CHAPTER – VIII

CONCLUSIONS

8.1 SUMMARY OF FINDINGS AND CONCLUSIONS

In this chapter, the key aspects of this research are summarized and conclusions are provided. The contributions of this research are addressed and scope for future research work presented.

Lean manufacturing is a business philosophy that continuously strives to shorten the time between a customer order and its shipment by eliminating all those activities that increase the cost and time. Lean manufacturing requires that all the wastes are identified and eliminated from the system. Some of the wastages that exist during manufacturing include waste of inventory, time, materials, idle time of machines, unnecessary movement of material, waste of capital, etc. A large number of industries implement Lean tools such as Value Stream Mapping, 5S method, Kanban etc. However, these techniques which are well developed address problems during manufacturing. However, many of these wastages can be reduced through proper product design that employs Lean Principles.

Lean Product design aims to reducing all possible waste during product design and development. For successful Lean product design, wastages that occur during design and development such as waiting, Transport, inefficient transmittal of information, over processing of information, etc. are reduced. Lean Product development comprises numerous interrelated techniques such as customer/supplier involvement cross functional team formation, etc.

Lean Product development is achieved through an integrated approach that involves the customers and their preferences, suppliers’ involvement, and design of cross functional teams. The success of new invention depends on the ability of designers in identifying needs and evaluate quickly for creating new products that minimizes product development time. Therefore, the present thesis addresses the problems involved in Lean product design and development with the following specific objectives:
**Objectives of the thesis:**

1. Study of the Lean Manufacturing Principles, different types of waste incurred in Manufacturing and product design, customer preferences evaluation methods and their limitations.
2. Study the customer preferences evaluation methods and to develop Analytical Hierarchical Process as method for incorporating structured, quantitative and qualitative preferences in product design.
3. Validate the AHP results and to overcome the limitations of AHP method through Data Envelopment Analysis approach.
4. Incorporate customer vague information through Fuzzy logic, and integrate it with AHP model for avoiding repeated data collection from the customer. Also to develop Fuzzy DEAHP for ranking alternatives.
5. Study of team formation in Product development and develop methodologies for team formation.

The thesis is organized and presented in eight chapters.

The FIRST chapter is a general introduction and describes the Lean principles of manufacturing and focuses on Product design and development, identifies the significance of Product design and development with customer’s information.

A review of literature is presented in the SECOND chapter. It includes review on Lean Manufacturing, implementation of Lean Principles in Product development, New Product development, Lean Product development, Analytical Hierarchical Process, Data Envelopment analysis, Fuzzy logic approaches in Product development, Modularization and Product design team formation. The various works carried out in the area of Lean manufacturing are reviewed in section 2.2. A review of Product design and customer integration methods, Analytical Hierarchical Process approach for product development is presented in section 2.3. The Data Envelopment Analysis review, and its importance to integrate with AHP is presented in section 2.4. Section 2.5 contains review on fuzzy logic importance to integrate Multi Criteria Decision Making Problems. The Team formation review is presented in section 2.6. And literature review on modularization is presented in section 2.7. In the final section 2.8 concluding remarks is presented.
On the basis of the review of literature it is inferred that Lean product development comprises numerous interrelated techniques, including customer integration, supplier involvement, cross-functional teamwork, and integration 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. Lean product development is in general achieved through an integrated approach that involves the customers and their preferences, supplier’s involvement and cross functional design teams of the firm.

The Chapter-III describes Customer requirements and their preferences evaluation methods, and introduces Analytical Hierarchical Process Approach in Product design and development. Two types of data are available from customer; one is unstructured data (Interview) and second is structured data (Numerical data). For fast analysis, structured data is more valuable and is suitable to Quality Function Deployment. Quality Function Deployment is the familiar method for Product designers with structured data but customers and designers have used different templates of data gathering and analysis. Designers identified customer needs in the form of product attributes and updated the current product. The data transferring from customer template to QFD matrix is a time taking process. In Lean product design, multiple data transfer is the waste that can be overcome by using AHP method, because customer and designer use single template for answering and analysis, respectively. Hence, AHP is preferred for consumer preferences evaluation in lean product design.

An application of AHP method to integral product (single piece) of Cell phone is presented in section 3.5.4. AHP calculations, which are laborious, when implemented on a spread sheet not only become easier but also permit check the consistency of the data. It also points out the inconsistency in judgement that occur at a single pairwise comparison. Hence, corrective action for inconsistent judgement is possible because of spread sheet. The spread sheet finally computes the Consistency Ratio (C.R). The various calculations involved in the AHP are automatically calculated with use of excel functions, is presented in section 3.5.5

As per Lean product development which focuses to minimize the wastages like unnecessary paper documentation, over processing, and so on, with the use of
Excel software, all the works are done in fully transparent manner, to minimize the calculation time and easy to discard inconsistent pairwise comparison matrices.

In 3.5.6 section of this chapter an application of AHP method to assembled product of customized computer assembly with multi layers is discussed. This attempt is discussed in two cases; first case is normal AHP weights calculation and finally computes global priority weights of six assumed systems of different configuration. The same procedure was followed, that is spreadsheet was designed for easy discard of the inconsistent pairwise comparison matrices.

The inclusion of additional layers (functional criteria) into the hierarchy of the AHP without disturbing the existing hierarchy is discussed in section 3.6, such additional layers may be needed at later stages for enhancing the product performance. The method involves adding the additional pairwise comparison matrices, and the consistency ratios are checked through the same spreadsheet that is integrated with the AHP and goal programming (GAHP). The composite weights of last layer in the hierarchy are considered as goals, which are alternative performances with respect to product criteria. For demonstrating, two alternatives from each module are considered and the performance of all possible configurations checked. In the present case a total number of systems are (16), considered as decision variables, a total number of goals (4 modules x 2 alternatives x 3 criteria) is 24 and the number of constraints (24 goals + 1 for system) is 25. TORA optimization software is used for solving the problem and computed the best configuration among assumed systems is determined.

The AHP methodologies together with the spread sheet developed, and the consideration of additional layers with the help of Goal programming (GAHP) facilitates the lean product design and development than other methods of incorporating customer preferences. Additional validation methods to validate AHP methodologies may be developed to enhance the applicability of AHP. Also, when a large number of decision alternatives have to be evaluated, a large number of pairwise comparison matrices have to be obtained which is difficult, costly and time consuming. To overcome these difficulties a new method called Data Envelopment Analysis is developed and integrated with AHP. These details are discussed in chapter-IV.
The Chapter-IV discusses Data Envelopment analysis (DEA) in Lean Product Design (LPD) as an integrating approach to Analytical Hierarchical Process (AHP). This chapter is divided in two sections, one is to validate the AHP results computed in Chapter-III, and the second is to integrate DEA with AHP to overcome the major limitations of AHP. In chapter-III, the application of AHP to evaluate customer preferences in fast manner is considered. Many a times it is always better to validate the results obtained. This is achieved through the employment of DEA in addition to the existing methods.

Section 4.4 discusses the development of DEA and its use to validate the AHP results. DEA is a method that tries to find the relative efficiency of homogeneous competing Decision Making Units (DMUs). The method considers the inputs and outputs of each DMU and by employing Linear Programming methodology arrives at the relative efficiency of DMUs. DEA method is applied for computing local weights from a consistent judgement matrix. Efficiency calculations using DEA require outputs and inputs. Each row of the judgement matrix is viewed as a Decision Making Unit (DMU) and each column of the judgement matrix is viewed as an output. Since DEA calculations cannot be made entirely with outputs and require at least one input and for the problems considered only outputs are available and no input is available, a dummy input that has a value of 1 for all the DMUs is employed. For finding the best criteria, the same pairwise comparison table is used to formulate the objective function and constraints with DMUs as criteria in a Linear programming format. The model is developed is presented in section 4.2.

Both AHP results and DEA results obtained from AHP input is presented in section 4.2.6. Rank Correlation coefficient is computed, and it shows ranking alternatives through both methods are very close, and the rank correlation coefficient is 0.800. Hence, DEA is most suitable tool for validating AHP results.

The section 4.4 of Chapter-IV discussed DEA as a method to overcome the major limitation of AHP model. Only five cell phone models (decision alternatives) are considered in the AHP application. The traditional AHP supports a very limited number of decision alternatives, which is usually not more than 15. When there are hundreds or thousands of alternatives to be compared, the pairwise comparison matrices to be provided by the traditional AHP is obviously infeasible. The proposed
integrated **AHP-DEA** methodology uses the AHP to determine the weights of criteria in the first layer. Next, data is obtained from the customers in linguistic terms, such as, E - Excellent, V- Very Good, G- Good, M - Moderate and P- Poor for all decision alternatives against all criteria. The DEA method is then employed to determine the values of the linguistic terms. Therefore, instead of using saaty scale for filling pairwise comparison matrix, customers are asked to give grades for all the alternatives with respect to each criterion. In addition to a substantial reduction in the number of pair-wise comparison matrices, the time taken for filling the data sheet is shorter than AHP pairwise comparison template.

TORA optimization software is employed for solving the LPP to obtain optimal weights for each of the five grades. The procedure is repeated for each of the six criteria. Finally, for each decision making unit a composite weight is obtained that utilizes the optimal values of the LPP and the data supplied by the customers. The DMUs are ranked in the descending order of composite weights.

DEA method is used for ranking 17 cell phone models instead of AHP to reduce 17 pairwise comparison matrices of size 17. Such a big matrix computations is time consuming process in AHP method and customer feel uncomfortable for answering pairwise comparison questionnaire. Therefore, the developed model is useful for evaluating large number of alternatives and facilitates the customer to answer in comfortable manner. In DEA process, customer asked to give linguistic measures viz., Excellent, V.Good, Good, Poor and Very Poor instead of Saaty ranking (1 to 9). Hence, Customer feels more comfortable to express his preferences than AHP method. Therefore developed DEA model facilitate designer to analyze more number of products of same group. In addition, if an alternative is eliminated from consideration, then the new ordering for the remaining alternatives should be equivalent (i.e same ordering) to the original ordering for the same alternatives. In the developed DEAHP model, the weights of alternatives (i.e the efficiency scores) are calculated separately for each alternative using separate linear programming model. The traditional AHP uses arithmetic normalization (sum of all alternatives is equating to one), no such normalization is done in DEAHP. Further, the DEAHP weights are calculated relative to the weight of best rated alternative. Therefore, the DEA model in Linear programming format has flexibility to add alternatives for evaluation.
process without disturbing the other alternatives efficiencies that is not possible in AHP method.

The Chapter-V presented Fuzzy based analytic hierarchical Process (Fuzzy-AHP) to efficiently tackle both quantitative and qualitative decisions involved in the selection of design of product, which satisfies customer needs. A fuzzy logic-based approach is employed to handle the vague, imprecise and uncertain information and fuzziness preferences of a customer regarding a module or subsystem. This chapter discussed in two sections viz., application of fuzzy logic approach for AHP problem with crisp data from the customer regarding his requirements of criterion and second is an integration of DEA with Fuzzy AHP for ranking the alternatives.

The section 5.3. of Chapter-V evaluates customers’ fuzzy preferences. MATLAB’s fuzzy logic module is used for performing this work. Mamdani FIS (Fuzzy Interface system) editor is used for creating the file. The fuzzy sets for each input and output variables and their linguistic values (levels) have five levels. However, in the current problem the input variable is a module of computer assembly, levels are equal to available number of alternatives under each module, and it is an attempt to introduce different levels of input variable (Venkatamuni & Rao, 2010). The computer assembly for demonstration of GAHP of Chapter-III is considered for this attempt. Computer assembly has four modules that is Monitor, Processor, Graphic card and Sound card and these are the input variables and levels are existing alternatives under each module. The output variables are reliability, cost and ease of assembly with five levels, which are Excellent, Very good, Good, Poor, Very Poor. The level of each input variable is an alternative. The various levels of input variables under each module are transferred to Triangular fuzzy numbers (TFN) based on AHP weights. The membership function rules are framed, using IF- THEN rule based format (5 monitors x 4 Processors x 3 Graphic cards x 3 Soundcards = 180 rules). These rules are constructed from the priority weights, instead of using fuzzy set theory to reduce more time in computation of fuzzy weights.

Hence, this method leads to reduction of product design wastages like repetition and over processing of customer information. The performances of systems of different combinations of modules with respect to output variables (Reliability,
Cost, and Ease of assembly) after fuzzification are viewed and analyzed in graphical manner therefore, this type of approach is more suitable for Lean product design.

The section 5.4 discussed the integration of Data Envelopment analysis (DEA) with fuzzy logic results to analyses for ranking or computing efficient and inefficient assembled systems for Benchmarking. DEA is used for computing efficiency of set of homogeneous units with inputs and outputs for 25 systems is considered from the rule editor. DEA maximization output model is used for solving this problem. TORA optimization software is used for solving and ranking the alternatives based on the efficiency of each DMU (System. Hence, this is an attempt to integrating DEA to fuzzy AHP process for computing very clarity results than fuzzy approach, so we conclude that DEA is most suitable for analysis the fuzzy result, and is a new Fuzzy DEAHP integration method for Lean Product design.

The Chapter-VI discussed the problem of Team formation in Lean Product design. The application of a combined AHP and integer programming models is presented as an alternative to existing methodologies. Also an attempt is made to compute various team members' efficiencies through DEA approach.

The section 6.3 of Chapter-VI discussed the development of product development teams with different specializations as per engineering characteristics by using Analytical hierarchical Process. The multi-functional teams' formation problem is formulated as an integer programming model and is presented in section 6.3.1. The model is based on the engineering characteristics-team member type priority incidence matrix. The number of teams and number of types of specialization are the major constraints in this study. TORA optimization software is employed for solving this IPP problem to obtain team members of each team (Venkatamuni, and Rao, 2010).

The section 6.3.2 of Chapter-VI discussed, DEA as a method to compute efficiencies of various team members with respect to performance matrix obtained in the section 6.3.1. The composite weights of engineering characteristics with respect to team member are converted to outputs, the number of people available in each specialization is input and Specialization of team member is considered as Decision Making Unit (DMU). TORA optimization software is employed for solving the LPP
to obtain efficiency of each specialization in the concern product development. It is an attempt to know the team members effectiveness in team formation.

The developed model permits a great amount of flexibility in the formation of teams, i.e one can add an additional factor to the team selection hierarchy and perform the analysis without restricting the entire model. Similarly, the factors can be removed when necessary. Hence, the developed model facilitates designer to compute team members as per availability constraints like budget, Team size, Time, Space, etc. Each factor is separately adding the constraints to main problem without disturbing object equation, which is obtained from AHP preferences matrix.

The Chapter-VII discussed the concept of modularization as applied to product design has been studied along with mathematical modeling to theoretically examine and simulate a given system. Among the various approaches of mathematical modeling available, the one based on the parameters of interface constraint factor and supplier development index is used and presented in section 7.3.3.

The method involves computing various modularization function values at different stages with respect to supplier buyer partnership index. Mathematical model is studied from the literature and with excel functions a spreadsheet is assigned for computing the modularization function values and it is presented in section 7.3.4. The model involves non linear relationship between modularization and interface constraints which is characterized by the number of components and respective interfaces. One of the main emphasis is to demonstrate that a change in the interface compatibility at one level of analysis can have significant impact at their levels in short period of computing time.

The approach presented in Chapter-VII is an alternate tool for Design For Manufacturing (DFM) that computes number of components, numbers of interfaces from designed spread sheet. It is more flexible to integrate components to modules in the presented approach than traditional DFM methods.

8.2 SIGNIFICANT CONTRIBUTION OF THE THESIS

The following are some of the important contributions of this thesis

1. Study of many methods of customer preferences evaluation methods and identification of AHP as the preferred application tool for minimizing product
design lead-time, as the evaluation process is coming under category of Multi Criteria Decision Making Structure (MCDM).

2. AHP consumes more time to address issues related to more number of alternatives and criteria. To overcome these major difficulties of Analytical Hierarchical Process, Data Envelopment Analysis (DEA) model is developed for evaluating large number of alternatives with customer preferences.

3. Data Envelopment Analysis (DEA) is integrated with Fuzzy-AHP for better defuzzification results than Fuzzy logic approach. The solution obtained from Fuzzy AHP has to be presented in graphical form and is difficult to interpret. The new Fuzzy DEAHP integration method for Lean Product design is developed.

4. The New Fuzzy-AHP introduced for Lean Product design, the AHP weights of both criteria and modules with respect to criterion are transferred to Triangular Fuzzy Numbers for constructing membership function of input variables in Fuzzy logic Mamdani module software.

5. All the above works are designed through Excel spreadsheet for easy and more flexibility of computation of different values at different stages, as complete AHP calculations are based on consistent judgement matrices. Inconsistent customer preferences are discarded from the process, as part of the Lean product design and minimization of repetitive computations.

8.3 SCOPE FOR FUTURE RESEARCH

Although, the thesis endeavors to address some of the problems, still a large scope exists for future contemplation. Some of the issues that may be addressed in any future study include

1. The developed method may be used for finding Alternative manufacturing Process with multiple criteria and manufacturing processes.

2. A real life application by a design team of a manufacturing firm using the methodologies as developed in this thesis brings out the practical issues involved more thoroughly.

3. DEA can be applied to Variable Returns Scale for validation of AHP results

4. AHP weights can be used and to test the various membership functions other than Triangular Membership Function available in Mamdani for same inputs and outputs.