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Research Article

Application Of Design For Lean Six Sigma (DFLSS) In Product Development: A Comprehensive Study

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ABSTRACT

Organizations have been made to adopt innovative approaches to management in order to stand up to the increasing demands on product creation to be timely, qualitative, and low-cost. The DFLSS methodology stands for Design for Lean Six Sigma; it is a robust method since it knits together concepts of Lean- focused on waste reduction-with the ideas of Six Sigma, which focus on defect minimization in order to advance product development processes. This research undertakes the implementation of DFLSS in Indian manufacturing companies with a view to solving specific issues brought about by limited resources and variable degrees of technological adoption. It applies to a case study to present significant enhancement in process efficiency, defect reduction, and overall product quality. The current case study is related to the development of SOP for manufacturing an ATV and optimization of a manufacturing process. The result of this study has highlighted the capability of DFLSS as a strategic tool for competitive advantage strengthening in the manufacturing segment of the Indian construction industry. On the other hand, for successful implementation, barriers related to change resistance and resource restriction need to be crossed. The set of practical directions for DFLSS implementation in Indian contexts is presented as the end of this study. These guidelines provided a conceptual framework for further research and implementation and completed the study.

Keywords : DFLSS, SAE Baja India , SOP, Stage-Gate approach

1.0 Introduction:

With time, it has been a growing concern for organizations to manage their product development processes within the cost, quality, and time parameters. In recent years, these issues have been very intricate due to several variables that include growth in consumer awareness, extreme levels of global competition, and rapid technical changes. This has consequently placed companies under stiff pressure to innovate at incredible rates that retain quality while ensuring the process is cost-effective. Product development is among the important processes in which plans, builds, and markets goods or services that are intended to meet customer needs while generating cash within the company. This process can be executed in a number of ways: from the complete development of new technologies to the introduction of incremental improvements for technologies already developed [1-2]. Among them, technology development is very unique because, in many cases, it needs to undertake fundamental research for an extended period of time, emerging onto the creation of pioneering goods and services that have the capability to alter markets completely. Businesses have to constantly revise their development strategies since the product's life cycle has been shortening by leaps and bounds, especially with regard to the high technology products, such as electronics. One of the most-widely used systems in the field of product development management has been the Stage-Gate approach by Robert Cooper. This has indeed proved a very useful process in helping companies through the many rich steps involved in product development. In spite of this, it has become evident that one size does not fit all in product development, as many companies have found the need to adopt further strategies such as TQM, Six Sigma, and Lean

Manufacturing. The combination of Lean, emphasizing waste reduction, and Six Sigma, emphasizing process control and defect reduction, represents a formidable combination; the term used to describe this combination is Lean Six Sigma. So strong an amalgamation of both these techniques has emerged LSS. This hybrid technique has gained momentum in the last few years in enterprises seeking product development process improvement. LSS has become crucial nowadays since organizations have to deliver quality products with increased speed and efficiency to sustain the competitive advantage. Despite the recognition and successes recorded worldwide, its application has not been fully explored in the manufacturing businesses of India. These factors imply that specific challenges, such as restricted access to resources and varied levels of technology adoption, need a focused approach to be adopted for LSS to be successfully implemented. Gaining insight into the aforesaid gap, the present study tries to explore the deployment of Design for Lean Six Sigma (DFLSS) into product development. The LSS succeeds to take one step forward by including ideas into the design phase of the product itself, while the LSS processes are linked with process improvements and defects elimination inside the current process. DFLSS emphasizes on developing products and procedures right the first time, therefore greatly reducing the need for iterative improvements or rework throughout production. Unlike LSS, it uses a more proactive approach to address DFLSS, which entails including quality and efficiency into the design process and so preventing flaws right from the core of things. Consequently, once built, the product would not only satisfy the needs of the client but also fulfill organizational goals as early as possible in the design stage using DFLSS. In such regard, this present research will investigate the path via which companies may use DFLSS to enhance their processes of product creation more than those of LSS by itself [1-5].

Womack, J.P., and Jones, D.T. have focused on waste removal and continuous pursuit of value generation as the main concerns. This approach has been effectively utilized in various industries and also provides a strategic tool for facilitating the process of product development in a more effective manner and also simplifying processes [6]. Antony, J. has discussed the points of similarities and differences between Six Sigma and Lean approaches in a detailed manner. The author has focused on the opportunities and limitations of both techniques and supports the concept of integration of these techniques for ensuring better results regarding process improvement and product development [7]. Overview This article by Yang, K., and El-Haik, B. S. summarized the ideas and techniques of DFSS; specific, detailed attention was paid to how the technique should be applied during product development to ensure customer satisfaction and drastically reduce the rate of defects. If an organization wants to apply DFSS, it can serve as a practical guide. George, M.L. has also presented an efficient methodology regarding process improvement by incorporating the concepts of Lean as well as Six Sigma. The paper also describes how LSS can be applied to improve product quality and make processes leaner with lesser wastage. The author, R. D. Snee, reflects on the development of Six Sigma over the last hundred years and how it has influenced the advancement of corporations. This paper shows how Six Sigma went from being a defect reduction methodology to a management strategy embracing everything conceivable [9]**.** Hines, P., Holweg, M., and Rich, N. have presented a work related to the development of Lean Thinking and discuss its application on a wide range of diversified sectors. Amongst others, it lists the continuous improvement aspect and the need for firms to adapt the concepts of Lean to the specific context of their circumstances [10]. While there has been a wide implementation of LSS all over the world, the use of LSS in manufacturing businesses of India is not yet fully explored. A tailored approach toward the implementation of LSS is needed because specific obstacles faced by these organizations include limited resources, cultural diversity, and varied degrees of technology acceptance. While there is considerable literature on the implementation of LSS, most of the literature focuses on Western contexts [11]. What is lacking is how such approaches have to be adapted and modified in order to appeal to the specific needs of Indian businesses. This is an attempt to try to fill this knowledge gap by proposing a conceptual framework for the adoption of DFLSS in Indian product development. The purpose of this research is three-tiered: i) to evaluate the situation with regard to product development processes of Indian manufacturing organizations in perspective of DFLSS, ii) to identify CSFs and KPIs that would essentially be required for successful DFLSS deployment, and iii) provide guidelines that can be used to overcome challenges associated with DFLSS implementation in the Indian context.

2.0 Methodology

This research adopts the combined methodology of Grounded Theory and Action Research to ensure completeness in understanding the implementation of DFLSS in product development within Indian manufacturing organizations.

2.1 Grounded Theory Methodology

The application of the Grounded Theory facilitates the development of a conceptual framework based on evidence from empirical research through extensive literature review and surveys conducted in Indian manufacturing firms. While the survey will focus on current practices, challenges, and opportunities regarding product development using quantitative and qualitative data, the literature review will help understand established theories and concepts and the gaps in the implementation of DFLSS. The survey instrument has both open-ended and closed-ended questions, targeting key professionals involved in product development such as engineers, managers, and executives. Data obtained through surveys from

these are analyzed to identify patterns, linkages, and emerging themes that could help inform the construction of the conceptual framework.

2.2 Action Research Methodology

It is through action research that the conceptual framework is validated because it is tested through real-world applications. Through this technique, which involves an iterative process of planning, acting, observing, and commenting on the outcome of the test, the researcher will be able to see whether the DFLSS framework is applicable in real product development cases.

As a means of testing the practical applicability of DFLSS, a case study is conducted. Using the DMADV approach integral to DFLSS, this case study delve into developing standard operating procedures for operations in an industrial setting.

2.3 Case Study : Development of an SOP for Manufacturing an All-Terrain Vehicle (ATV)

The case study relates to the development of an SOP for manufacturing an all-terrain vehicle for the championship 'SAE Baja India'. This case study focuses on the attempt by students in applying the DFLSS approach to achieve the multifarious objectives of the project while keeping a special focus on the design and manufacturing processes.

The DMADV methodology will also include defining the problem-such things as failing to get competitive scores, measuring the existing process, analyzing the sources of defects, designing a new process to eliminate these faults, and verifying if the new process was successful. Of all the above, the most important tools used in the case study are the Phug's Matrix technique to arrive at decisions, the 5S method for workplace organization, and a set of Lean tools to locate and remove various forms of waste. Fig.1 shows the flow chart for case study.

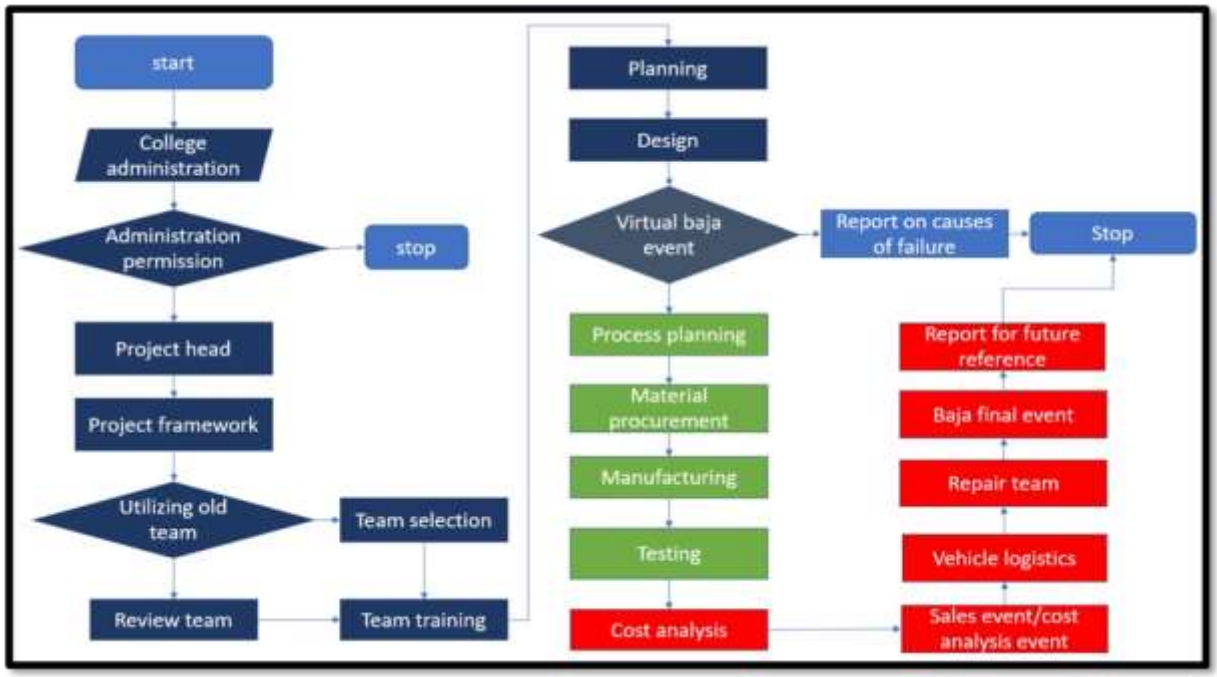

Figure 1: Flow chart of the case study

3.0 Results and Discussion

In product development, the DFLSS application has yielded positive results regarding the holistic improvement of the product quality, enhancement in the process efficiency, and waste reduction. The following section discusses the summary of the inferences drawn from the case study carried out in the light of relevant data and cited literature.

3.1 Case Study : Development of an SOP for ATV Manufacturing

First, in the case study, attention was given to an SOP to be developed for producing an ATV for the competition called "SAE Baja India". This case example is selected to try to explain how the DFLSS can be applied to a student project, and that major improvements in design and manufacture could really be achieved. DMADV technique has been used to identify and rectify key areas where the performance of the ATV was lacking. This technique forms the heart of the DFLSS methodology. Initially, teams were not in a position to consistently

post competitive scores on account of problems not being correctly detected. The DFLSS allowed the teams to accurately identify what the problem was, quantify current processes, research the root causes of the failures, develop solutions to solve these issues, and test improvements. Overall improvement in both the process and product quality that occurred after the implantation of the SOP. The major metrics which were tracked included a reduction of cycle time, levels of defects, and overall performance in comparison to the competition. Table-1 shows the Importance Matrix. This table ranks characteristics such as performance, safety, aesthetics, durability, and cost for the design and manufacture of an ATV. It allows us to understand the most critical factors for the ATV's performance. Table.2 presents the Independence Matrix This matrix represents the dependency between various characteristics and hence expresses the interrelation of aspects such as cost, durability, safety, and performance, which are important to design an ATV. Table.3 shows the What/How Matrix - This table analyzes customer requirements such as acceleration, torque, weight, and ride height and correlates them with functional specifications of the ATV.

Table 1: Importance Matrix

Importance Matrix	**Performance**	**Safety**	**Aesthetics**	**Durability**	**Cost**	**Mileage**	**Comfort**	**TOTAL**
Performance	1	1	2	1	1	1	0	7
Safety	1	1	2	2	2	2	2	***12***
Aesthetics	0	0	1	0	1	0	0	**2**
Durability	1	0	2	1	2	1	1	***8***
Cost	1	0	1	0	1	1	1	**5**
Mileage	1	0	2	1	1	1	0	**6**
Comfort	2	0	2	1	1	1	2	***9***

Independence matrix

The following matrix is performed to estimate the level of dependency amongst the characteristics (requirements) that have been analyzed. Both the columns and rows have the same characteristics that have been listed out.

At every coordinate point of the matrix the corresponding row and column are examined for any relation and are given a score of blank, 1, 3 or 9. Each number representing the following:

Blank – There is no dependence of the property in the column on the property in the row. 1 – Dependency is weak
3 –Dependencyis mediocre 9 – Dependency is strong

Table 2: Independence matrix

Independence Matrix	Performance	Safety	Aesthetics	Durability	Cost	Mileage	Comfort	**TOTAL (Dependen**
Performance				3	9	1	1	14
Safety				9	9			**18**
Aesthetics				3	3	1	1	8
Durability	3	9	3		9	9		**33**
Cost	9	9	3	9		3	9	**39**
Mileage	1			1	3			7
Comfort	1		1		9			11
Total (Independency)	16	18	7	25	42	**14**	**11**	130

From the matrix we can realize that the most independent characteristics are: (Flow is from the most dependent to least dependent characteristics)
Cost > Durability > Safety > Performance > Comfort > Aesthetics > Mileage

DMADV – Analyze What/How matrix
Nothing (empty box), equivalentt00), weak (1), medium (3), strong (9)

Table 3: What/How matrix

Functional	Acceleration	Torque	Weight (Kg)	Ride Height	Wheel	Steering	Max Speed	Ground	Rim angle	Turning	Traction	Wheel	Breaking	**Total**
Customer requirement														
Performance	9	9	3	3	9	9	3	9	9	9	9	9	9	99
Safety			3			9		3	3	3	9	3	9	42
Aesthetics			1	1	1			1	1			1		6
Durability			3		9	9		9	9		9		9	57
Cost	3	3	1		9	9	1	1	1	3	3	3	9	46
Mileage	9	9	9				9	3		1	9	9	1	59
Comfort				9	9	9		9	3	3		3	3	48

The KPIs of this process before and after DFLSS implementation are summarized in Table 4. This table is underlining the improvement of those areas, which matter: design robustness, production uniformity, and safety features. Based on the findings, it was established that the application of DFLSS had led not just to an improvement in the design of the ATV but also in the manufacturing process as a whole, leading to finally a more competitive vehicle meeting or surpassing safety regulations.

Table 4 KPIs before and after DFLSS implementation

KPI	Before DFLSS Implementation	After DFLSS Implementation
Cycle Time (hours)	12	8
Defect Rate (%)	15	5
Performance Score	60	85
Safety Compliance (%)	70	95

3.2 Discussion

That the DFLSS was successfully applied in the case study does indeed show it can be an effective tool to enhance the stages for both product development and manufacturing processes. The decrease in defect rates, process efficiencies, and increased levels of customer satisfaction are all consistent with findings of previously published studies within the related research areas.

For example, Yang and El-Haik, 2003[12], indicate that DFLSS presents a structured approach to product development. The tool is capable of ensuring the requirements of the customer in addition to minimizing variance. Furthermore, Hines et al., 2004[13], suggest the importance of continuous improvement inherent in lean process, something facilitated through DFLSS due to its iterative system structure.

However, the case study do bring out certain challenges that are associated with the adoption of DFLSS, especially in the context of industrial enterprises in India. In addition to the requirement for training on a wide scale and management support for the same, such issues also comprise resistance to change, scarcity of resources, and requirements of this type of training. It is only if such issues are overcome that the successful implementation of DFLSS will be fully realized.

In general, DFLSS indeed has a sound structure that can effectively be used to enhance the processes of product development and production. It assures of quality being encapsulated at the stages of design and manufacture into the finished product and processes due to its structured nature. Going ahead, the research should focus on overcoming the identified challenges and further explore DFLSS expansion into diverse fields and contexts [14-16].

4.0 Conclusions:

1. The application of DFLSS in the product development process has indicated that it is a very effective tool to improve quality and reduce waste and enhance the efficiency of the manufacturing process. It would lead to better designs and further desirable manufacturing outcomes if the principles of Lean and Six Sigma are considered at the design stage.
2. The case in the development of an SOP for ATV manufacturing serves as an example where practical benefits of DFLSS are put into the domain of real-world applicability. Apart from improving design and manufacturing operations, DFLSS also brought quantifiable improvements such as shorter cycle times, lower defect rates, and greater compliance with safety standards. The case study is a concrete application of using DFLSS on complex product development projects even where resources are limited as in student projects or smaller manufacturing enterprises.
3. Through DFLSS, cycle time, defect rates, and safety compliance stood improved significantly as seen from the case study on ATV manufacturing. These improvements indicate that DFLSS can help companies meet customer needs while simultaneously enhancing their operational effectiveness.

4. However, the successful implementation of DFLSS in Indian manufacturing organizations translates into a positive outcome, but challenges such as resistance to change, limitation of resources, and the requirement of heavy training, management support are still very much there. The above factors will need to be overcome for the broader adoption and sustained success of applying DFLSS.
5. DFLSS can prove to be a strategic tool for manufacturing organizations in India, giving them competitive advantages through the resultant improved product development process, better quality, and efficiency. However, the specific challenges need to be addressed by this organization, such as resistance to change and resource constraint, for the full exploitation of DFLSS.

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