A Hierarchical Model Development for Lean Manufacturing and Six Sigma Integration through Axiomatic Design Principles

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Abstract In India, small-scale industrial improvements are slowing not because of less opportunity or knowledge but because of a lack of step by step guidelines to implementing six sigma and lean manufacturing principles. This research work was carried out to develop a model to help implementation by integrating Lean Manufacturing principles and Six Sigma DMAIC methodologies with the help of an FR, DP design decomposition, the key process of Axiomatic Design. This paper presents the resulting guidelines for improving manufacturing systems in production or design. We call the integrated approach to achieve the advantages of both "Lean-Sigma" intended for small scale industry. Practical implementation of the model and AD designed methodology has been validated through a case study triangulation based approach with one production company manufacturing automotive connecting rods. As the main objective of our research was to test if an integrated system Lean-Sigma approach provides value, we chose not to model an entire production system in the case study, but to just test if an axiomatic design generated hierarchical decision structure could make the decision-making process easier.

1 Introduction

Since 1991, the Indian economy is progressively modernizing with its integration into the global economy depending on the growth of small and medium scale industries. On the one hand, globalization has provided unprecedented opportunity for the growth and expansion of Indian industry in general and manufacturing in particular. On the other hand the Indian industry has had to defend from competition from imports while continuing an effort to grow its export competitiveness.

Indian manufacturing industry has largely improved the quality of its products by successfully implementing quality concepts such as TQM, Six Sigma and 5s, but industry still has a long way to go to completely integrate quality across their value stream. This future integration is essential to achieve high operational performance, increased global market share and a higher customer satisfaction in the supply chain [1].

Literature identifies the key features where manufacturing organizations are implementing Lean Manufacturing [2]. Lean manufacturing is implemented to achieve quality, efficiency, flexibility and improved design.

Lean manufacturing provides the set of rules and techniques which make organizations more responsive to rapidly changing markets. These techniques are useful for adapting to today's ever demanding customer. Reducing no value added activities, a first step in Lean manufacturing implementation helps organizations become more flexible. However Lean manufacturing also addresses improved quality and better organization and cooperation in the work place. It facilitates every area of the manufacturing process. It is predicted that Lean manufacturing will supersede current mass production technology and become the next paradigm. The slow rate of corporate adoption is not due to lack of knowledge of Lean. Rather the fault lies in making the transition from theory to implementation. The organization's need to respond to change with stable and long-term, yet flexible and responsive, process capabilities is greater than ever before [3]. According to George, the principle of Lean-Six Sigma is that activities that create the customer's critical-to-quality issues and longest time delays in any process offer the greatest opportunity for improvement in cost, quality, capital, and lead time [4]. Six Sigma does not directly address these Lean metrics. So the lack of improvement in lead-time in companies applying six sigma methods alone is understandable. In a similar manner, those companies engaged in Lean methodology alone show limited improvements across the organization due to the absence of Six Sigma implementation culture. According to Smith, Six Sigma projects take months to finish, and the training produces elite

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black belts who are disconnected from the shop floor. Lean boosts productivity yet doesn't provide tools for quality issues. According to Smith, lean brings action and intuition to the table, quickly attacking low hanging fruit with kaizen events, while Six Sigma uses statistical tools to uncover root causes and provide metrics as mile markers [5]. For practical success in Indian industry, the production manager needs a step by step unambiguous road of implementing processes that lead to improve quality. A combination of Lean and Six Sigma will have an improved impact on employee morale, helping to inspire the workplace culture, because teams can see the results of their efforts put to work immediately. Small-scale industrial improvement will accelerate with a step by step guide to implementing Six Sigma or Lean manufacturing principles together. These methods also support more use of data in decision-making and methodologies to promote a scientific approach to quality [6]. In our paper our development of a systematic tool for the integration of Lean Manufacturing principles and Six Sigma DMAIC methodologies with the support of Axiomatic Design analysis is presented.

2 Axiomatic Design: A glance

Axiomatic Design (AD) defines design as the creation of a synthesized solution in the form of products, processes or systems that satisfy perceived needs through mapping between Functional Requirements (FRs) and design parameters (DPs) [7]. Dr. Suh defines the four design domains presented in Figure 1. These domains help to understand customer expectations and follow the systematic approach of AD (Axiomatic Design), from which a hierarchical solution model can be developed [8].

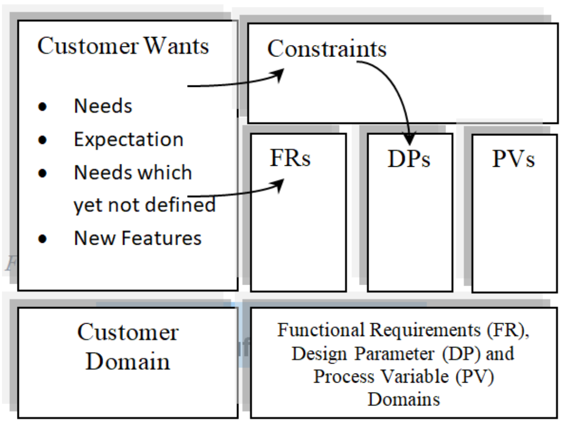

Fig. 1. Design Domains [7]

To eliminate waste is one of the simplest form of Lean manufacturing. The identification and removal of waste is a complicated process where production level Subject Matter Experts (SMEs) face many challenges. Because of shortages in skilled manpower at both the SME and upper management levels, there is often no support for production staff to make trade-off decisions on when and how to use the different quality methodologies [9]. Integration of Lean manufacturing and Six-Sigma into a single applicable process will eliminate some of the confusion and support decision making on when and where to use each process.

Axiomatic Design theory have been applied before to prepare a skeleton for production system development. Cochran has studied the application of Axiomatic Design of Manufacturing system. He developed four primary functions of any manufacturing system to be achieved: [10]–[12]

1. Clearly separate the objectives from the means of achievement,
2. Relate low level activities and decision to high level goals and requirements,
3. Understand the interrelationship among the different elements system, and
4. Effectively communicate the information across the organization.

Considering Axiomatic Design concepts, the highest level functional requirement for any organization/manufacturing firm is Maximizing Organizational profitability.

To develop a single Lean-Six Sigma approach, we developed a decomposition to deliver the top level FR of maximum profitability using the quality model approaches of both Lean and Six Sigma processes. The hope was to see a more unified single approach, without the duplication of two separate approaches, that would still apply to all cases. Please see our high level decomposition presented in Figure 2 (Annexure-I) with the structure expanded into our proposed decomposition of FRs and DPs [13] .

Decomposition is an iterative process at each level. The DP decisions of each level give a hint and idea of the direction of the next child level decomposition. We iterated our design with an eye on the available solutions from our two component philosophy/processes. Our goal was to reach an uncoupled design which satisfies all the higher level functions necessary to maximize profitability, employing the tools of both Lean and Six Sigma. Annexure-I, Figure 3 shows our decomposition tree diagram of a full function model prepared with the help of Acclaro DFSS software.

3 Case study

We searched for a manufacturing system that we could observe thoroughly, and then with the help of our AD Lean-Six Sigma process design, develop a proposal for change that we can test. We note that a similar case study approach was implemented by Jadeja in a JIT research project. [13].

To implement our model, we worked with a manufacturer of connecting rods. Its major manufacturing line for connecting rods was investigated in the first phase of the study. Thena step wise implementation was done as per the hierarchical structure developed through our functional decomposition of a Lean – Six Sigma approach. Triangulation research methodology, frequently used in qualitative research, is applied in our study.

Our test manufacturing line was observed, investigated, modified and analyzed to implement our model and to observe the outcomes. Research presented in this paper is the output of extensive time spent in the field at the manufacturing case study line, brainstorming with the company experts and collecting feedback from others.

Applying our AD developed solution for the system level application for six sigma statistical tools of DMAIC and lean techniques, this data driven approach was used to propose process improvements. Primarily, our model proposed Lean manufacturing techniques to reduce process waste and increase process effectiveness through faster delivery and shorter lead time.

For example, as per the decomposition, takt time must be defined to reduce delay in process and to satisfy FR2.4 i.e. sales revenue.

$$Takt\ Time = \frac{Available\ work\ time}{Customer\ Demand\ Rate}$$

Available takt time considering 50 minutes of break (two sessions) becomes 33,000 seconds/day for one shift working for 10 hours/day. Customer demand rate is 18,000 rods/month which turns to 72 rods/hr considering 25 working days and 10 hrs of shift. So takt time to satisfy customer demand and to reduce the delay is 46 sec/part. (FR2.4.2.1)

This basic information was used to follow the re-engineering process and to prepare the new process layout and operation sequence. Data related to cycle time analysis is prepared to ensure and match production cycle time to takt time. (FR2.4.2.2). Further a Special Purpose Machine (SPM) was introduced to match part arrival rate to service rate. (FR2.4.2.3). Four operations having higher takt time difference have been identified and with the help of SPMs two operations have been performed together. Figure 4 and 5 show the before and after cycle time comparison after reengineering process of FR 2.4.2.2.

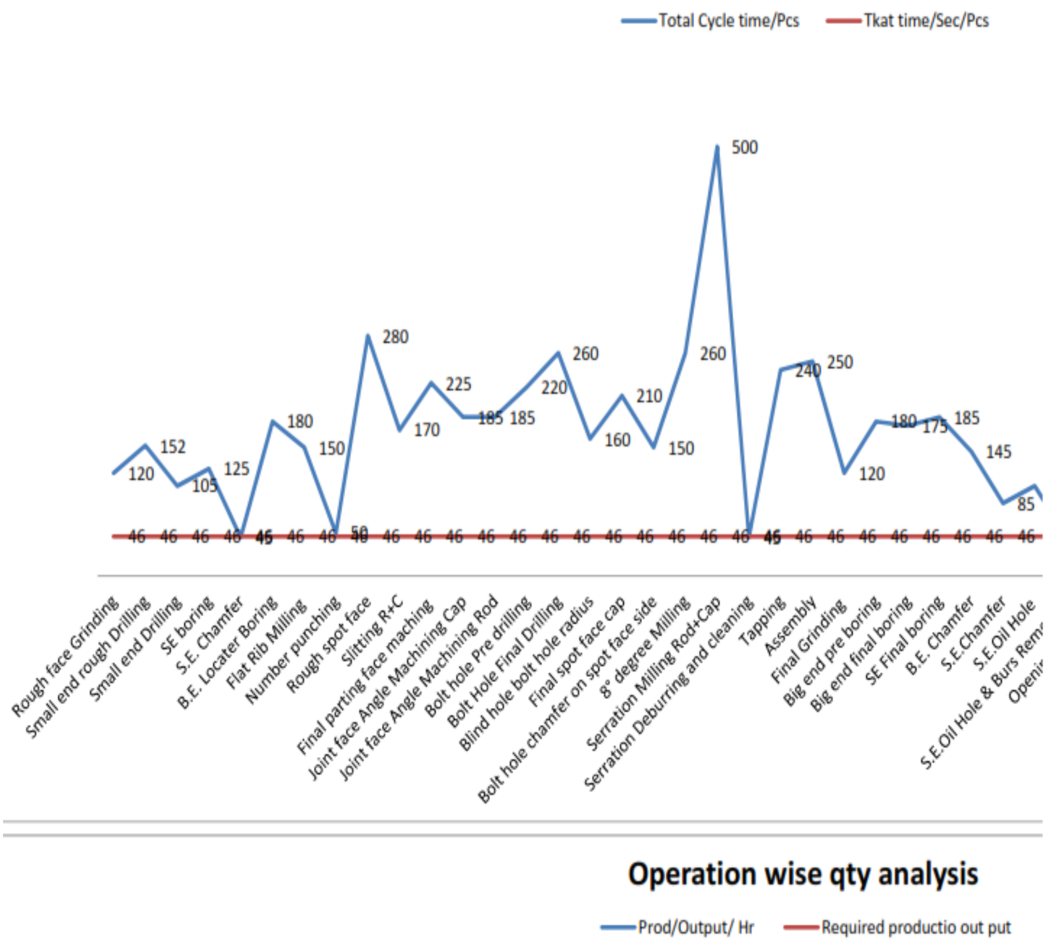

Fig. 5. Operation wise quantity analysis (Before)

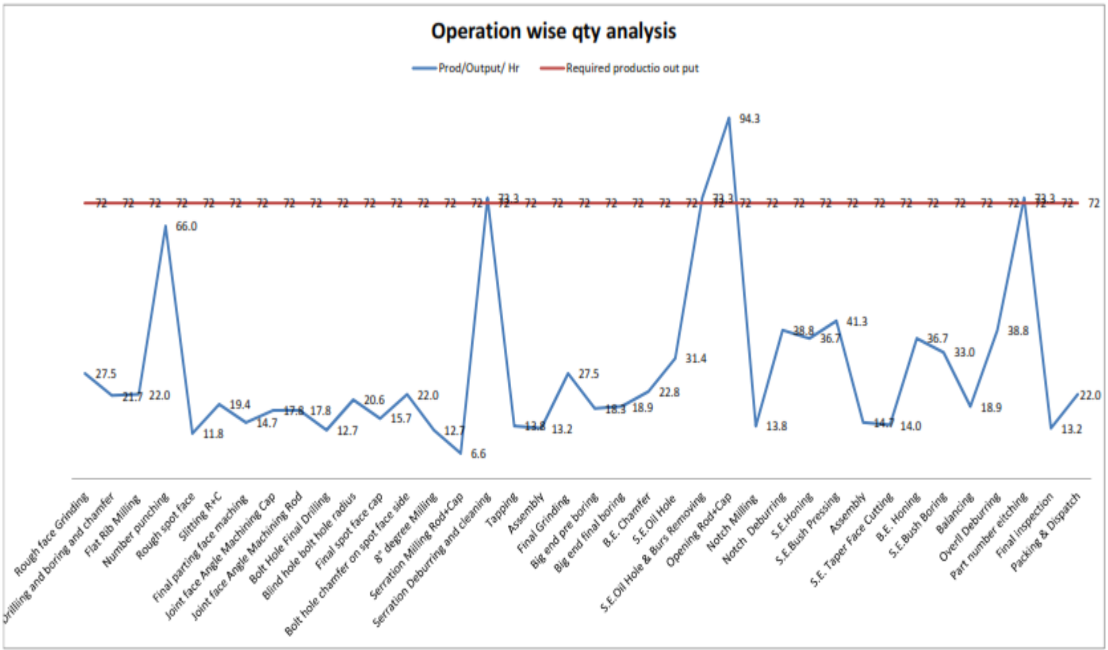

Fig. 6. Operation wise quantity analysis (After)

Additional change to the manufacturing system layout or worker reduction proposed by Six Sigma aspects of our analysis model were not implemented because of management decision. Although it was a small production line we worked on the Lean-Six Sigma concepts we proposed achieved successful results.

4 Conclusion and further research

We have stated that we believed that small scale industry improvements were slow due to the complexity of dualing quality Lean and Six Sigma processes as well as other less continuous improvement strategies. We proposed that a single process that implemented the value add of both Lean and Six Sigma methodologies would bring value. We proposed that the axiomatic design framework was the best method to develop this integrated approach.

In our research a systematic tool for the integration of Lean Manufacturing principles and Six Sigma methodologies with the help of FRs, DPs and PVs, the key elements of Axiomatic Designed templates has been developed. This research is an attempt to provide a guideline for the specific required change or modification of manufacturing systems in production and design through a systematic structured approach to achieve the advantages of both called “Lean-Sigma” for small scale industry.

Our research is far from exhaustive, just scratching the surface. We could not test if applying both quality models separately, with different staff, was better or worse than our integrated mode. We encountered a lot of small practical issues that caused us to iterate our approach during the research, which is not good methodology. We also had limited influence to try all aspects of our solution on the connecting rod manufacturing line. Plus we had limited time where time is needed to make many of the changes proposed. Yet we feel that applying axiomatic design to create an integrated model was useful and effective. If we continue the work we will try to bring into our decomposition other quality models.

5 Acknowledgement

Authors are grateful to Amul Industries Pvt Ltd for providing the facilities, information and data for this research. Authors are also thankful to Functional Specs Inc for providing Acclaro Software. (www.functionalspecs.com).

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7 Annexure-I

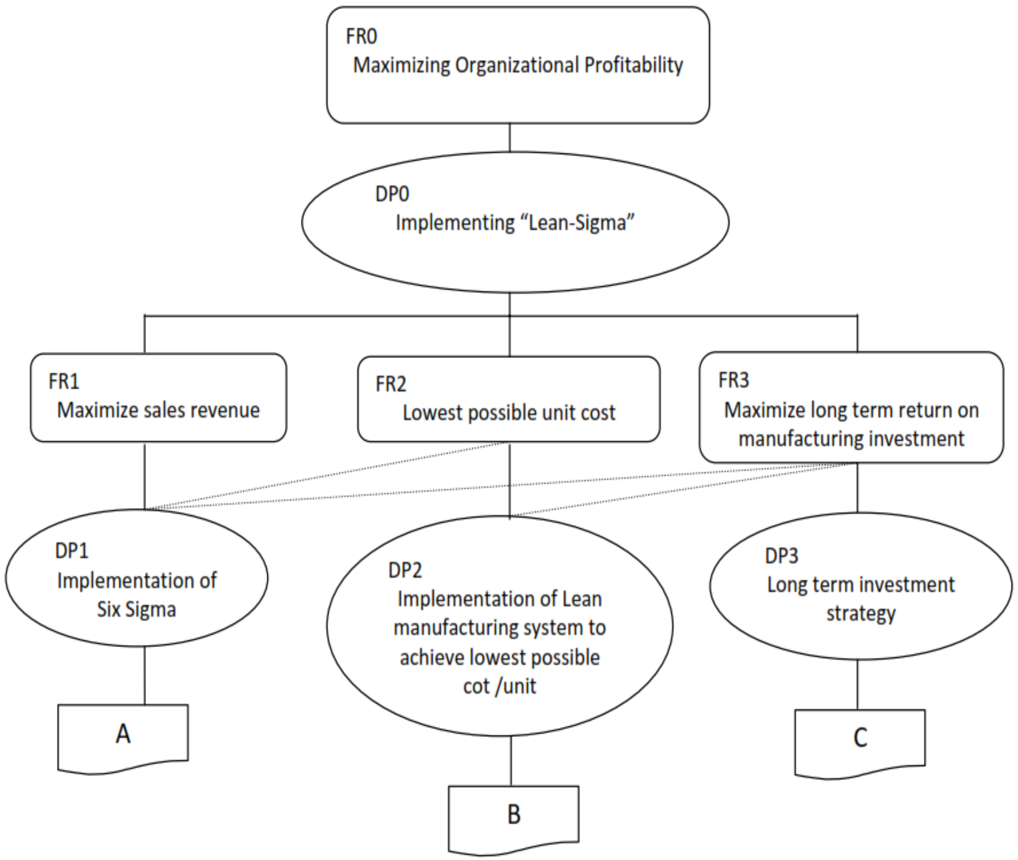

Fig. 2. Axiomatic Model of LeanSigma

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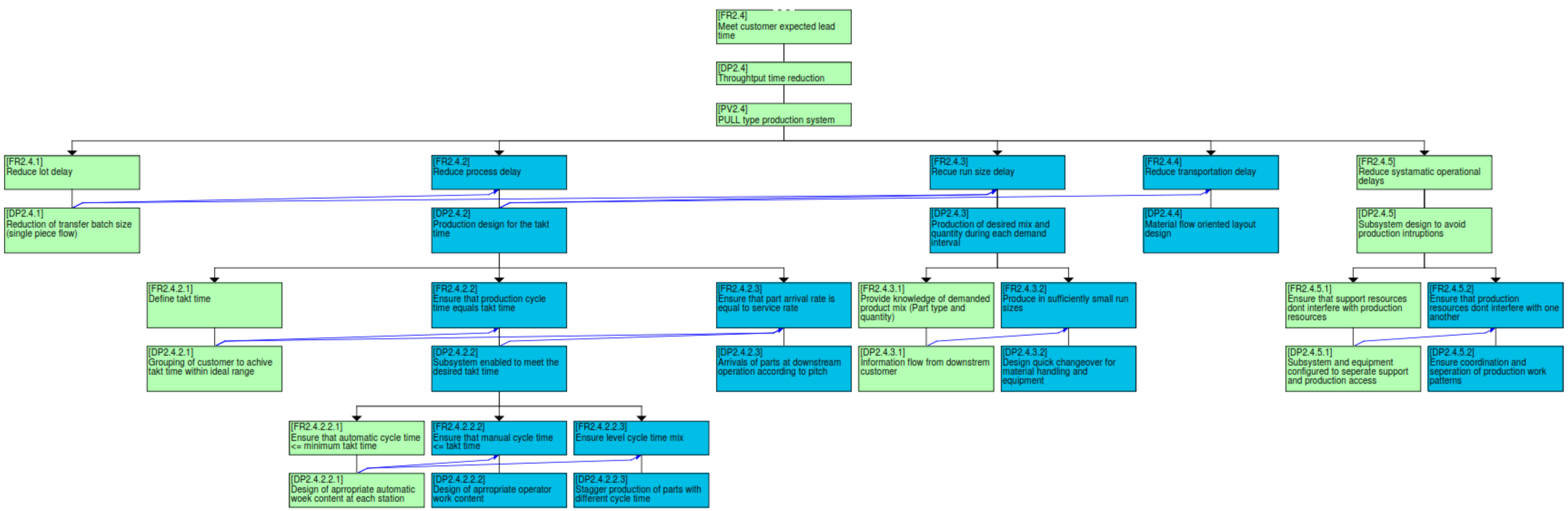

Fig. 3. Lean – Six Sigma Process Functional Decomposition

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