about consumers’ preferences and behaviour.

Burton and Patterson (1999) state that until the middle of the 20th century, innovation was based on what manufacturers could do and wanted to supply. The majority of new products resulted from technology push innovation, which means that the development of these new products was driven by a technological advance or invention. Later on, the post-war consumer and manufacturer boom led to growing competition between products.
Simply supplying products became insufficient to maintain competitive advantage. Hence began the systematic investigation of consumers to discover what they wanted and what was most important to them. In this market pull model of innovation, it is suggested that companies should focus on the markets they serve (Claeys et al., 1995, Franke, 2004). Since that time, many methods and techniques have been developed to help product developers improve the quality of their decisions. The availability of these methods and techniques, however, does not mean that they are generally accepted and used in the NPD process.

Miller and Swadding (2002), pointed out that even though the widely accessible research and modelling approaches for NPD, many are not widely employed. Nijssen and Bailetti, 1995 investigated the use of methods and models for NPD within a sample of small industrial companies. In general, the use of NPD methods is not widespread. Besides their low use, many methods are not used in a focused way. Instead of their intended use for specific stages (e.g. idea generation, product optimization, etc.), practitioners apply them to other stages and problems.

Product life cycles are becoming shorter, which leads companies to reduce the time it takes to introduce new products at the market. Person early is generally believed to gain a significant competitive advantage. Companies that take too long in bringing new products to the market run the risk that others will get there first, or that consumer needs and wants will change. Consumer research is time-consuming and extends relatively then shortens the NPD process. Moreover, consumer research requires additional resource investments (Miller and Swaddling, 2002).

Consumer preferences evaluation must often be used by both marketing and R&D. Both marketing and R&D employees often complain that they have difficulty understanding each other. One of the reasons for this misunderstanding is that marketing has its own set of technical terms, and so has R&D (Nick Oliver et al., 2004).

As a result, consumer preferences evaluation can be difficult to comprehend. Comprehensibility of information is the ease with which the receiver can decode and fully and unambiguously understand the information (Nick Oliver et al., 2004).
2.3.7 Structure of data collection

Michael Z. Brooke et al., 2004 addresses the way data is collected in consumer studies varies substantially in its level of structuredness. Structure is the degree of standardization imposed on the data collection instrument. In highly structured data collection, the questions to be asked and the responses permitted are completely predetermined. An advantage of the structured task is that the obtained responses are directly in quantitative terms and require no further subjective interpretation.

Kenneth B. Kann, 2001 observed that, structured data collection offers advantages like more speed in data analysis, lower costs and more convenience for respondents. However, the designer must have a good feel for the range and types of responses, so that meaningful and valid response categories can be constructed.

In a highly unstructured questionnaire or interview, the questions to be asked are not necessarily presented in exactly the same wording to every participant and participants are free to respond in their own words. The advantages are that in-depth and detailed responses can be queried for, which may provide the designer with new insights and ideas for the NPD process.

2.3.8 Analytical Hierarchical Process Approach

The AHP approach was developed in the early 1970s in response to military contingency planning, scarce resources allocation and the need for political participation in disarmament agreements (Saaty, 1994). All these problems rely heavily on measurement and tradeoff to elicit performance opinion from decision makers. Its methodological procedure can easily be incorporated into multiple objective programming formulations with reference with interactive solution process.

The AHP approach involves decomposing a complex and unstructured problem into a set of components organized in a multilevel hierarchic form. A salient feature of the AHP is to quantify decision makers' subjective judgements by assigning corresponding numerical values based on the relative importance of factors under consideration and synthesizing the judgements to determine the overall priorities of variables (Saaty, 1994)
The AHP has been proposed in recent literature as an emerging solution approach to large, dynamic and complex real world multi-criteria decision-making problems (Stan Lipovetsky 1996).

An early survey provided over 200 known AHP applications (Zahedi, 1986). The AHP has also been applied in a variety of formats such as: the design tool for large scale systems or composite ratio scales, the instrument for pairwise comparison in the application of artificial neural networks (Chad M. et al., 2008) and the primary structure of decision support system (Lee et al., 2008).

Carlsson, (1995) proposed An AHP approach to determine the optimal facility location site among alternatives under multiple criteria. Yang Taho and Chunwei Kuo,(2003) identified objective coefficient and parameter values in multiple-objective LP problems used in site selection

Jiaqin Yang and Ping Shi (2002) proposed the AHP for evaluating firm’s overall performance, especially for firms under its unique economy, financial and marketing conditions in China.

Dyer (1990) have been raised some concern regarding the AHP for the arbitrary ranking occurred when two or more alternatives have similar or quasi-similar characteristics or the rank reversal caused by the addition or deletion of alternatives. These undesirable effects, however, do not invalidate the AHP method, argued by Harker & Vargas (1987) and Saaty & Vargas (1993).

Perez et al., (1995) argued that, almost all ordinal aggregation methods exhibit rank reversal. It has been shown that the rank reversal will not be a problem in real world applications because it is very rare to encounter two alternatives with very similar characteristics, and special precautions (e.g., grouping similar alternatives) can easily be taken to avoid any rank reversal (Saaty & Vargas, 1993).
2.4 DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) is one of the most popular tools in production management literature for performance measurement, while the analytical hierarchical process (AHP) is a popular tool in the field of multiple-criteria decision-making (MCDM). MCDM has been succinctly defined as making decisions in the face of multiple conflictive objectives. (Zions, 1992).

The term 'Decision Making Unit (DMU) was used for the first time in the CCR model proposed in Charnes, Cooper and Rhodes (1978). The term DEA (Data Envelopment Analysis) was introduced in their report “A Data Envelopment Analysis Approach to Evaluation of Program flow Through Experiment in U.S. Public School Education (1978). DEA originated from efforts to evaluate results from an early 1970’s projects.

John Doyle and Rodney Green (1994) examined an LP/DEA-based techniques for establishing an overall ranking of alternatives that are ranked on multiple criteria, which themselves are ranked. This two stage process involves one LP in the first stage and Number of LPs in the second stage to rank N alternatives.

William M Bowen (1990) discussed on using subjective judgments as reflected in a analytical Hierarchy Process (AHP) of site selection, a comparison is made to an objective data envelopment Analysis (DEA) selection procedure.

Sueyoshi T. (2001) highlights the relationship between DEA and Multi-Criteria Decision Analysis (MCDA), “Indeed in common with many approaches to multiple criteria analysis, DEA incorporates a process of assigning weights to criteria”. Ranking is common in MCDA literature, especially when we have a discrete list of elements or alternatives with single or multiple criteria which we wish to evaluate and compare or select. Various approaches are suggested in the literature for fully ranking elements, ranging from the utility theory approach (Keeney Raiffa, 1976) to the AHP developed by Saaty (1994).

Zilla Sinuany-stern et al., (2000) presented a two stage model for fully ranking organizational units where each unit has multiple inputs and outputs. In the first stage, the Data Envelopment Analysis for each pair of units is applied separately. In second stage, the pairwise comparison matrix generated in the first stage is utilized to rank
scale the units via AHP. And also checking of the consistency of this AHP/DEA evaluation can be done statistically.

Jen Shang et al., (1993) addressed the problem of selecting the most appropriate Flexible manufacturing system (FMS) for a manufacturing organization. A unified framework is proposed to facilitate decision making in the design and planning stage. The recommended framework contains three individual modules such as an Analytical Hierarchical Process, a simulation module and an accounting procedure. These modules are unified through an efficiency measurement method called Data Envelopment Analysis.

Yang Taho et al., (2003) proposed an analytical hierarchical process and data envelopment analysis approach to solve a plant layout design problem. A computer-aided layout-planning tool was used to generate a considerable numbers of layout alternatives as well as to generate quantitative decision-making unit outputs. The qualitative performance measures were weighted by AHP. DEA was then used to solve the multi-objective layout problem.

As Per Seifert, L.M et al., (1997) investigation excess and deficits in Chinese industrial productivity for the years (1953-1990) are studied by combining data envelopment analysis with other management science approaches improvement factors like incorporation of a prior information through Delphi, AHP and assurance region (AR) techniques. Various multiple input and output sets are selected to study overall performance, industrial development, and product-related efficiency of Chinese industry.

As per Finn R. Forsund (2002), the standard DEA model can be applied to mix of categorical and continuous variables by entering all combinations of them as different types of inputs and/or outputs and also theoretical implications for the nature of feasible peers.

2.5 FUZZY ANALYTICAL HIERARCHICAL PROCESS IN PRODUCT DESIGN

In the traditional formulation of the AHP, human’s judgments are represented as exact (or crisp, according to the fuzzy logic terminology) numbers. However, in many practical cases, the human preference model is uncertain and decision-makers
might be reluctant or unable to assign exact numerical values to the comparison judgments. For instance, when evaluating different services, the decision-makers are usually unsure in their level of preference due to incomplete and uncertain information. Since some of the service evaluation criteria are subjective and qualitative, it is very difficult for the decision-maker to express the strength of the preferences and to provide exact pairwise comparison judgments.

Kristin L et al., (1992) introduced the fuzzy set theory to deal with the uncertainty due to imprecision and vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objectives with a continuum grades of membership. Such a set is characterized by a membership function, which assigns to each object a grade of membership ranging between zero and one.

Numerical data obtained across a human subjectivity are called fuzzy data. The motivation for the use of words or sentences rather than numbers is that linguistic characterizations are, in general, less specific than numerical ones. (Shih-Wen & Hsiao, 1998).

Bellman and Zadeh (1995), have compared different methods to incorporate and manage imprecision available in engineering design decision-making processes. Similarly, Gungor, Z. and Arikan, F. (2000) affirmed that fuzzy set theory is applicable to the earliest stages of preliminary design evaluation under multiple attributes or in situations based on a semantic assessment of relative performance levels. They proposed the application of fuzzy set theory to a multiple-attribute engineering design evaluation process.

Wang (1999), followed a similar procedure for engineering design evaluation and QFD. Hsiao (1998) used a generalized weighted mean in the design for assembly and decision-making stages respectively, to evaluate candidates with respect to several attributes.

Shih-wen Hsiao (1996) proposed a fuzzy decision-making method for selecting an optimum design from design alternatives. The evaluation objectives are arranged in hierarchical structure with several levels. The relative contribution (weighting function) of each objective to all the overall value of the solution and
rating or degree of approximation of a solution with respect to given objective are qualified with membership functions of a fuzzy set.

The fuzzy AHP method, which combines AHP and fuzzy logic, allows a more accurate description of the decision making process. The earliest work on fuzzy AHP is due to Bellman (1995) who compared fuzzy ratios described by triangular membership functions. A logarithmic least square was used to derive the local fuzzy priorities. Later, using a geometric mean, Bellman (1995) determined fuzzy priorities of comparison, whose membership functions were trapezoidal. Kwong (2002) proposed a simple, improved approach using fuzzy logic. Because of the accuracy obtainable by using the fuzzy AHP method in the decision-making process, it has been applied to many different areas.

Some of its applications to various engineering fields are now presented with a focus on those cases in which fuzzy AHP is used in concept selection. Kwong and Bai (2002) recommend the use of a fuzzy AHP approach to determine the importance weights of customer requirements in QFD. Kwong and Bai (2002) have shown that the determination of importance weights for customer requirements in QFD can be performed using a fuzzy AHP with the extent analysis approach.

Weck et al. (1997) evaluated alternative production cycles using the extended fuzzy AHP method. Lee et al. (2001) proposed a fuzzy AHP approach in modular product design and presented a case example to validate its feasibility in a real company. Furthermore, there are some examples in the open literature where AHP and simulation techniques have been used together to solve various MCDM problems.

2.6 TEAM FORMATION

Designs of teams are multidisciplinary groups composed of members representing many engineering disciplines. Specialists from various disciplines (e.g. Manufacturing, Design, Reliability etc) are gathered to develop a new product.

The Project groups include formal but temporary assignments to groups, committees, and special projects. After a project has been completed, project group members return to their routine activities or go to another temporary project group. To reduce the project complexity, one way to build teams is to decompose large, complex
design processes and project organization into a set of smaller task groups corresponding to different teams.

Several team building applications exist in research literature concerning different engineering management issues, such as design project management, production management and construction management. In this work, it is focused on the team building applications in the field of new product design and development.

According to Chen and Li (2002), a team should consist of several designers with dissimilar technical backgrounds and skill, contributing to design task as part of the whole design project. It is predictable that essentially, a team model should represent the interdependence between teams such that team has its own objective and constraints for distributed design problem.

Array-based clustering methods could be efficient in order to group the tasks and the actors into families simultaneously. In the engineering design project field, Chen and Li (2002) proposed an integrated methodological framework in team member assignment.

In the software development project field, Gronau et al. (2006) developed an algorithm to propose a team composition for specific task by analyzing the knowledge and skill of the employees. This method is based on Knowledge modeling and Description Language (KMDL). Tsai et al (2003) implement a critical resource diagram (CRD) and the Taguchi method, in order to select the right team members for the software development project.

In the project management field, De Korvin et al., (2002) developed a personnel selection model for a multiple phase project. The "fuzzy compatibility" method is used to select potential team members for project phase.

Durmusoglu et al., (2008) proposed a team building process using axiomatic design principles. After fixing the families, the selection of those team members who will process the information and the planning of their skill development are determined according to the specifications of the families. Therefore, the procedures applicable to members are formed first. Then the skill development procedure is prepared to ensure maximum utilization of team members' talents.
Caron et al., (1999) taken an interest in the classic assignment problem recognizing qualification. In their work on a particular version of the assignment problem with side constraints, Caron et al., (1999) used a mathematical model for a variation of the classic assignment problem in which there are m agents and n tasks, not every agent is qualified to do every task, and the objective is utility maximization.

Campbell and Diaby (2002) proposed an assignment heuristic for allocating cross trained workers to multiple departments. This paper is concerned with solving a mathematical programming problem that models a multi-department, labour-intensive service environment, such as that faced by hospital nurses. Factors to consider in making such allocation include demand levels in various departments and the capabilities of available workers.

Wu (2007) provided a framework for a fuzzy linear programming model for the function management division dealing with manpower allocation within matrix organization. The proposed model reveals how the function management division seeks a minimized costs and satisfies the requirements of functional departments under limited manpower and project cost.

Peters and Zelewski (2007) developed a model for the assignment of employees to workplaces. Employees will be assigned to workplaces according to their competences and preferences to ensure that motivated employees carry out tasks effectively and efficiently. Two-goal programming models are introduced with input valuation using analytical Hierarchical Process.

Eiselt and Marianov (2008) proposed a model for the alignment of tasks of employees when several goals are to be considered, and when there constraints exist regarding employees capabilities. They define a skill space, in which each dimension represents a skill or ability. Each employee can be mapped into this space, his/her position representing the level acquired in each skill. Similarly, tasks can also be mapped into the skill space, and their position will represent the required level in each skill. After feasible task assignments are determined, tasks are assigned to employees.
2.7 MODULARIZATION IN PRODUCT DESIGN

Product architecture is the scheme by which the performance quality (function) of a product is allocated to physical components (Ulrich, 1995). In a modular product, the mapping from performance to components is one to one. Properties of complex modular systems have been studied in detail with respect to coordination and localization of functions (Sanchez and Mahoney, 1996).

Baldwin and Clark (2000) argue that modularization adds to the real option value of any products design. While integral products have to be redesigned and tailored for each application, modular architectures can be used as platforms because of their flexibility in several variations of the basic product (Sanchez and Mahoney, 1996).

Product modularity also induces economics of scale due to component commonality, and these production efficiencies have be factored into product line decisions (Kim and Chhajed, 2000). Other advantages of modularity arise from the ability to reuse previously designed components, save product design lead time and costs in logistics, and focused knowledge development. In spite of the advantages of modular systems, integral product architecture is preferable under certain circumstances (Ulrich, 1995).

Hsuan (1999) proposed that time could be used as an effective medium to price discriminate with one product in a vertically differentiated market. When a firm produces multiple products to discriminate in such a market, low end customers exact a negative externality on the firm’s ability.

As per Yuval Sered and Yoram Reich, (2006) modular innovation can be more effective than systematic innovation because of the ability of the organization to transfer accumulated knowledge across successive generations of new products, resulting in durability of the platform and wider variety of models developed in short span of time.

As an alternative to restraining innovation, Paschalina (2002) showed that by foregoing its ability to offer its preferred or installed base customers a special upgrade price for the improved product, a firm will be able to suggest to its customers that their purchase decisions in the first period will not be unduly used to the firm’s
advantage. Though this solution is applicable to markets where identifying the buyers of the basic product is impossible, special upgrade prices are an important tool for firms to encourage its installed base to make repeat purchases in many industrial settings.

Modular product architectures are flexible platforms, which enhance the scope for creating a large number of product variations, enabling a firm to gain cost savings through economies of scale from component commonality, inventory and logistics. Some reasons for product change include upgrade, add-ons, adaptation, wear, consumption, flexibility in use, and reuse.
2.8 CONCLUDING REMARKS

Detailed studies on various interlinked elements of Lean Manufacturing and Product design methods have been presented for consumer preference evaluation for opportunity identification which reflects a more creative, pro-active side of product development as a complement to confirmative research. Unfortunately, most NPD methods focus on solutions to consumers' current problems and limit themselves to continuous innovation. The difficulties that consumers have with expressing their needs and evaluating the potential of new products do not mean that consumer research should be left out.

There is clear void in literature in indicating evaluation methods such as including additional layer without disturbing the existing hierarchy to overcome the major limitations of AHP (Rank reversal and large number of alternatives). Integrating DEA with fuzzy logic results to analyse for ranking or computing efficient and inefficient assembled systems for Benchmarking. Integrating DEA with conventional method team formation for computing team members effectiveness with available inputs.

Lean product development comprises numerous interrelated techniques, including supplier involvement, cross-functional teamwork, and integration (as opposed to coordination) of various functional aspects of each project. A successful move toward lean product development requires approaching these interrelated techniques as elements of a coherent whole (Ping-Kit Lam, et al., 2005). Lean product development is in general achieved through an integrated approach that involves the customers and their preferences, suppliers involvement and cross functional design teams of the firm.