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Lean Manufacturing and Six Sigma

Behind the Mask

Edited by Fausto Pedro García Márquez, Isaac Segovia Ramirez, Tamás Bányai and Péter Tamás

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Meet the editors

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Contents

Preface

Lean Manufacturing, also called lean production, was originally created in Toyota after the Second World War, in the reconstruction period. It is based on the idea of eliminating any waste in the industry, i.e. any activity or task that does not add value and requires resources. It is considered in every level of the industry, e.g. design, manufacturing, distribution, and customer service. The main wastes are: over-production against plan; waiting time of operators and machines; unnecessary transportation; waste in the process itself; excess stock of material and components; non value-adding motion; defects in quality.

The combination of the comprehensive and flexible Six Sigma system integrated with lean manufacturing is called Lean Six Sigma, which can increase profit, improve efficiency and effectiveness, and develop employees' structure. Six Sigma is a collection of different tools and techniques for improvement of quality of processes, which was introduced by Bill Smith in 1980. Six Sigma projects include five important steps: define the system, measure key aspects, analyze the data, improve the current processes, and control the future state.

The diversity of the issues is covered from algorithms, mathematical models, and software engineering by design methodologies and technical or practical solutions. This book intends to provide the reader with a comprehensive overview of the current state, cases studies, hardware and software solutions, analytics, and data science in dependability engineering.

The editor would like to thank all the authors of these chapters for their contribution and commitment, which made the publication of this book possible.

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Chapter 1

Introductory Chapter: Introduction to Lean Manufacturing

Fausto Pedro García Márquez and Isaac Segovia Ramirez

1. Introduction to Lean Manufacturing

Lean manufacturing, also called lean production, was originally created in Toyota after the Second World War in the reconstruction period [1]. It is based on the idea of eliminating any waste in the industry, i.e., any activity or task that does not add value and requires resources [2]. It is considered in any level of the industry, e.g., design, manufacturing, distribution, and customer service. The main wastes are as follows:

- Overproduction against plan
- Waiting time of operators and machines
- Unnecessary transportation
- Waste in the process itself
- Excess stock of material and components
- Non-value-adding motion
- Defects in quality

The wastes eliminated should improve the improvement of the quality and the reduction of the cost and time in the manufacturing. The main tools are [3, 4] the following:

- *Five S.* seiri (sort), seiton (set in order), seisō (shine), seiketsu (standardize), and shitsuke (sustain).
- Multiprocess handling. The manufacturing is preformed sequentially for multiple processes, contributing to the flow of materials.
- *Value stream mapping*. The tool compares the current state and future state of the events that depend on the product in order to reduce wastes. It is focused on the areas that incorporate value to the product.

- *Kanban* (pull systems). The lead time and cycle time are measured in several areas of the production in order to detect any problem and avoid it, e.g., to establish an upper limit to work in process inventory to avoid overcapacity.

- Mixed model processing.

- *Total productive maintenance*. The production system is considered as a whole, and the maintenance is focused on that. It leads the integrity of the maintainability, safety, quality to the assets, and human resources that add value to the production system.

- Elimination of time batching.

- *Control charts.* For checking mura (unevenness).

- *Rank order clustering. It is* employed in production flow analysis, considering the classification of machines and the technological cycle information control and generating a binary product-machine matrix.

- Single-minute digit exchange of die (SMED). The idea is that the changeovers and startups will be done in a "single-minute digit," usually 10 minutes. A similar concept is one-touch exchange of die (OTED), where the "single-minute digit" should be less than 100 seconds.

- Redesigning working cells.

- Single point *scheduling*.

- *Poka-yoke* (error-proofing). It is considered as the tool that leads to the operator to avoid (*yokeru*) mistakes (*poka*). It leads to reduce or eliminate the product defects.

The diversity of the issues is covered in this book from algorithms, mathematical models, and software engineering by design methodologies and technical or practical solutions [5, 6]. This book intends to provide the reader with a comprehensive overview of the current state of the art, case studies, hardware and software solutions, analytics, and data science in dependability engineering.

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Chapter 2

Model of Tacit Knowledge Transfer in Lean Management Implementation in an Organization

Norani Nordin, Roshidah Mohamed and Naoshi Uchihira

Abstract

The increase in competition worldwide had driven organizations to face with new challenges. The situation had prompted the manufacturers to perform a variety of effective strategies such as the implementation of lean manufacturing system in their organization. In this study, the key elements in developing the lean tacit knowledge transfer within the organization were identified. In addition, this study also investigates the transfer of lean tacit knowledge, which involves the sender and the recipient of lean knowledge within the organization. Data were collected through a single case study for a period of 2 months in an automotive manufacturing plant in Malaysia. The results of the study found that the lean knowledge could be developed through a number of key elements. A model of tacit lean knowledge transfer was developed to help improve work performance during the implementation of lean manufacturing system. In addition, the development of the model can explain how lean knowledge was developed and transferred from one party to another in the organization. The existence of such a model could assist an effective lean manufacturing implementation with every organization should has a good lean knowledge and understand how to properly implement lean in the production process.

Keywords: lean manufacturing, lean knowledge, tacit knowledge transfer, case study.

1. Introduction

Changing the lean manufacturing is a radical process and not an easy task. A significant organizational change must take place within the organization in order to create the basis for lean to take hold. The lean transition process requires significant changes in the company's function [1]. There must be a form of sharable knowledge at an organizational level to ease the transition. In the comprehensive review of the literature by [2], two gaps were identified that required an understanding of sharable knowledge development processes. Both of these concerns dealt with the individual knowledge development and the methods of how an organization developed a sharable knowledge from individual knowledge to organizational knowledge.

Three domains that serve as the foundation of this study are: knowledge development, knowledge management driven by knowledge development and conveyance, and strategic change implementation (change management), primarily process innovation. To have a level of organizational knowledge is to say that knowledge was held at the organizational level rather than individual level. At an organizational level, the organizational norms, behaviors, and viewpoints changed because of the developing knowledge process. Lean manufacturing has two fundamental elements, which are a systematic approach to process improvement by removing waste, and develop the people who work within the service to create a culture of continuous improvement [3]. The concern that becomes the foundation for this study is that there are many failures in lean manufacturing implementation. Each failure can be attributed in two difference causes, which include lack of understanding the concept of waste, and the fundamental issues of lean culture [4]. The problem addressed in this study is the lack of insight into the development and conveyance of tacit knowledge, which lead to the failure of lean manufacturing implementation an organization.

Therefore, the purpose of this chapter is to understand how the tacit knowledge could become sharable as organizational knowledge by proposing the model of tacit knowledge transfer in lean manufacturing implementation. The existence of such a model could benefit the company involved in the implementation of lean manufacturing system in their company. The implementation of lean manufacturing system will be more effective if every company had a good lean knowledge and understand how to properly implement lean in the production process.

2. Background of lean manufacturing

2.1 Introduction

Since year 2000, the lean concept has become more contingent and the scope has been extended to include the perspective of organizational learning. Some analysts, like Hines et al. [5] and Jorgensen et al. [6], thought that the lean concept has a greater change of progress and maturity in the future. Evolution can be compared to organizational learning through a phased process. Shah and Ward [7] believe that lean manufacturing is a multifaceted system. The lean system's integrated nature includes both individuals and process components. It is also linked to the company (i.e., internal) and components of the supplier and customer (i.e., external). In the analysis of the Toyota Production System, [8] points out that lean works on two main principles: "continuous improvement" and "respect for people." Many senior managers outside Toyota have ignored "respect for people" and misunderstood "continuous improvement" [9]. Lean manufacturing is rooted from kaizen or continuous improvement, which requires skills and a common way of thinking to systematically eliminate waste and improve the value of activities. The lean concept has therefore advanced to a stage that includes the management of knowledge creation, which aims to create a learning organization in which people are the soul of a lean process [10, 11].

One of the main barriers to its implementation is the misunderstanding of the real concept and purpose of lean manufacturing. Herron and Braiden [12] suggest that the reason for this misunderstanding is due to cultural differences during the implementation of the transition or translation of the lean concept. The concept's misunderstanding leads to several major problems, such as the piecemeal adoption of lean tools and techniques [13], the misuse of lean tools [12], and lack of lean culture development that supports lean production in the company [6].

2.2 Tacit knowledge in lean manufacturing

Lean manufacturing consists of a large number of practices and techniques. An analysis of 100 lean tools and techniques done by Bhamu and Singh Sangwan [14] has shown that a large number of lean practices exist with multiple names, overlap with other tools, and even have different methods of implementation proposed by different researchers. Herron and Hicks [15] have classified lean practices based upon the types of knowledge embedded in the tools known as tacit and explicit knowledge. Explicit knowledge, such as statistical process control (SPC), failure mode and effect analysis (FMEA), single minute exchange of die (SMED), fool proofing or poka-yoke, and value stream mapping, are techniques that are well documented and relatively easy to learn from literatures. In contrast, tacit knowledge that include continuous improvement or kaizen, total productive maintenance (TPM), Kanban, 5S, standardized working, and policy deployment (hoshin kanri), are techniques difficult to implement without the right support. Transferring tacit knowledge takes a long time because it often requires a change in culture and substantial experience to be gained.

According to [16], 42% of the knowledge in an organization is stored in human mind, 26% is in the form of paper documents, 20% is in electronic documents, and 12% in the electronic-knowledge base. The knowledge in human mind is referred as tacit knowledge, which is the most important aspect that should be understood and realized by the company. Tacit knowledge has been classified into two dimensions, the technical and the cognitive dimension. The technical dimension can be viewed as expertise "at ones fingertips" and it encompasses information and expertise in relation to "know-how." The cognitive dimension consists of mental models, beliefs, and values, and it reflects the image of reality and vision of the future. This study focuses on the technical dimension of tacit knowledge in lean manufacturing. However, tacit knowledge is very difficult to transfer when compared to explicit knowledge. On the other hand, tacit knowledge can be able to help the company to succeed if they have the right approach in transferring the knowledge to other individuals in the company.

The development and transfer of knowledge can be referred to SECI (socialization, externalization, combination, and internalization) model, as shown in **Figure 1**. SECI model is the model of knowledge creation is developed by [17]. The model has been tested and applied in various empirical studies in the field of information and communication technology, education, banking, manufacturing, and many more.

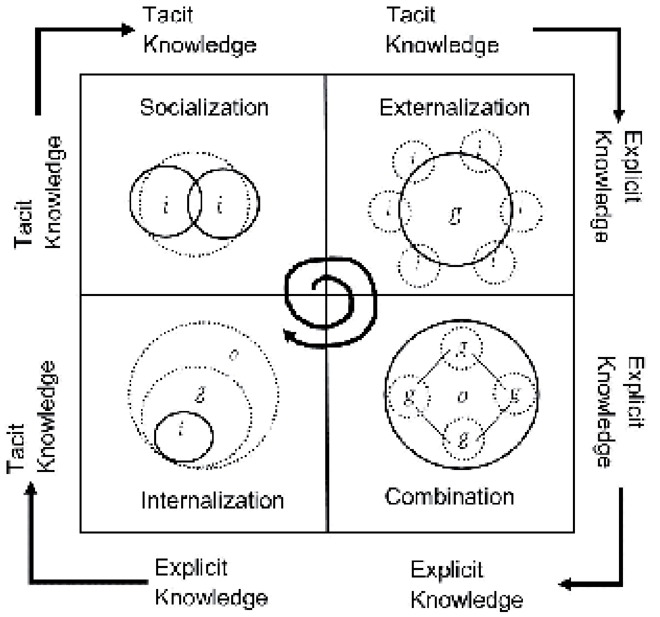

Figure 1.
SECI model of knowledge creation.

All these studies have suggested that the SECI process has improved the performance and achievement in the organizations. The selection of SECI model in this study is in the ground that SECI model is the most popular model in the creation of knowledge, and this model could give the clear description of the development and transfer of knowledge.

3. Research method

One Malaysian automotive manufacturing company, Company A was chosen for the case study. The company is selected based on the criteria which have been set. The criteria are: (1) the company must apply lean, (2) must have lean department or unit, and (3) included in Malaysian Automotive Institute (MAI) database. The data collection was prepared by first contacting the company to be studied to gain their co-operation, explained the purpose of the study, and recorded the key contact information. A semi-structured interview guide was developed upon a common case study protocol inferred from the review of literature. The interview protocol was developed to probe the development and transfer of lean tacit knowledge during the lean implementation process. To explain the process of the data collection, **Table 1** shows the measures taken in the overall research design in detail.

The same interview protocol was used for triangulation purposes to improve the reliability of research. The need for triangulation stems from the ethical need to confirm the validity of the obtained data. The subjects of the interview are questioned about their actual experiences. For each respondent, an interview was conducted for about 2 h. The respondents were the key employees in the company directly in the lean manufacturing. **Table 2** provides a summary of the respondents' background.

Method of data collection	Data obtained	Data analysis
Interview	Transcript of each interview	Thematic analysis Cross-comparison analysis between wweach respondent
Site observation	Observation notes Checklist	Content analysis
Documents	Written documents (newsletter, past progress report)	Content analysis

Table 1.
Data collection and data analysis.

Respondent	Position	Working experience	No. of years working in Company A
A	Company Manager	5 years	5 years
B	Assistant Manager	21 years	9 years
C	Technical Assistant—Operations Department	20 years	9 years
D	Supervisor—Operations Management	17 years	8 years

Table 2.
Respondents' background.

4. Results and discussion

4.1 Lean manufacturing implementation in Company A

Company A is established since 1992 in Selangor, Malaysia. The company started to grow their business by opening the other three factories in Gurun, Kedah (1996), Tanjung Malim, Perak (2007), and Bukit Beruntung, Selangor (2012). Company A expanded the business in designing and producing automotive plastic and metal components. In addition, the company is also the supplier to two Malaysian car producers, which were Proton and Perodua.

Company A started to implement lean manufacturing system since 2009. This implementation was under supervision of a team known as Lean Improvement Team which was created in each factory. This team was responsible in the lean manufacturing system implementation in their factory on an ongoing basis. Furthermore, the team is the main resource in identifying the opportunities to enhance the production productivity by applying the lean thinking system.

All the lean implementation approaches started from discussion with the employees who directly involved in solving the problems in the chosen area or department. The team also conducted meetings to discuss matters relating to the implementation of lean improvement every week. The aim of the meeting is to ensure the goals and targets set could be reached within the specified time.

The Lean Improvement Team is also responsible in delivering information of lean manufacturing concept to other employees. These information were relayed through various ways such as meeting in small groups, through social networks and training. The aim was to ensure all the employees truly understand the lean concept until the company reaches to the high level of effectiveness.

However, the implementation of lean manufacturing in Company A was limited due to financial reasons because it involved sending the team members to relevant trainings with external experts in lean manufacturing system. Therefore, the authors have come to the conclusion that Company A was not comprehensively a lean company, as it did not receive a full support from the top management in the lean manufacturing implementation. Even though, the Lean Improvement Team has been working hard to improve the company's progress in lean manufacturing system, the team members need to enhance their knowledge, especially in advanced lean manufacturing tools and practices.

4.2 Understanding of lean manufacturing concept

To understand the lean manufacturing system know-how is an important element in implementing lean effectively in Company A. In an effort to ensure employee involvement and motivation, understanding of the thinking behind the implementation of lean is very important [18]. **Table 3** shows the understanding and interpretation of the respondents in lean manufacturing system. It shows that lean manufacturing system has different dimensions and meanings in the context of each respondent.

4.3 The development and transfer of tacit lean knowledge

The knowledge and skills in lean manufacturing gained had prompted them to apply lean manufacturing system to increase the productivity in the company. The respondents' knowledge and expertise of lean were developed and transferred from the number of activities or approaches such as lean training, case studies, simulations, industrial visits, and database sharing.

Respondent	Lean manufacturing system is
A	• A systematic production system. • Activities which could reduce seven wastes, reduce cost, and facilitate task monitoring and handling. • An efficient operation.
B	• A system for fixing the manufacturing operations. • A system to fix production processes from the material demand to customers' product delivery.
C	• A system to reduce seven wastes in production.
D	• A way to reduce seven wastes. • Reduce cost.

Table 3.
Respondents' understanding and interpretation of lean manufacturing system.

4.3.1 Lean training

Lean training is one of the common activities to develop lean tacit knowledge. According to the respondents, they acquired the information and knowledge related to lean from training conducted by MAI and their customers. As mentioned by Respondent A;

> *I started attending lean training in year 2010. At that time, the program was under the MAI and the facilitators were from Proton and MAI lean experts.*

Whereas, Respondent B revealed that he developed the lean knowledge and skills from lean training conducted by the Company A's customer;

> *My first exposure on lean manufacturing system was from Perodua. At that time, Perodua organised a lean training to ensure all its vendor able to improve quality products through the implementation of lean. Second, I also participated lean training organized by Proton. The company invited a number of representatives from all its vendors to join a lean training in Shah Alam. The training involved consultants and experts from outside. Through the training, made me know to some extent about lean manufacturing.*

At the same time, Respondents C and D only gained knowledge lean through training conducted by Respondents A and B after their lean program organized. Such knowledge has led them to begin seeking about the implementation of effective lean operations. From the exposure given, Respondents C and D began to move actively in looking for ways the implementation of lean effectively through discussions and meetings with Respondents A and B.

4.3.2 Case studies

Case study is another approach to develop lean tacit knowledge. Respondent B revealed on how case studies were conducted;

> *Case studies did appear to be tedious and difficult. We were taught to see the problems that arise and frequently occurred. If there are some problems, we were taught on how to solve them. In order for us to fully understand the concept of lean manufacturing system, we tried to solve the program again and again.*

According to the respondents, case studies performed were also related to the Value Stream Mapping (VSM), where they were assigned to study their own factory. During the period of case studies, they were often monitored and assisted by the consultants who were experts from Japan in solving the problems that arise.

After conducting case studies, Respondents A and B confessed that their understanding and skills in lean manufacturing system improved tremendously. Then, they started to see the benefits of implementing lean system in the company. This was mainly due to the coaching done by the lean experts who taught them to solve problems according to lean approaches. When asked about how the lean experts trained them, Respondent A stated:

> *They (Japanese experts) taught us and showed all the photos of what to do and what is not right. Everything which is not right, was corrected immediately.*

Respondent B:

> *The lean experts came every two weeks from morning until afternoon to help us solve problems that occurred in our factory. From there, they gave advice and showed us the right approach lean manufacturing system.*

Understanding and learning directly in the operation helped them to better understand and apply their knowledge in implementing lean manufacturing system in their company.

4.3.3 Simulation approach

Another method in developing lean tacit knowledge among employees in Company A is simulation. Respondents A and B mentioned that in lean trainings, one of the approach employed by the lean experts was game simulation. The main benefit of the simulation tools is that the trainees would be able to experience different responses and actions to a real life situation. This could increase their understanding in the actual implementation of the lean.

4.3.4 Industrial visits and information sharing

In addition to lean training, case studies, and simulation games, industrial visits to successfully implemented lean companies and sharing a database relating to the implementation of lean is also other ideas used in developing and obtaining knowledge of lean manufacturing system. It is revealed by the respondents as below:

Respondents A:

> *We went for gemba to watch new working situation and the way they work. During the gemba, we saw a different view. If a system is well organized, people could see it and able to understand the process. So we were able to see some good examples and try to implement it in our company.*

Respondent B:

> *I watched what other vendors did. For an example I went to Perodua. I received a database and documents on the technical information on lean manufacturing implementation and kept them. I also watched how the operators (in other vendors) did the tasks. If I saw good approaches, I applied them in our factory.*

Respondent C:

> *I went to visit other factories and watched them performed Kaizen and Kanban. From there, I tried to search new ideas to implement in the factory.*

4.3.5 Internet resources (videos)

Rapid technological developments led many individuals find information quickly and fast. Undoubtedly, Internet resources are also a resource for the sender to acquire knowledge and skills in applying lean manufacturing system in the company. A variety of lean techniques and practices available from YouTube make learning lean system more easily attained and implemented by individuals within the company. This situation was disclosed by Respondents A, B, and D on how they develop knowledge and skills in the implementation of lean.

Respondents A:

> *I learned how to apply Kaizen through examples from the Internet by watching videos. I also watched how other factories did. Usually the videos described the process very details and step by step. Then, we applied the techniques and processes in our factory.*

Respondent B:

> *After we watched the videos on lean activities, we will do some benchmarking on our factory. Then, we will take some suitable approaches or techniques to put them into factory operations.*

Respondent D:

> *When the top management requested us to carry out Kaizen, I searched the internet and watched how other factories did Kaizen in their production. From there I got the idea. From the idea, I will add my own ideas and carried them out in the factory.*

Learning through a variety of methods is the most effective action in developing lean thinking culture in the organization. Knowledge and skills of lean manufacturing are important to ensure that the company continues to be successful in implementing an effective lean manufacturing system. According to [19], skills, knowledge, and experience of the employees are necessary for effective lean manufacturing implementation across the company.

4.4 Model of tacit knowledge transfer in lean manufacturing system implementation

The success transfer of lean tacit knowledge is very important in a company in order to enhance the understanding of lean manufacturing concept and culture among the employees. From the information obtained, the authors have developed a model of tacit knowledge transfer in lean manufacturing system implementation as a guide to assist manufacturing companies in Malaysia in developing the tacit lean knowledge in their companies, such as continuous improvement or kaizen, total productive maintenance (TPM), Kanban, and 5S.

Figure 2 shows the developed model based on the case study conducted. For the transfer of knowledge to be successful, the sender and the recipient must be willing to participate in the knowledge transferring process. There are two dimensions involved in the transferring process, such as externalization to internalization. Both of these dimensions have their own distinctive elements in developing and transferring the lean knowledge.

From the sender, the dimension involved is the externalization. The sender should be an individual who is knowledgeable and skillful in tacit lean knowledge before transferring the knowledge to the other employees in the company. Therefore, the sender must clearly demonstrate, summarize, and translate the tacit knowledge that he obtained to comprehensible information, known as explicit knowledge.

For the recipient, the dimension observed is internalization. This process involved the transfer of lean knowledge, which is sharable from explicit knowledge to tacit knowledge. Internalization refers to the application of knowledge in real situation. Through internalization, a clear knowledge will be converted to the tacit knowledge of an individual and then developed as the basic knowledge of the organization [20]. According to [17], the process of internalization involved "learning by doing" in order to create the employee's tacit knowledge.

Therefore, to effectively transfer the tacit knowledge of lean manufacturing, such as Kaizen, 5S and TPM, organized lean activities should be arranged. The lean activities have three steps, which are lean training, practical, and continuous assessments, as shown in **Figure 3**. These steps are in continuous loop until the company has achieved the organizational basic lean knowledge.

As shown in **Figure 3**, the first step of lean activities is lean training. During the training, the recipient is exposed to the concept and application of lean manufacturing. The purpose of training is to create the basic knowledge of lean manufacturing to the recipient, especially for the new workers. The lean training could be done either directly (training, meetings, simulation, and case studies) or indirectly (coaching and informal discussion). An effective training should be conducted in a small group and performed regularly, so that the knowledge and understanding of lean manufacturing is transferred to the recipient.

The second stage in the transferring of tacit knowledge of lean manufacturing is through "learning by doing." In order to strengthen the understanding of the recipient, practical training is very important. The sender can describe lean manufacturing in detail and clear by demonstrating the lean practices, so that the recipient or workers could perform what they have learned in real working environment. An example of learning 5S or Kaizen, the concept of learning by doing could be done on ongoing basis.

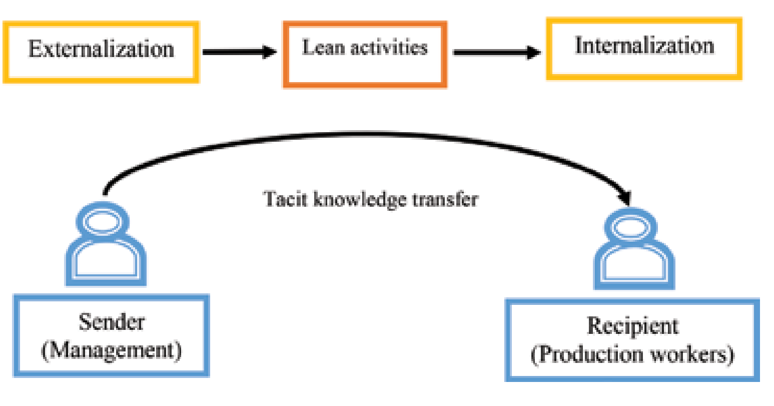

Figure 2.
Model of tacit knowledge transfer in the implementation of lean manufacturing.

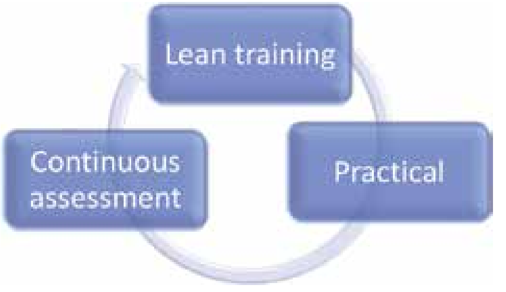

Figure 3.
Steps of lean activities.

The final step is the assessment after transferring the lean knowledge to the recipient. The purpose of assessment is to ensure that the recipient understands and is able to apply the knowledge learned. According to [21], the most important element in knowledge is through migration, identification, development of knowledge, and followed by evaluation and implementation. The transfer could be more effective if the assessment could be done continuously either individually or in group within the company. Hence, the new knowledge could continue to grow and become the fundamental knowledge of the company.

5. Conclusion

Based on the findings, the effective transfer of lean tacit knowledge plays an important role in ensuring the level of successful implementation of lean manufacturing system in a company. The right approach of lean tacit knowledge transfer able to increase the ability of employees toward effective lean thinking. However, in order to be able to transfer the knowledge, the senders need acquire the lean knowledge to be competent. Therefore, this study has identified five approaches such as lean training, case studies, simulations, industrial visits and database sharing, and Internet resources (videos). A model was also developed to guide the manufacturing companies, especially the lean implementation team, on how the tacit knowledge of an experienced individual on lean manufacturing can be transferred or shared to other employees. Hence, the implementation of lean manufacturing will be more effective, if every company has a good lean knowledge and understands on how to properly implement lean in the production process.

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Chapter 3

A Novel Space Systems Management Methodology Based on Shortcomings and Strengths of Conventional System Engineering Tools Used in a Design Thinking Framework

Cecilia Michelle Talancon, Josué López-Leyva, Dalia Chávez-García, Miguel Ponce-Camacho and Ariana Talamantes-Álvarez

Abstract

In this chapter, several systems engineering tools are presented and analyzed to determine shortcomings of these tools to improve the efficiency and efficacy of them working together in a modified design thinking methodology framework for space systems management. The space systems projects impose a high risk in all its stages, so that it is very important to reduce errors as possible based on activities that ensure the adequate project performance. Finally, specific systems engineering tools are used in particular stages and sub-stages of the proposal design thinking framework depending on the shortcomings and strengths of each one. This proposal framework accelerates the conventional process for a space project that usually requires a lot of resources and it is not suitable for both emerging countries and space agencies.

Keywords: systems engineering tools, design thinking, space projects, shortcomings-strengths, efficiency

1. Introduction

From its origins, the human being has looked for ways to transform nature, for that reason his ingenuity and creativity have been the transforming force of the world. Thus, the way of taking ideas to concrete facts using scientific knowledge is called engineering. In a more technical way, engineering is a discipline that uses scientific and technical knowledge to imagine, design, create, make, operate, maintain and dismantle complex devices, machines, structures, systems and processes that support human effort [1]. On the other hand, the set of parts that interact with each other to achieve an objective is called system [2], which can also be a combination of interacting elements organized to achieve a purpose [3]. The combination of these two words is known as systems engineering and it is the structured application of scientific knowledge for the design, creation and management of a set of interacting elements to achieve an objective. The beginnings of systems engineering go back to the effects of the World War II in the 1950s and 1960s when systems engineering was named for first time in several publications as a distinct discipline. The recognition of systems engineering as a unique activity evolved for the rapid growth of technology and its application to major military and commercial operations during the second half of the 20th century [4]. In the past years, systems engineering was closely linked to the methods used in electronic communications and aerospace engineering, and that is why it obtained its place within these disciplines since it was the responsible of finding solutions to reduce levels of complexity in the situations of human-machine interaction [5]. Currently, there are several definitions about systems engineering but the most important is defined in the systems engineering manual of the National Aeronautics and Space Administration (NASA), where it describes that systems engineering "is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system" [6]. It is important to mention that the systems engineering objective is to ensure that the system has been designed, constructed and operated in such a way that it fulfills its purpose in the most profitable way possible, contemplating performance, cost, schedule and risk [6]. The aforementioned to produce systems that satisfy the needs of customers and increase the likelihood of system success [7]. In addition, innovation is an important aspect, therefore, professional human resources are required to develop management and engineering solutions for actual and future complex space systems challenges. Thus, the systems engineer must be able to apply his work, understand and recognize a problem, problematic situation or process in his context to apply, adapt and manage technological solutions. In particular, systems engineers usually begin their studies with an Engineering in electronics, mechanics or any of their interests and then choose to look for certifications such as the International Organization of Systems Engineering (INCOSE) or even for postgraduate studies in systems engineering [8].

Unlike the Project Manager, a systems engineer has a fundamental knowledge associated with the principles of engineering management. However, it is possible that the role of a systems engineer is not fully understood or appreciated since it is less defined than a Project Manager in many organizations [8]. In fact, the perspective of a project manager on a problem is very different in comparison to the perspective of the system engineer and, based on that they do not usually work together, there is not an "optimal solution," that could be achieved using tools and techniques of both systems engineering and project management [9]. Projects related to the aerospace sector can be more successful having systems engineer at the team, since they know the technical domain: hardware and software. Systems engineering provides a framework for problem solving, if a system or problem is more complicated, the processes are more useful for systems engineers to do their job and improve the overall performance [10]. The space systems engineering is defined as the art and science of creating space systems capable of comply strict requirements, through the interdisciplinary participation of various areas of engineering, such as: electrical, mechanical, electronic and computing [11]. The mentioned is reached based on a team activity in which the people involved are aware of the relationship between specialties and their roles in development as an organizational process. It can be said that the space systems engineering consists on designing, building and managing the efforts for the administration of the mission and the space operations, i.e., helping the team to implement the necessary techniques to deliver the project on time and under the budget. Thus, the objective of space systems engineering is to apply the principles, methods and tools of systems engineering necessary to transform the fundamental technical, economic and social requirements into an integrated space system solution [12]. This integration includes hardware, software and human resource, integrated in a clearly articulated value proposal and in the general architecture of the system. In particular, the space systems engineers help to the design effective space missions because they are focus on overall activities (e.g., verification, validation, operations, among others). They must ensure that the cost estimation of the project/program life cycle is within the budget and current NASA policies, which establish that projects must submit sufficient budgets to guarantee a 70% probability of achieving the objectives without exceeding the budget [6]. This is the reason why it is necessary to establish processes to estimate, evaluate and control costs in each phase of the project.

The "program/project life cycle" mentioned above is one of the fundamental concepts used by NASA in systems administration, which consists in the categorization of everything that must be done to achieve a program or project in different phases, separated by key decision points (KDP) [13]. The KDP refers to the moments where the leader determines the preparation of the program or project to move on to the next phase; if a program or project does not approve one of the KDPs, it is possible to try again afterwards or simply finish the project [13]. Remember that all systems begin with the recognition of a need or the discovery of an opportunity and advance through various stages of development to a final disposition [6]. This program/project life cycle is divided into two main segments (formulation and implementation) and these in turn into seven phases (conceptual studies, concept and development of technology, preliminary design and completion of technology, final design and manufacturing, system assembly, integration-test-launch, operations and maintenance, ending) [14]. In addition, there are metrics for the evaluation of systems engineering processes generally divided into three categories. These metrics measure the progress of the systems engineering effort divided in the quality of that process and those that measure its productivity (progress in the schedule (S), quality (Q) and productivity (P)). Additionally, these metrics attempt to quantify the efficiency and productivity of the process and its organization, and are often very useful for engineers in space systems [6]. According to the metrics mentioned, the quality metrics relationship should serve to indicate when a part of the systems engineering process is overloaded and/or breaking down. Also, these metrics can be defined and tracked in different ways, e.g., the metrics related with the productivity provide an indication of the systems engineering output per input unit. Although there are more sophisticated input measures and the most common being the number of hours of systems engineering devoted to a particular function or activity. Finally, the schedule-related metrics can be depicted in a table or graph of planned quantities versus actuals quantities, for example, comparing planned number of verification closure notices against the current one [6].

On the other hand, innovation is defined as a process to convert opportunities into practice widely used [15]. Therefore, systems engineering and innovation have common characteristics in many aspects, among them there is a successful system [16], so innovation is also very important in the engineering of space systems. In addition, creativity and innovation are the key in most levels of engineering education, although these topics are rarely expressed, researched, and studied explicitly during the career [17]. Without training in the fundamentals of creativity, only 3% of the population associate creativity and engineering [18]. Engineering education is a paramount in providing the nation with innovative, creative, and critical thinking human capital that contributes to sustainability of the economy [19]. The need for creativity in engineering has led to the development of a lot of creativity support tools to enhance the creative design process. In addition, these tools not only address technology for the creative process, but also include measurement for assessment [17]. Currently, there are several methods of innovation, however, the one that matters to us in this work is the method of design thinking. Design thinking is a methodology that consists of thinking as a designer, it is the way to solve problems reducing risks and increasing the chances of success, focusing on human needs to reach a humanly desirable technically viable and economically profitable solution [20]. The design-thinking ideology asserts that a hands-on, user-centric approach to problem solving can lead to innovation, and innovation can lead to differentiation and a competitive advantage [21]. The important aspect about the design thinking method is its emphasis on the understanding and commitment of the user from the start, it is also particularly useful for engineers, who often see the process of innovation from a perspective of technological push [21].

In particular, the design thinking methodology involves six stages (see **Figure 1**) [22]. This methodology is developed following a process in which five of its important characteristics are valued: the generation of empathy (knowing the people and the users, understanding the client not as a client but as a human being, as a person who moves and lives in a context), teamwork (interdependent persons that are spontaneously and naturally coordinated, with the motive of common project [23]), the generation of prototypes (execute vision since seeing and feeling a prototype has more value than an image printed on a paper), and environment that promotes playfulness and techniques with great visual content (see **Figure 1**) [24]. It should be emphasizing that innovation methodologies are part of systems engineering because they support their practice, however, systems engineering makes the tools used in innovation methodologies more effective and efficient [25]. Therefore, innovation is important in the engineering of space systems. In addition, projects in the space sector are very important and, considering that the technology used changes very quickly, the implementation of innovative techniques is essential so as not to degraded the overall performance. Finally, the studies of analysis, architecture, synthesis and compensation used in space systems engineering directly support innovation and changes management through configuration management. Also explains the evolution of data and information through data management and joining components integration, verification and validation in the innovation process [16].

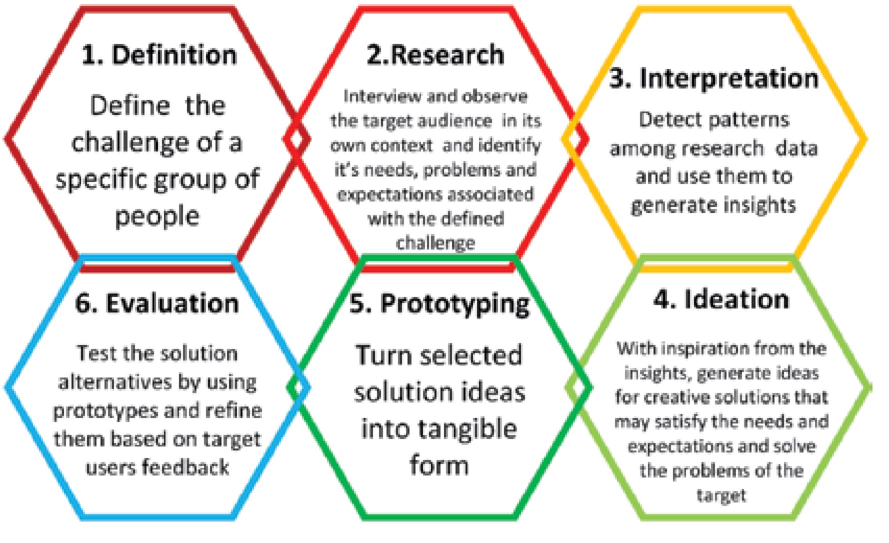

Figure 1.
Design thinking stages. Own elaboration. Information retrieved from [22].

In this chapter, a realization of a framework for the development of space projects using the systems engineering tools and the bases of the design thinking methodology is proposed. This methodology will serve as support or guidance for countries that are beginning in the development of space projects and do not have many resources, this is because currently there are only work methodologies proposed by NASA and European Space Agency (ESA) that contemplate an important diversity of resources. The general structure of the document is as follows: Section 2 presents and analyzes the traditional qualitative and quantitative tools for space project management and their shortcomings, Section 3 shows the methodology proposed for the administration of space projects based on the design thinking methodology and analyzes the relevance and repercussions of the proposal. Finally, Section 4 presents the conclusions and future research and activities to be considered related to the issue and proposal.

2. Qualitative and quantitative tools for space project management

2.1 Qualitative tools

Qualitative tools or methods generally help to identify scenarios that contribute to potential risk, providing an input to quantitative methods and supporting quantification based on the measurement of technical performance [6]. In general, there exists a lot of qualitative tools used in project management, but only a few tools with potential use in space project management will be described.

2.1.1 Risk matrices

Figure 2 shows the risk matrix "N×M" that helps to manage and communicate risks, since it combines qualitative and semi-quantitative probability measures with similar consequences. A risk matrix helps to track the status and effects of risk management efforts, as well as to communicate information about the status of risks [6]. The risk matrix should contain key information about the description of the risk regarding to cost, time, quality, criticality of the risk, summary of the

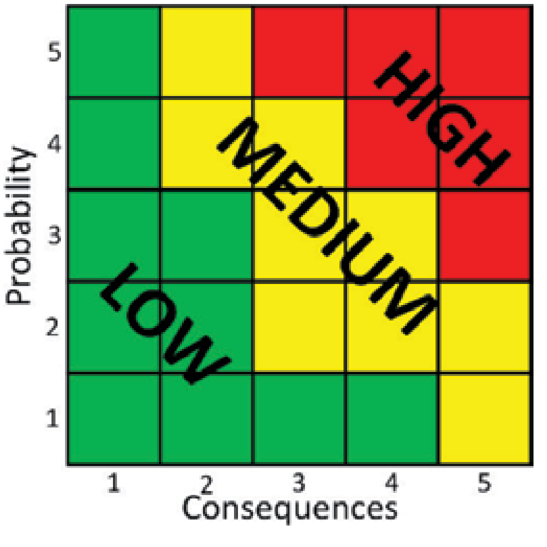

Figure 2.
Risk matrix. Own elaboration based on [6].

possible causes of the risk, consequences, impact on the success/costs of the project, probability of risk occurrence, evaluation of the risk effects based on predefined criteria, description of preventive technical measures, measures to control and countermeasures that should be initiated if the risk occurs. Classification level for risk matrix are shown in **Table 1**.

As each project can have its own parameters and keywords, the information used by NASA and the US government agencies will be used as a reference [6]: (a) green color (low risk): means that there is reduced or no potential for cost increase, interruption of the schedule or degradation of performance, therefore, the actions taken are important to control an acceptable risk; (b) yellow color (moderate risk): means that it may cause an increase in cost, interruption of programming or degradation of performance, it may require special action and management attention to manage the risk; (c) red color: means that a significant increase in cost, interruption of programming or degradation of performance is highly possible. Thus, important additional actions and high priority attention will be taken.

2.1.2 Failure modes and effects analysis

The failure modes and effects analysis (FMEA) is used to identify the possible failures in the process, as well as the effects and causes. Using the FMEA, preventive actions for various tasks can be found and decrease the risk of making mistakes. An FMEA can be used to develop policies, specifications and controls that can avoid the negative consequences of an event. Using this method can be sufficient to prevent or mitigate failures, thus avoiding costs or irreversible damages [26]. The benefits of the FMEA when done correctly are: confidence that all risks have been identified early and appropriate countermeasures, priorities and rationales for actions to improve products or processes, reduce waste, rework and manufacturing costs have been taken, preservation of the knowledge of the product and the process, reduction of failures in the field and cost of guarantee, documentation of risks and actions for future designs or processes [27]. An example of FMEA format is shown in **Figure 3**.

The determination of the risk priority number (RPN) is done by multiplying the values of severity, occurrence and detection, using the information presented by **Tables 2–4**, respectively.

#	Consequences	Probability
1	Despicable	Rare
2	Minors	Unlikely
3	Moderate	Possible
4	Greater	Very likely
5	Catastrophic	Almost sure

Table 1.
Levels of classification for risk matrix.

Process:
Institution:
Responsible:
Core Team:

Prepared by:
Date:
FMEA original date:

Process	Potential failure mode	Potential failure effects	Severety	Potential causes	Ocurrence	Current controls	Determination	Risk Priority Number (RPN)	Actions taken

Figure 3.
Example of FMEA format. Own elaboration.

2.1.3 Ishikawa diagram

Ishikawa diagram (shown in **Figure 4**) was invented by chemist Kaoru Ishikawa who noted that this diagram can be used as an analytical tool in project management and quality search [29]. This diagram is also known as a fishbone or cause-effect diagram and it presents schematically the possible causes of a problem. It can

Severity		
Effect	**Criteria: Severity of Effect**	**Rank**
Dangerous without warning	The highest severity rating of a failure mode, which occurs without warning and the consequence is dangerous.	10
Dangerous with warning	Classification of higher severity of a failure mode that occurs with warning and the consequence is dangerous.	9
Very high	The operation of the system or product is broken down without compromising safety.	8
High	The operation of the system or product can be continued, but the performance of the system or product is affected.	7
Moderate	The operation of the system or product continues and the performance of the system or product is degraded.	6
Low	The performance of the system or product is seriously affected and maintenance is needed.	5
Very low	The performance of the system or product is less affected and maintenance may not be necessary.	4
Less	System performance and satisfaction with a minor effect.	3
Very minor	System performance and satisfaction with a slight effect.	2
Any	Any.	1

Table 2.
Severity levels. Own elaboration based on [28].

Occurrence	
Criteria:probability of failure	**Rank**
Extremely high: almost inevitable failure	10
Very high	9
Repeated failures	8
High	7
Moderately high	6
Moderate	5
Relatively low	4
Low	3
Remote	2
Almost impossible	1

Table 3.
Levels of occurrence. Own elaboration based on [28].

be said that the Ishikawa diagram does not have specific rules for its elaboration, the only important aspect is the way in which the causes can be found. They are divided into 5 categories that are defined and known as the "5M" (Men, Machines, Methods, Measurements, Materials). Each branch of the diagram represents a category

Detection		
Effect	**Criteria: Severity of Effect**	**Rank**
Absolutely impossible	The design control doesn't detect a possible cause of failure or the subsequent failure mode, or there is no design control.	10
Very remote	Very remote possibility that the design control detects a possible cause of failure or a subsequent failure mode.	9
Remote	Remote possibility that the design control detects a possible cause of failure or a subsequent failure mode.	8
Very low	Very little chance that the design control will detect a possible cause of failure or a subsequent failure mode.	7
Low	Little chance that design control will detect a possible cause of failure or later failure mode.	6
Moderate	Moderate possibility that the design control detects a possible cause of failure or a subsequent failure mode.	5
Moderate high	Moderately high chance that design control will detect a possible cause of failure or later failure mode.	4
High	High probability that the design control detects a possible cause of failure or the subsequent failure mode.	3
Very high	Very good probability that the design control detects a possible cause of failure or a subsequent failure mode.	2
Almost sure	The design control detects a possible cause of failure or the subsequent failure mode.	1

Table 4.
Detection levels. Own elaboration based on [28].

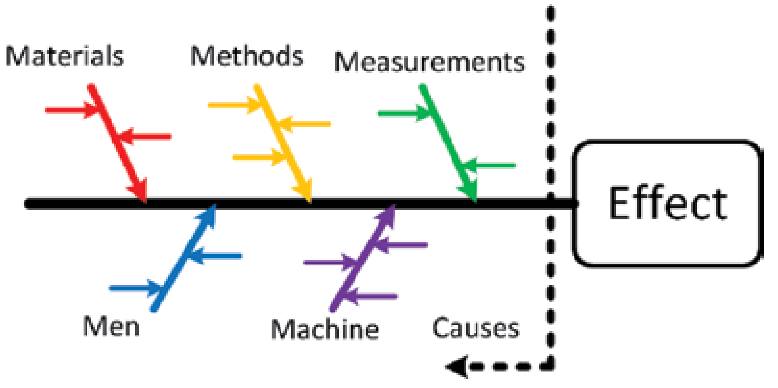

Figure 4.
Ishikawa diagram. Own elaboration.

and these in turn have sub-branches that represent the causes. The categories are described as follows:

- Men: anyone involved in the project.
- Machines: all equipment or tools used.
- Methods: from how the process is carried out to the specific requirements.
- Measurements: all the generated data that are used to evaluate the quality.
- Materials: raw materials used to produce.

Ishikawa diagram provides a methodology which may include all possible considerations and although it looks slightly different from the form it takes, it is very similar to the mental map where all ideas are puts together based on a group brainstorming [30].

2.1.4 Fault tree

A fault tree is a model that represents graphically and logically the various combinations of possible events, both defective and normal, that occur in a system that leads to the unwanted future event. The main advantage of the method is its systematization, since it allows determining the multiple factors that contribute to the failures. It is used for the qualitative analysis to determine the situation of risk, and for the quantitative analysis, which allows to determine the probabilities of event sequences. Generally, its elaboration is a complicated and slow task, since the first step is to determine the individual superior event, then to analyze the sub-events enough data [31, 32]. **Figure 5** shows the basic symbols used for the fault tree elaboration.

Next, a brief description for each basic symbol is given. In addition, **Figure 6** shows a basic fault tree example.

Basic event: represents the origin (commonly called root) of the fault or error, generally found in the lower part of the fault tree [33].

Intermediate event: represents the negative event and it is commonly located at the top of the tree, although it can also be found throughout the tree to indicate other events [32, 33].

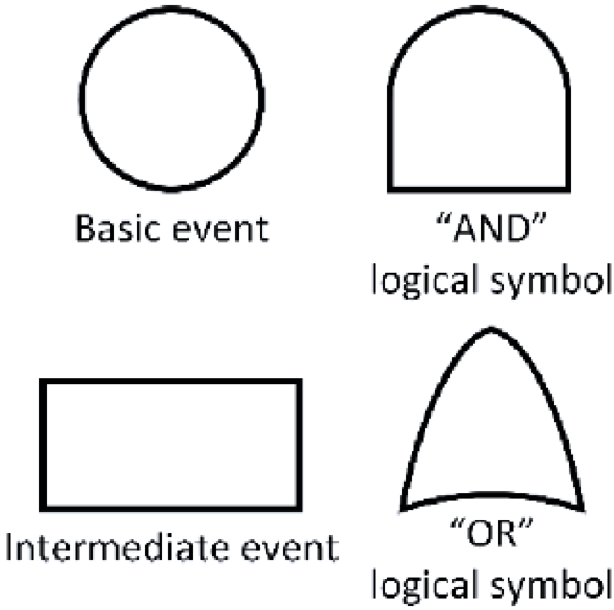

Figure 5.
Fault tree symbols. Own elaboration.

¨AND¨ logical symbol: represents a condition where the output occurs only if all the inputs occur in the result event, i.e., it will only occur if all the input events exist simultaneously [32, 33].

¨OR¨ logical symbol: condition where the event will occur only if one or any combination of the input events occurs [32].

2.2 Quantitative tools

Quantitative tools help to obtain a measureable prediction of the probability of occurrence of a failure or risk in such a way that they can be prevented [6]. These tools are usually from the field of statistics.

2.2.1 Gantt chart

The Gantt chart is a very simple time charting tool that is quite effective for planning and evaluating the progress of projects [34]. **Figure 7** shows a custom Gantt chart. Basically, the Gantt chart is a bar graph placed on its side, where the horizontal axis corresponds to time and the vertical axis to related activities [35]. Among the advantages of the Gantt chart is that it clearly shows which activities are advanced or delayed, so it becomes an excellent communication tool, and almost everyone can read or build it [36]. Consequently, the Gantt chart can be used as a controller for project planning as it can ensure that all problems are addressed as required [37].

2.2.2 Critical path method

The critical path method (CPM) is a technique based on a network diagram, similar to PERT, except for the handling of uncertainty in the context of activities, i.e., it is also used with a property, in addition to a unique time estimate for each activity [38]. This method is widely used in project management as it serves to

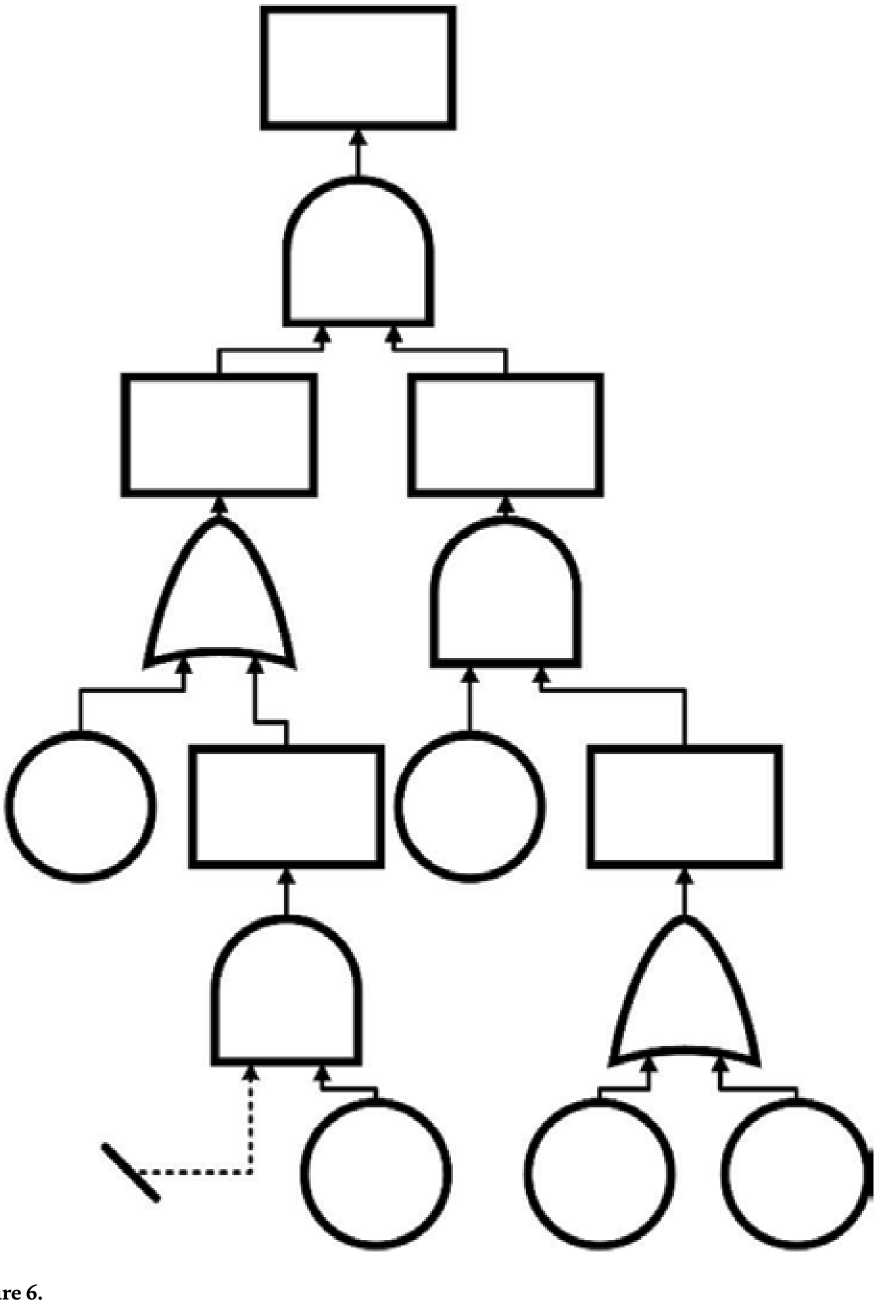

Figure 6.
Fault tree example. Own elaboration.

develop strategies and schedules using a one-time estimate for each activity that comprises the project [39]. An important benefit of this method is that it summarizes in a single document the general image of the entire project, which helps to avoid omissions, quickly identify contradictions in the planning of activities, achieving that the project is carried out with a minimum of stumbling. In particular, the method consists in the following stages: identify all the involved activities, establish relationships between the activities, decide which one should start before and which one later, construct a diagram connecting the different activities to their precedence relationships, define costs and estimated time for each activity, identify the critical path and slack activities, and finally, use the diagram to help planning,

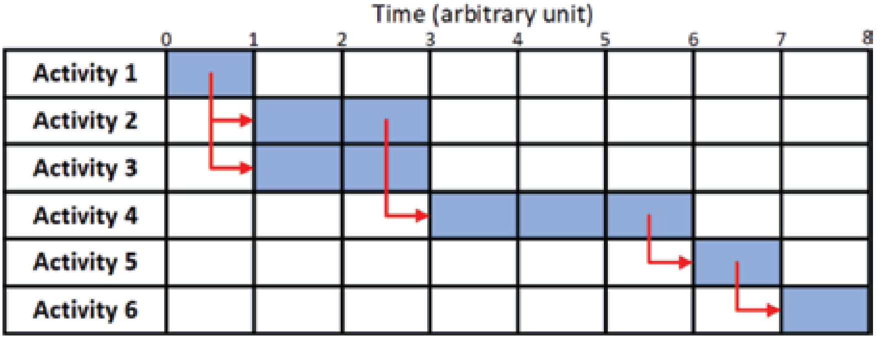

Figure 7.
Gantt chart example. Own elaboration.

monitoring and controlling the project. The elaboration of the critical path method consists of the following two cycles:

***Cycle 1*:** consists of the definition of the project, creation of a list of activities, matrix of sequences, time matrix, network of activities, costs and pending activities, understanding of the network, time constraints, economic resources and elasticity matrix [40].

***Cycle 2*:** consists of the execution and control of the project, it ends when the last activity of the project is running and, meantime, it can have adjustments based on the differences between the scheduled and expected activities [40].

2.2.3 Program evaluation review technique diagram

The program evaluation review technique (PERT) is a method to plan and program a project that models the uncertainties for each activity using optimistic, probable and pessimistic time estimation [41]. A PERT diagram can be as simple or complex as needed, but it always involves three basic elements for its elaboration: circles where activities are written, lines that represent the direction of progress and dates that indicate the time of completion. The steps to perform a basic PERT diagram are: define the activities, indicate the necessary requirements before starting each activity and estimate the time required for each activity [42]. **Figure 8** shows a PERT diagram example.

The PERT diagram provides a methodology that is used to estimate the probability of completing the project for a specific duration. This methodology is based on calculating the standard deviation (difference between pessimistic and optimistic time, divided by 6, see Eq. (1)), variance for each activity and variance for critical activities to obtain the standard deviation of the complete project and finally the probability of success [38].

$$\text{standard deviation} = \frac{\text{pessimitic time} - \text{optimistic time}}{6} \tag{1}$$

The standard deviation for the project is the square root of the sum of the variances of the critical activities. Once obtained this value, the probability is determined by calculating the z value and using a probability table for multiple z values as Eq. (2) shows.

$$z = \frac{D - t_e}{\text{standard deviation for the project}} \tag{2}$$

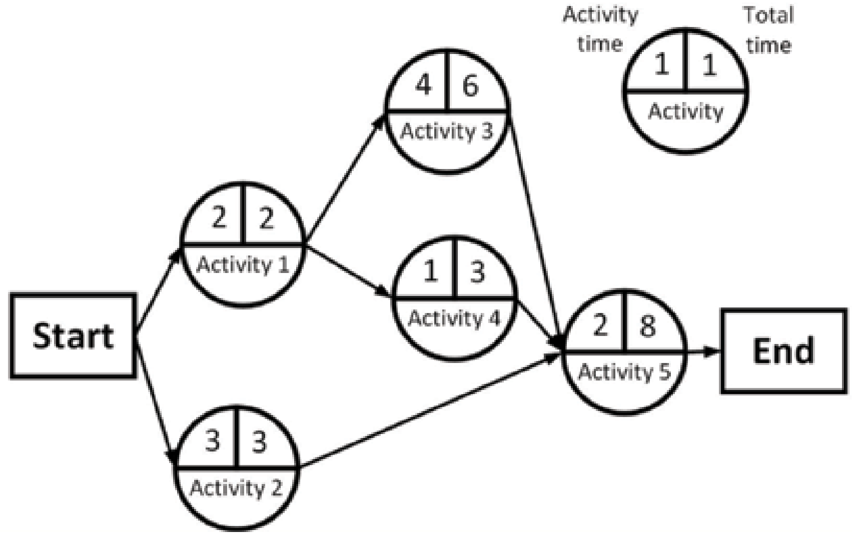

Figure 8.
PERT diagram example. Own elaboration.

where D is the date on which the project must be completed and t_e is the estimated termination in accordance with the critical path (maximum time required to complete the project).

2.3 Shortcomings of space systems management tools

The tools used in project management, despite being widely used, sometimes can omit important aspects of the project, i.e., they have important deficiencies and particular trade-off during their application. Occasionally, these shortcomings are not mentioned or known by the project team, so, the probability of success is decreased drastically. However, these tools are still very useful in project management because they can be applied to any type of project to have an orientation of what and how should be achieved. **Figure 9** shows some shortcomings of space systems management tools mentioned.

Figure 9.
Shortcomings of space systems management tools. Own elaboration. Information retrieved from [6, 27, 35, 43, 44].

Thus, if the shortcomings of these tools are found in a space project, they could cause great economic losses, since some parts of the project may be too important for an adequate development and performance. For example, when an Ishikawa diagram is applied for space projects, it is very important to consider all the possible causes of failures without exception to identify clearly critic activities. Thus, the previous analysis permits the team to act in case of any occurrence. Hence, it is necessary not to limit oneself to the moment in which it is being carried out and to dedicate the necessary time. In particular, the shortcomings of these tools are sometimes considered and a countermeasure to reduce them is to have a wider selection criterion on the personal who will be responsible for implementing the tool in the project. Otherwise, when these shortcomings are not considered, the results of the project may not be as expected or may simply be incorrect, even if the leader and personal believe that the project performance is adequate.

3. Proposed methodology

The methodology for the management of space projects proposed in this document is based on design thinking framework and it uses the tools mentioned in Section 2 (see **Figure 10**). To increase the performance of the proposal, the tools mentioned will work together using the brainstorming technique in different stages of the design thinking framework according to the shortcomings described. In addition, this methodology proposes the use of meetings that will serve as reviews between each stage of the design thinking method to prevent the progress to the next stage if something is unusual, i.e., review meetings will serve as filters based on a continuous feedback.

In particular, the methodology is described as follow:

- At stage 1 (definition) the Gantt chart is used to plan the overall project, from the activities order and time required until to define the person carries out such activity. Also, the Ishikawa diagram and FMEA can be used to contemplate critical activities. The purpose of the review meeting after stage 1 is to clarify the objectives to be achieved, so as not to move on to the next stages without having a unique specific definition. This stage is one of the most critical because the success of the project depends to a great extent on it.

- At stage 2 (research) the risk matrices, the fault tree and the Ishikawa diagram are used, since they will help from the first stages to identify possible causes of failure risk for the project. After stage 2, another revision meeting follows since it is important to verify that all possible failure causes have been considered by systems engineering tools.

- At stage 3 (interpretation) the PERT diagram and CPM are used to recognize the critical path of our project. At the end of stage 3, another review meeting is held since this is the intermediate stage of the project and making the meeting at this point helps us to follow the rest of the project along the best path.

- At stage 4 and 5 (ideation and prototyping) all tools could be used. Between stages 4 and 5 as well as after stage 5, review meetings are important because at these points the project is already taking shape and it is completely close to what will be its end.

- At stage 6 (evaluation) the FMEA can also be used to evaluate the possible causes of problems and identify how to control or eliminate them.

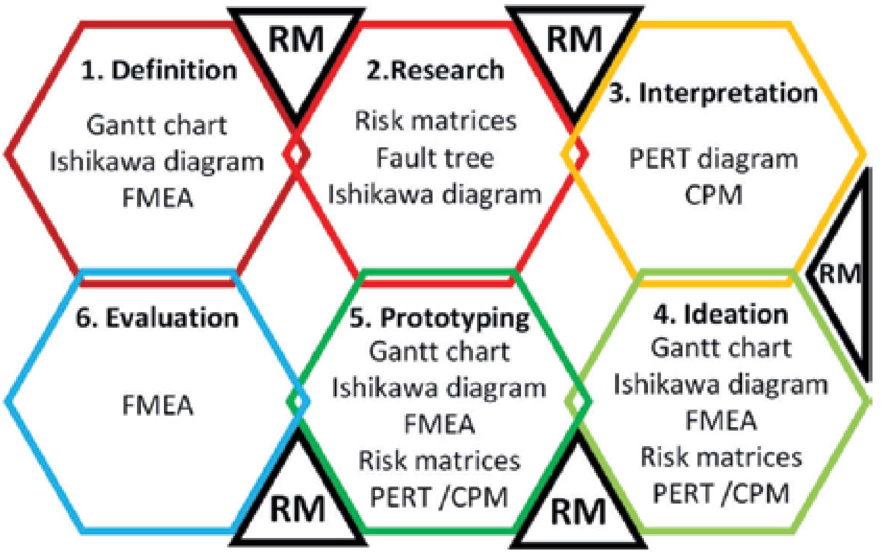

Figure 10.
Proposed methodology stages. RM: Review meeting.

- The final revision meeting it is essential because is necessary to ensure that everything that was done is correct. In addition, a feedback of the whole project is given.

The brainstorming technique could be used in all stages because it is a support tool. However, other tools can be used to complement or support all stages of the project. Finally, the conventional design thinking methodology presents an important disadvantage; unclear rules and statements were considered to determine the particular stage and future stage of a project. Therefore, our proposal uses management tools in different stages of the methodology proposed. In addition, it is possible to use Markov chain theory to determine the transition probability among the stages of the project.

4. Conclusions and future research

Conventional systems engineering tools were analyzed to be used in a design thinking framework for space project management. Each tool analyzed presents inherent shortcomings. In fact, although these tools are widely used in many engineering sectors, their trade-offs have not been investigated in deep to improve the overall project management using innovative countermeasures. Thus, the use of methodology proposed will help to make the conventional space systems projects management more efficient, because it will reduce the shortcomings of existing tools and to improve the prevention of possible failures causes as well as their effects. Although many high-end methodologies regarding the space project management are used around the world, our proposal is suitable for emerging countries and space agencies that require to optimize their resources to accelerate the aerospace industrial sector based on the academic and scientific regional contributions. In this context, the present proposal is being analyzed to be applied in a real space project, either for particular space products (e.g., antenna systems, attitude actuators and sensors, payloads, structures, solar panels and power systems, among others) or small satellites missions.

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Chapter 4

Value Stream Mapping: A Method That Makes the Waste in the Process Visible

Nuri Ozgur Dogan and Burcu Simsek Yagli

Abstract

Defining customer and value in lean thinking is crucial. All wastes that do not add value to the customer in business processes should be eliminated. In the real world and related literature, there are various methods used to eliminate waste and improve processes. One of the methods frequently used is the value stream mapping (VSM). VSM is preferred since it enables to take the picture of a process. Moreover, VSM is the identification of all activities that create and/or do not create value in the processes, from the supplier of the product or service to the customer. This chapter deals with lean philosophy, lean techniques and specifically the VSM method. In addition, some examples of VSM applications in the service and production sectors are discussed and the findings obtained from these applications are evaluated. Finally, the chapter concludes with some managerial implications as well as potential future research areas.

Keywords: lean thinking, lean techniques, production and service sector, value stream mapping, waste

1. Introduction

Originating from Toyota production system (TPS), lean production (LP) or lean manufacturing (LM) has now become a well-known and widely adopted philosophy all over the world. Its first usages were limited with the production industry and therefore its initial applications emerged in the manufacturing businesses. As time passes, the service industry has begun to utilize from the LP philosophy and/or techniques. As the adaptation of lean expanded from production sector to service sector, its concept transformed from LP to lean thinking (LT).

Historical evolution of the "lean" started with TPS and continued as LP/LM, and finally became LT. No matter what anyone says, each of these terms indicates the same concept. Eliminating or at least minimizing the waste (Japanese: muda) in a system is the basic philosophy of lean and to produce the maximum output by using minimum resources is the main goal of it. Lean seeks for a system that tries to detract non-value added things from the processes and bring the value-added things into the forefront. These efforts become meaningful if the value is defined correctly and the system is designed and conducted truly. Value must be defined by the customer since he/she is the end user of the product and/or service. Thus, to give exactly what the customer wants, businesses must take into consideration the concepts of efficiency and quality. It is clear that an efficient and quality focused system uses the resources exactly as needed and produces products and/or services that satisfy the customers.

Many organizations from production or service sectors implement lean production as its main system or apply lean principles partially in its specific activities. These organizations utilize from LT with the aims of becoming more efficient, more competitive, and more quality oriented. Furthermore, in recent years LT spread from a single business to supply chains of multiple businesses. It is possible to say that LT attracts many businesses and these businesses want to transform into a lean business. Lean transformation process is an important inflection point for a business and it must be carefully initiated, designed and managed. The starting point of this transformation process is crucial and right method(s) must be used during the phase. Value stream mapping (VSM), one of the methods of LT, is the most suitable method that can be used in the first step. VSM is a paper and pencil based method that focuses on the current state of a process, makes all value and non-value added activities visible, and proposes a lean future state. VSM is dealt with in this chapter in a detailed way.

The rest of the chapter is organized as follows. Section 2 focuses on lean philosophy. Lean techniques are examined in Section 3, and VSM is explained in Section 4. In Section 5, there are VSM examples from the service and production sector for a better understanding of the subject. Finally, this chapter ends with discussion and conclusion.

2. Lean philosophy

Businesses should be recognized the importance of customer and value concepts. Customers do not want features that do not create value in products or services. All sectors, both product and service sector, should pay attention to this situation in order to compete with their competitors. This is because customers are not willing to pay extra for features that do not create value. Value can be categorized into three types: value added, non-value added and necessary non-value added operations [1]. Value added operations are processes that please the customer and must be in the process. Necessary non-value added operations are wasteful but necessary. Lastly, non-value added operations are completely wasteful and must be eliminated.

Lean philosophy is defined by Radnor et al. [2] as *"Lean as a management practice based on the philosophy of continuously improving processes by either increasing customer value or reducing non-value adding activities (muda), process variation (mura), and poor work conditions (muri)."* As can be seen from the definition, lean philosophy has emerged within the framework of some elements, especially waste (muda). Lean production is typically believed to be 7 types of waste [3]. These wastes are over production, waiting, transportation, over processing, inventory, unnecessary motions and defects (**Figure 1**).

The importance given to the service sector is increasing day by day. The lean production mentality continues to be implemented in the service sector. Lean philosophy, both production and service sector value, optimization, quality, standardization and simplification principles are common [4]. However, the wastes defined as 7 types in lean production are 10 types (**Figure 2**) in the service sector [5].

If the wastes are eliminated and the costs of waiting in stock are reduced, customer satisfaction and related sales will increase. Therefore, the purpose of both customers, employees and business partners will be achieved through the adoption of lean philosophy. On the other hand, in order to ensure continuous improvement, the wastes in the process must be converted to value. Furthermore, due to the rapid change in customer expectations, it is important to achieve perfection. Thus, Womack and Jones [6] proposed a *The 5 Steps Model* to help transform from value to perfection [7]. **Table 1** contains the 5 steps model and explanations of the expressions [6–11].

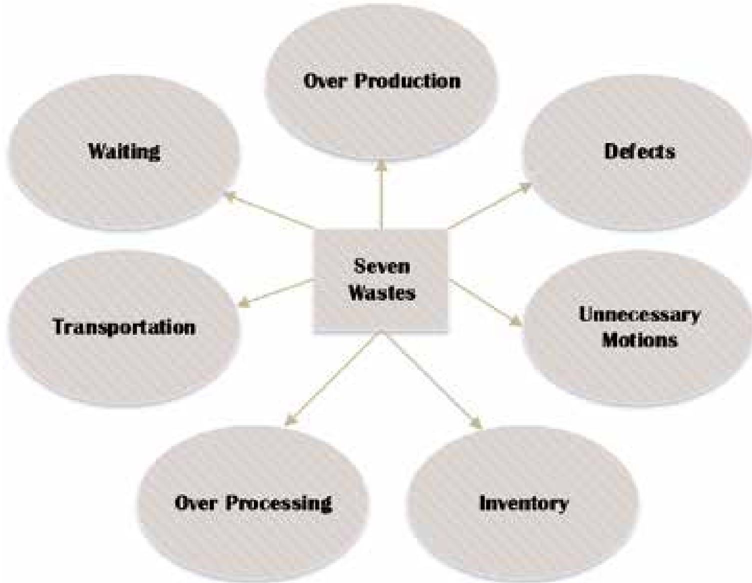

Figure 1.
Seven types of waste.

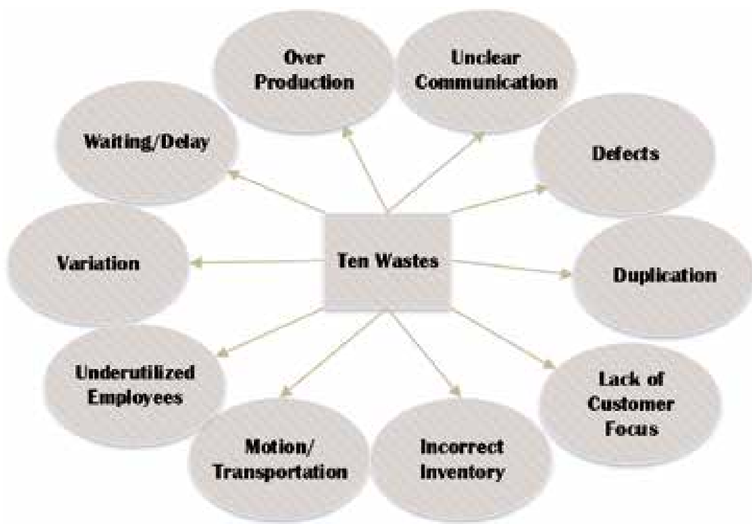

Figure 2.
Ten types of waste (service sector).

A number of lean methods are used in the realization of these steps (detailed descriptions in the next section). JIT and Kaizen, in particular, are the main philosophies in achieving continuous improvement and in reaching perfection [12]. Besides, lean philosophy has many benefits for businesses, employees and customers. These benefits are, reduced lead time, less rework, financial savings, increased process understanding, reduced inventory, less process waste, satisfied customer, standardized processes, improved knowledge management [3, 13].

There are some principles to apply the lean philosophy successfully in a organization [14]. It is a pyramid with 4P of lean way formed by the Liker's 4P of the Toyota way [15]. The 14 principles are represented by 4P [16]: philosophy, process, people and partner, problem solving (**Figure 3**).

The steps	Explanations
1. Value	Value is the source of the pleasure and needs of the customers who buy the product or service. It is the starting point of lean philosophy. It is necessary to understand the needs of the customers, to define the value correctly, and to implement this in all processes
2. Value stream	The value stream is all the activities needed during the generating of the product or service. These activities may be activities that add or do not add value to the product or service. Additionally, with all activities being seen, wastes that non-value adding will be recognized
3. Flow	Continuous flow can be achieved by detecting and eliminating the wastes in the process. Furthermore, it is necessary to implement this throughout the value chain to ensure full flow, not just one process
4. Pull	The pull system means that production or service will not be commenced without a customer approval. This is the exact opposite of the push system. Production will be tailored to the customer in this system. In addition, over production and unnecessary inventory are prevented by JIT applications
5. Perfection	Perfection is the last step that separates value and waste. This step regulates the flow, ensures the continuity of the flow and initiates the pull system. Perfection is maintained by continuous improvement. Perfection means that lean thinking is adopted and implemented

Table 1.
The 5 steps model.

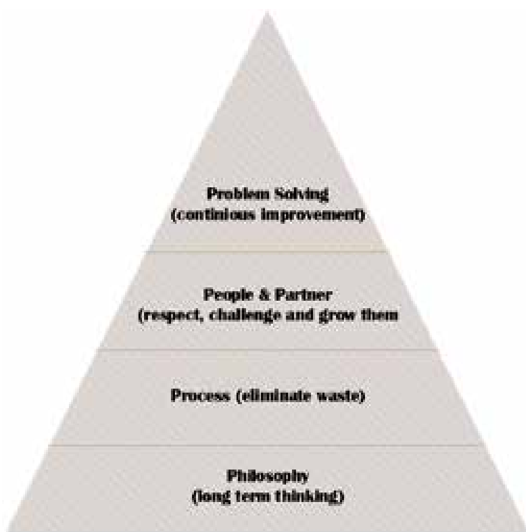

Figure 3.
The 4P of the lean way [10].

Koskela [17] also defined the principles (11 principles) adopted in lean thinking as Liker [10]. The main theme of the lean principles proposed by the two authors is similar to that of Womack and Jones [6] in the 5-step model. This theme consists of defining the value, providing the flow, solving problems with lean techniques and aiming to reach perfection.

3. Lean techniques

Within the scope of lean thinking, there are numerous methods used to reach the targets and minimize the wastes. Some of the lean methods for becoming lean as a system are crucial in the lean systems such as value stream mapping (VSM), single minute exchange of dies (SMED), the 5S system, one piece flow, just in time (JIT), pull system (Kanban), Poka-Yoke, total productive maintenance, Kaizen, visual controls/management, 5 whys (5N), standardized work, spaghetti diagram, DMAIC, PDCA and so on [12] and they will be briefly described in this section.

3.1 Single minute exchange of dies (SMED)

SMED method is developed by Shingo in the 1950s and later perfected by Toyota over the years [18]. SMED has become the best practice to simplify and reduce the time spent on set up. Time is very important in lean systems and is not expected to be wasted. That's why, this method has an important place in lean techniques. Thanks to SMED method, changeover time is reduced from hours to minutes. In simple terms, it is attempted to decrease the preparation time on a machine or any process to less than 10 minutes [12]. Perhaps the best example of the application of this method is automobile racings.

Set up times is separated as internal and external. The activities performed by stopping the machine are called the internal set up time, while the activities carried out around the machine without stopping the activity are called external set up time [19]. In this point, some of the internal tasks may need to be converted to external tasks without stopping the machine [20]. Thus, continuous flow can be achieved and processes become faster and more efficient. With the improvements in internal set up time, labor savings are achieved and the downtimes of the machine decrease. Moreover, improvements to external set up times do not have a direct impact on stopping time, but may give operators the freedom to take time for other activities.

3.2 The 5S system

The 5S system is a visual communication technique that enables the working area to be well organized [11]. It also helps to reduce waste in the working area through general cleaning. This method is preferred when it is aimed to ensure cleanliness and organized workplace layout, to improve processes, to ensure transparency and to rise up employee satisfaction. Five Japanese words, starting with the letter *S*, are used to create this method. These words are *seiri-sort*, *seiton-straighten*, *seiso-shine*, *seiketsu-standardize* and *shitsuke-sustain* [13]. Buesa [21] stated that some experts add two new terms are safety and security. Lastly, with the implementation of the 5S cycle, it is possible to change the working environment with low costs. Moreover, employees respect to their organizations and themselves, and inventory and material costs are decreased.

3.3 One piece flow

By the one-piece flow technique, it is intended to move a single piece at a time between operations. The one-piece flow method takes into account factors such as sorting jobs, calculating installation time, and determining job shop production policy [19]. Therefore, these factors need to be examined during production planning. Planning a production according to one-piece flow is an important component of lean production strategy. The installation time, the stock levels and the delivery time are directly affected by the lot size. In view of these situations, it is very important to be an agile business to respond to customer needs without creating inventory [12]. This can be achieved by reducing the lot size in lean production.

3.4 Just in time (JIT)

The just in time philosophy adopted by Toyota is a system that regulates the stock level and optimizes the flow of materials. According to the JIT production strategy, what is needed is produced in the desired amount and time [22]. In this concept, the production of more than the amount needed and stocking are considered as waste. Thus, wastes in processes are eliminated by using the JIT philosophy. Furthermore, the quality-related problems are easily identified thanks to the low level of inventory. In addition to these advantages, JIT offers businesses the flexibility and speed required to keep up with global competition.

3.5 Pull system/Kanban

In lean thinking, workflows are usually applied with the pull system. The pull system is defined as the system by which the customer decides to start production or service [23]. In this system, since the production is started when there is demand, the wastes like excess inventory and overproduction is prevented. In addition, the companies that decide to implement the pull system must fulfill their customer demands within a certain time frame. For this purpose, it is inevitable to use *Kanban* cards. Kanban cards is a Japanese term given to cards used to control the flow in the process such as inventory control [19]. Additionally, control of the variations in demand and production can be provided with Kanban cards [24].

3.6 Poka-Yoke

A Japanese word, Poka-Yoke, means mistake proofing and error avoidance [25]. In this way, errors are detected at the source and prevented from passing to the next step. The basic principle of the technique is to reduce the cost by reducing the number of defective parts that can occur during the production process to zero [26]. Poka-Yoke is preferred for quality at the source. Moreover, the Andon technique, which consists of lights that make it appear when errors occur, are also used.

3.7 Total productive maintenance

Lean systems attach importance to continuous flows. The businesses want to avoid as much as possible the failures and machine errors that may occur during the process. For this reason, total productive maintenance (TPM) technique, should be implemented as routine preventive maintenance with the participation of all employees. TPM is an approach that requires the participation of all the employees within the daily production activities, which also brings the necessity of the maintenance of the equipment that it works on, prevents the errors and maximizes the efficiency of the equipment [27]. However, it is necessary to provide interdepartmental trainings to employees for this maintenance.

3.8 Kaizen

The main philosophy of lean system is the adoption of continuous flow and improvement. All other lean methods try to achieve this philosophy to perfection [28]. Kaizen, based on the concept of continuity, is a process improvement program that will never end. In order to make improvements in the existing production system and to find solutions to the problems identified, employees from different disciplines must come together in the Kaizen activities. In this meeting, wastes are defined and attempts are made to prevent the occurrence of other wastes. Lastly, the main basis of continuous improvement is undoubtedly the fact that top management believes the lean philosophy and provides full support to employees.

3.9 Spaghetti diagram

The spaghetti diagram is the visualization of the movement and transportation of the product or service in the value stream [29]. Employees can collect the data via this method [13]. Because the movements of products and services are clearly visible with this activity. Thus, the wastes during the flow can be easily determined. Besides, the problem determination and solution suggestions for eliminating non value added work steps and distances can be collected with the help of the opinions of the employees.

3.10 Whys (5N)

The 5N method is briefly the process of defining and writing specific problems. As it is understood from this definition, it is questioned why the problems arise and their answers are written under the determined problem. If the answer is not the root cause of the problem [13, 30], the evaluators will continue to ask until the root cause is determined. In the 5N method, it is tried to eliminate the wastes by asking the questions of the cause and the reason causing this problem [31]. In this way, the root of the problem is determined and solved not to occur again.

3.11 Standardized work

The standardization of works and processes has been developed based on the kaizen philosophy [32]. In order to ensure continuous flow, it is necessary to repeat the processes with the same quality every time. By using the standardized work method for repetitive tasks, employees will be trained in the steps of the processes according to the predetermined standards, which will allow quality improvement. Moreover, as employees know exactly what to do, their work satisfaction and motivation increase.

3.12 Visual controls/management

Visual control is a method based on organizing the working area so that management and workers can understand whether there is something going wrong in a way. The use of visual control method wherever the process takes place and its adoption can be evaluated as visual management. By using simple visual schemes, the communication between the employees becomes clear and the areas of responsibility of the employees can be determined by ground lines. In this way, processes can be viewed visually, employees are not forced and errors are prevented.

3.13 DMAIC and PDCA cycle

DMAIC and PDCA are cycles that monitor and examine business processes from start to finish. DMAIC (define-measure-analyze-improve-control) is an integral part of the six sigma method. This method is a systematic and result oriented. If there is flexibility during the processes, the most effective results can be obtained from this method. In addition, steps that do not add value are eliminated [33].

The PDCA (plan-do-check-act) cycle was first developed by Shewhart [12]. This method is more effective than the philosophy of doing it right the first time. Because, by using the PDCA cycle, better improvement methods are sought [33]. PDCA cycle consist of for stages: planning for improvement, doing improvement actions, checking the implications of improvement actions, and making effective permanent actions

Classification	Lean tools & methods
Assessment	Value stream mapping, 5 Whys (5N), A3, Ishikawa diagram, process mapping, Gemba walking
Improvement	5S's, spaghetti diagram, continuous flow, Kaizen, pull system/Kanban, one-piece-flow, Poka-yoke, team approach to problem solving, workload balancing, Andon, Jidoka, process redesign, Heijunka, physical work setting redesign, standardized work
Monitoring	Visual control
Assessment/improvement/monitoring	DMAIC (define-measure-analyze-improve-control), PDCA (plan-do-check-action)

Table 2.
Lean tools and methods and their classifications [35].

toward improvement. In these methods, precise measurements of product and process variability are made. In addition, all processes focus on statistical control [34].

Thanks to these lean tools and methods, to adopt the lean philosophy becomes easier; at the same time the philosophy is ensured to become permanent. These techniques are also thought to eliminate waste in production and service processes. Moreover, the lean methods are divided into three categories by Radnor et al. [2] as assessment, improvement and monitoring. In addition, these methods that frequently preferred in the literature are classified by Costa and Filho [35] the frame of three categories (**Table 2**).

VSM is the most important and most widely used method. In addition, since VSM forms the main framework of this chapter, it is examined in more detail in the next section.

4. Value stream mapping

As a result of increasing interest in lean thinking, executives strive to transform their processes into a lean system. Lean techniques help ensure the lean in processes. One of the commonly applied lean methods is the value stream mapping (VSM) method introduced by Rother and Shook [36].

VSM is a demonstration of whole activities that value added and non-value added in processes by using a pen and paper [36]. VSM; a technique that helps determine and understand the resource and information flow of a product or service throughout the process. It is desirable to eliminate the wastes in the value stream in this method [29].

The aim of the method is to identify activities that non-value added to the product or service in the eyes of the customer and to improve the process by eliminating the wastes. The steps of the VSM method created to accomplish this aim are shown in **Figure 4** [36–38]:

The first step in VSM is the selection of product family with common features or similar processes to avoid complexity. Then, the current state map showing the current process is drawn. What is important here is that the entire process from supplier to customer is included in the map. In the third step, the situations necessary for the development of the process that is dealt with the future state map are mapped. The color of the third step is different because VSM has no meaning if improvements are not recommended after the current state map [36]. In the last

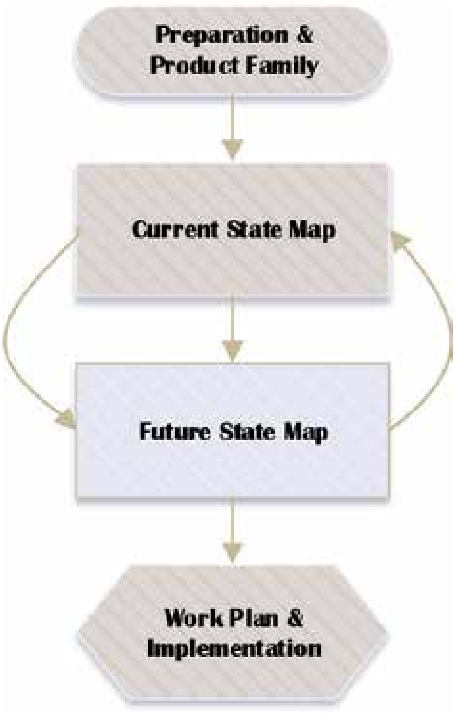

Figure 4.
The value stream mapping process.

step, based on the elements identified on the map, it is discussed and applied what needs to be done, how much time is needed, who should take responsibility in each field and what the expected outcome from each activity is.

Standard symbols are accepted for demonstrating material flow, information flow and general information in VSM [23]. Some icons representing these symbols are provided in **Figure 5**.

The use of the VSM method has several advantages. Advantages of VSM method are listed below [18, 39]:

- ensures that the examined process is handled from beginning to end
- provides visuality thanks to symbolic representation
- procure the identification of the resources causing waste during the process.
- shows the relationship between information flow and material flow
- includes different application steps and implementation plan for continuous improvement

In addition, VSM method determines the system's takt time, lead time and cycle times. In this way, the result of improvements in the future state map can be revealed. The terms here are briefly defined (see [19, 40]):

- *Takt time* is the speed at which goods or services must be produced to meet customer demand. Takt time is calculated by dividing the daily total production time by daily customer demand.

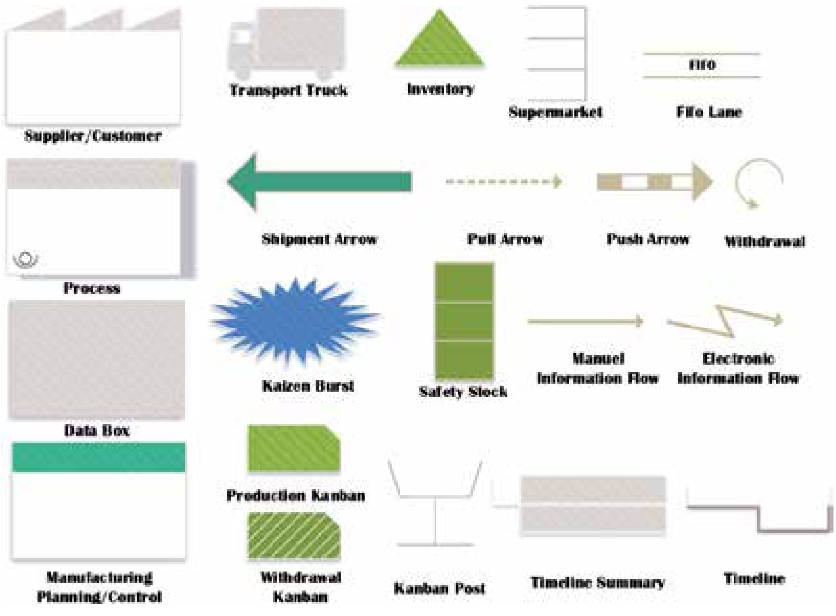

Figure 5.
Value stream mapping icons.

- *Lead time* (in days) is calculated by dividing the number of inventories between the processing steps into the daily demand.
- *Cycle time* is expressed as the maximum time spent on a unit in each station. Cycle time is calculated with a simple formula: 1/output rate per hour in units.

5. Sector specific applications of VSM

For a better understanding of the subject, it will be useful to support the VSM method with examples. In line with this purpose, two examples, one of them from service sector and other from production sector are given.

5.1 Service sector example

The first example is from the service sector. The graduation, specifically the exmatriculation process of university students is selected. As aforementioned earlier in this chapter, the first stage of the VSM method is the identification of the product/service family. Here; the exmatriculation process of a university is determined as the product family. Then, the current situation of the flow in this process is observed and the current state map (CSM) is created (**Figure 6**). As seen in **Figure 6**, there are 12 steps in this process. The flow starts with "transcript control" step and ends with "completion of process". In this map, various wastes stand out. For instance, unnecessary motions (meeting with advisor step), defects (meeting with advisor step), over processing (paper-work and head of department steps), waiting (head of department and filling out the survey steps), and inventory between processes (between department secretary and filling out the survey steps). A future state map (FSM) is drawn in order to eliminate these wastes (**Figure 7**). The first suggestion is that, student information system should be used actively. Moreover, various lean methods are proposed to eliminate the wastes generated during the processes. These lean methods are 5S, Poka-Yoke, quality at the source, kaizen, balanced work flow,

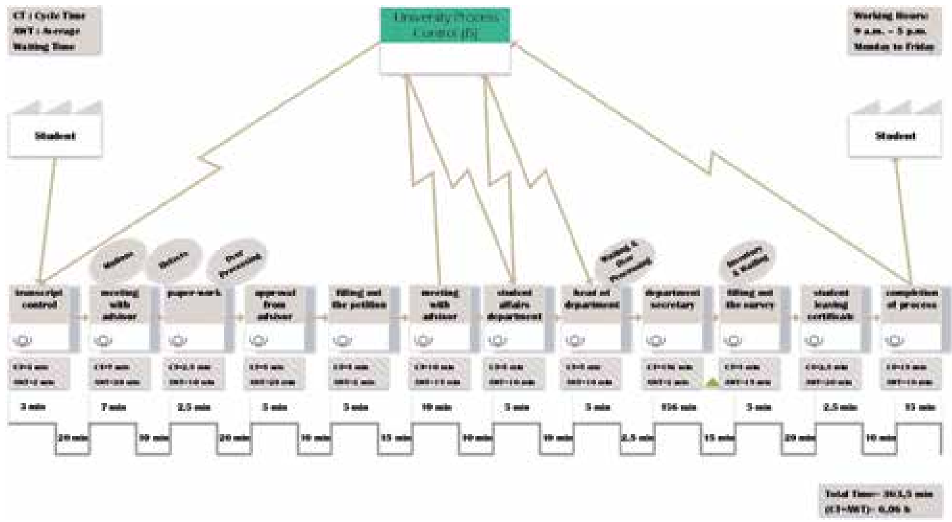

Figure 6.
Current state map (service sector).

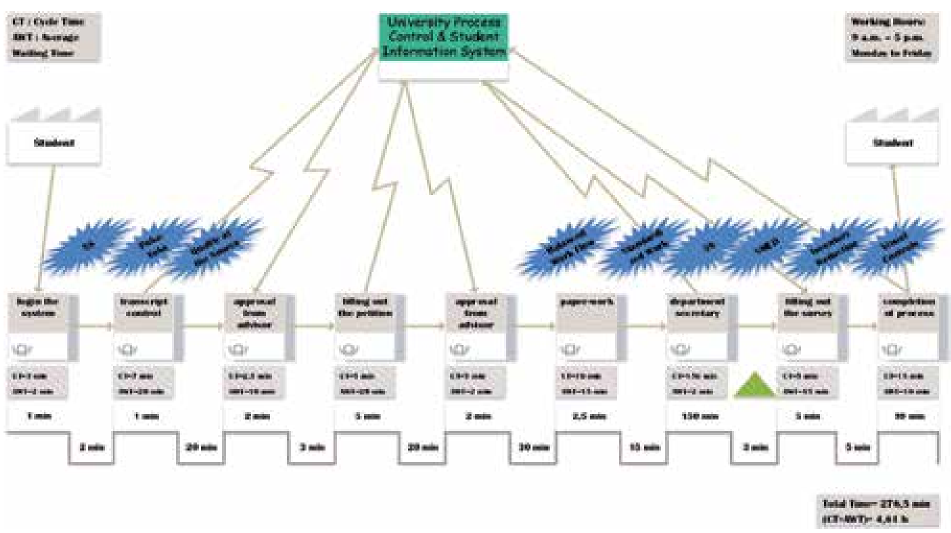

Figure 7.
Future state map (service sector).

standardized work, SMED, inventory reduction and visual controls. If the CSM (**Figure 6**) and FSM (**Figure 7**) are compared simultaneously, it is possible to see the wastes and how to eliminate them. As a result, while continuous flow is achieved, the total time is reduced from 363.5 to 276.5 minutes. This indicates an improvement of 0.24% in the process. In addition, resources are used efficiently and customer (student) satisfaction is ensured.

5.2 Production sector example

For the production sector application, a furniture factory is chosen. One of the sofa model (model A) produced in the furniture company is examined under VSM method (this example is derived from study of Dogan and Takcı [41]). Model A is now the product family of this example. As the second stage of VSM, the steps

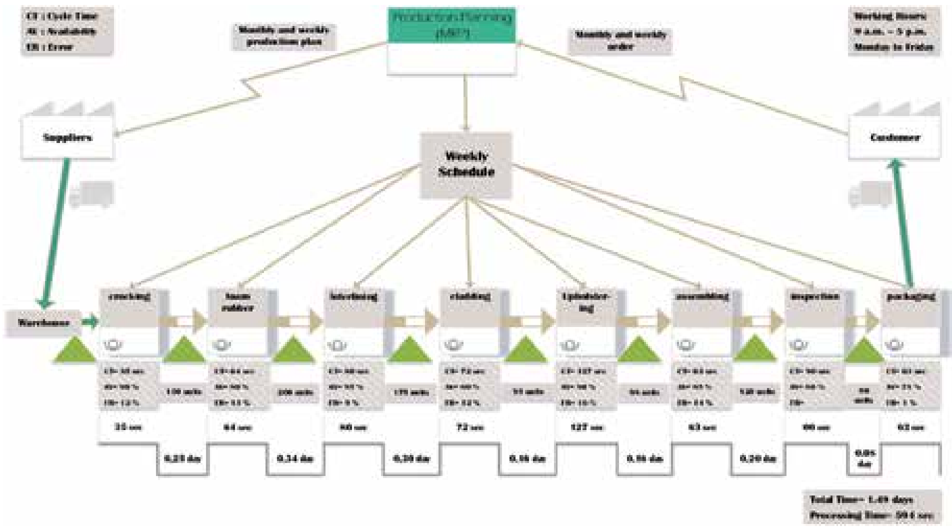

Figure 8.
Current state map (production sector).

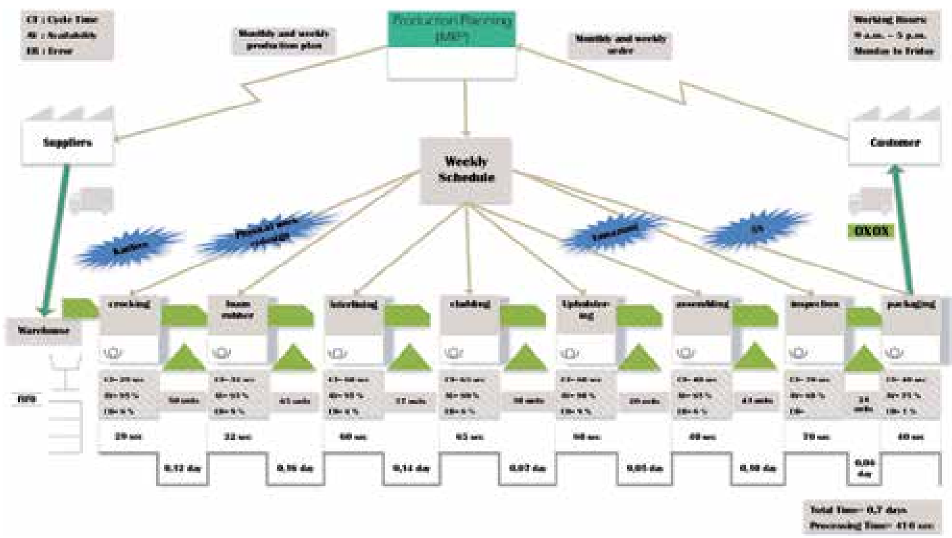

Figure 9.
Future state map (production sector).

in the production phase of Model A are focused. The current state map (CSM) demonstrating this process is shown in **Figure 8**. There are eight production steps in CSM (**Figure 8**). Production flow starts with "crocking" and ends with "packaging". When the current state map is analyzed, it is seen that the total time is 1.49 days and the processing time is 594 seconds. By drawing the CSM, some problems have emerged in the production area. The main problems are as follows: intermediate inventories between the processes; unbalanced workload; time losses due to the inadequate supply of the material and time losses cause quality errors (average 9.62%); time losses due to layout problem, unnecessary transportation and deficiencies like material identification. Then, to eliminate the problems identified with the CSM, a future state map (FSM) is drawn (**Figure 9**). In the FSM, the Kanban system is established, the pull system is applied to prevent accumulated intermediate inventories between the processes and the material transfer is controlled by FIFO. In addition, Yamazumi is proposed for balancing the workload and minimizing the quality errors and establishment of the Kanban system makes it possible to prevent time losses in production due to the lack of timely supply of the materials. Finally, it may be preferable to use 5S and physical work redesign in order to prevent the time losses due to the layout problem and the deficiencies in the material identification. Analysis of the production process of model A by VSM method showed that continuous flow is achieved; a decrease of approximately 53% in the total time, a decrease of 30% in the processing time and a 36% improvement in the quality error rate. As in the example of the service sector, when the CSM (**Figure 8**) and FSM (**Figure 9**) for production process of model A are examined simultaneously, the wastes, errors, defects and at the same time, improvements in the processes can be clearly seen.

6. Discussion

Lean thinking is the general framework of the implementation of the lean philosophy in the production and service sectors [42]. As stated by Womack and Jones [8] *"lean thinking is lean because it provides a way to do more and more with less and less—less human effort, less equipment, less time, and less space—while coming closer and closer to providing customers with exactly what they want."* LT is an endless process and implementation of continuous improvement. For continuous improvement, researchers and professionals prefer various lean methods like VSM, 5S, SMED, balanced work flow, standardized work etc. The primary purpose of these methods is to eliminate waste and ensure continuous flow.

Value stream mapping is one of the most preferred methods in literature. This is the mapping of the whole process. Mapping the stages of a process, will assist to discover the opportunities for improvement and prevent the loss of time and money of stakeholders [43]. VSM applications, with the aim of eliminating waste are not restricted to a single business; it can also be applied to the supply chain by focusing on all the steps from the first supplier to the end customer. The essence of the matter is that, VSM can be effectively used in all processes if a product or service flow exists.

7. Conclusion

This chapter has focused on lean philosophy and lean methods, especially the VSM. The motive for the detailed examination of the VSM method is that VSM is the first step to overcome how the lean production will be applied. The reason why this method is first preferred is that the whole operation is seen as a holistic approach, and at the same time, it proposes a prescription to eliminate errors and/or wastes. On the other hand, like many other methods, this method has also some limitations. Mapping complex systems with VSM can sometimes be difficult. At this point, large wastes or resources of wastes may be unnoticed. This can be a major problem in VSM, whose main goal is revealing and eliminating waste. Moreover, rather than using the VSM method alone, using with other lean methods will increase the reliability and efficiency of the results. To overcome these weaknesses, it is recommended to benefit from other methods together with the VSM method. For instance, theory of constraints, flowcharts, artificial intelligence and simulation are some of the methods that can be used with VSM.

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Chapter 5

Some Aspects of Visual Detection of Dumps

Andrey Alexandrovich Richter

The chapter describes some aspects of the method of visual detection of landfills from space images as one of the directions of remote monitoring of landfills.

Abstract

Waste location objects (unauthorized landfills, landfills, waste heaps, etc.) from the point of view of visual detection have deciphering characteristics, primarily shapes and textures that distinguish them from objects of the earth's surface of other types in space images. The technology of visual detection of landfills includes a number of issues, in particular: the definition, presentation, and analysis of deciphering features in visible images, algorithms and approaches for visual detection of landfills, deductive analysis as a way to get the maximum of productive information from the minimum "raw" only on the images themselves, research and mapping of landfills through interactive maps (Google, Yandex, etc.), and classification, texture, and structure of landfills and the environment from the point of view of visual detection from space images, etc. This chapter considers only some aspects.

Keywords: dump, landfill, littering, visual detection, visual interpretation, space monitoring, space image, logical analysis, deciphering signs, mapping

1. Introduction

Littering "incarnates" in various forms—from chaotically debris scattered over some surface to the "civilized" garbage Everest towering above the cities. The beauty of nature is truly extraordinary and unique; it can be described by countless many paintings, unique, emphasizing more and more of its shades. With the development of scientific and technological progress, a new phenomenon appeared that has an anthropogenic character but adorns nature along with its natural "colors," such as birch groves, fresh lakes, flood meadows, etc. Dumps can be a truly fascinating, spectacular spectacle, and the landscapes painted from them can claim painting exhibitions in galleries as a whole art direction. However, when you see a large dump and a small grove in one projection, something inside suggests the unnaturalness and absurdity of such interaction of artistic images. Such landscapes are surreal, i.e., some introduced, unnatural shade.

An absurd combination takes place in many aspects of modern human existence, for example, in the human consciousness, where completely dissimilar, incompatible components accumulate. And with all this, the processes of this consciousness are continuously occurring, due to which the activity of the unpredictable kind is "released." The physicochemical processes in landfills are similar; in particular, the composition of substances released from them in a liquid, solid, or gaseous state is just as unpredictable. This, i.e., a wide range of options for their "behavior," is dangerous, first of all.

Visual detection is one of the simplest and most widely available methods of monitoring, first of all, space monitoring. The essence of it is to study object on the image in an interactive mode, without developing and using special programs that automate this process. Images can be aerial photographs, space images, or fragments thereof; photographs of objects of study, taken with cameras; maps of objects on various maps, etc.

2. Dumps on high-resolution space images

2.1 Texture of dumps in images of high resolution

Dumps (*waste location objects*, *WLO*) refer to the observed objects, and they can be detected by the methods of space monitoring. In addition, WLO is easily detected in visible images, because they stand out against the background of *ambient environment* (AE) and have a characteristic texture.

At the same time, the *texture* of dumps is variable and diverse; it depends, first of all, on (1) the time of year and the day (the angle of incidence of the sun's rays), (2) the size, (3) the class of WLO, (4) component composition, (5) location region, (6) screening of the WLO surface, and (7) spatial resolution, which in Google Earth is regulated by scaling.

From the point of view of visual detection, the texture is characterized by some verbal description. For example, a typical WLO and its texture are shown in **Figure 1**. A *typical* WLO texture can be specified as follows: a combination of random and close shades from white to dark gray, in some places—with a small admixture of red. The first group of shades (from white to dark gray) is the main one, the dominant one, the second (red)—non-main, secondary. When red is applied in some places, various impurities are formed on the basic shades, such as pink, reddish, lilac, etc.

2.2 WLO and its structure in the Google Earth

We will show the structure of WLO and its AE in the example of the Torbeevo landfill—**Figure 2**: WLO (1) and its AE (2), conditionally allocated as a rectangle. In the AE zone, there is a settlement of the same name—the Torbeevo village. Also the landfill is surrounded by the villages Rusavkino-Romanovo, Rusavkino-Popovschino, Polushkino, Novy Milet, and Michurinets and other settlements of Balashikha and Lyubertsy districts. Many of them, it turns out, are located in the sanitary zone of the landfill, which is a direct violation of the rules *for planning*,

Figure 1.
Typical WLO (a) and typical waste texture (b) WLO in the vicinity of the Kuchino landfill in the Moscow region, July 5, 2010 (Google Earth).

Figure 2.
Isolation of WLO and its surroundings by the example of the Torbeevo landfill (Lyubertsy district, Google Earth).

operation, *and recultivation* (POR) of landfills [1]; by the rules the nearest apartment house to the landfill should be no less than 1 km from it. In fact, this is a minor violation compared to others, which are also observed by visual detection in the Google Earth program (this will be discussed later) [2–4].

The surface of the Earth has changed technologically very strongly over the past few years (**Figure 3**). In particular, (1) the dump itself has grown several times; (2) where there were farms, now there is the economic zone of the landfill with all the consequences; (3) the production of soil for storing waste and expanding the landfill occurs in large areas; (4) the thin forest belt has been cut down and large areas of fertile land have been destroyed; (5) the seizure of new areas under construction and production of soil and there are other features of the changes. It should be noted that the area covered by vegetation (forest, shrubby, grassy) steadily decreases with time in principle, replacing anthropogenic objects. So, the areas of forest plantations are insignificant in comparison with the areas of forest harvesting. A stable decrease in the area of vegetation coverage is also seen in the vicinity of the WLO (not shown in the figures).

The composition of the AE of the WLO Torbeevo landfill includes (see **Figure 2**) a high incidence of human settlements, a "dirty" storage area (I), a polluted river Chernaya (II), shaky roads (III), the remains of the former livestock farm—stable (IV), fading agricultural fields (V), and other objects of natural and anthropogenic origins.

It is noteworthy that many objects of the same class are attached to the environment of various landfills, such as cemeteries (AE of the landfills Kuchino, Dolgoprudny, etc.) and agricultural areas (AE of the landfills Lisya Gora, Torbeevo, etc.).

In general, AE can be represented by objects of numerous classes: (1) *natural objects*—water (rivers, reservoirs), forest (forest massifs, plantings), grassy (meadows, glades), and other zones; (2) *anthropogenic objects*—settlements (villages, settlements), *industrial* (factories, plants), *agricultural* (animal farms, agricultural fields), service areas (filling stations, parking lots), *transport* (roads, railways), and other zones.

Figure 3.
Changes in the vicinity of the Torbeevo landfill: (a) June 2003 and (b) April 2014 (Google Earth).

In this case, you can select objects of different levels—objects of a lower level enter objects of a higher level. So, trees are objects of the lower level; a forestry array made up of trees is an object of a higher one; house is the object of the lower level, the village—the upper one.

Similarly, WLO are structurally complex objects (top-level objects) made up of "cubes" of simpler objects (lower-level objects). Let us consider in more detail the structure of a WLO in the example of the Torbeevo landfill (**Figure 4a**).

The *structural object* can be cut in the first approximation, as shown in **Figure 4a**. The structure can be represented by polygonal areas and/or corresponding labels (1–4). We have four zones (sections): (1) storage area, (2) landfill area for storage of waste, (3) economic zone, and (4) zone for expanding the boundaries of the landfill for storage of waste (presumably).

In turn, each zone is divided and/or contains more private objects. For example, the economic zone is represented by numerous *technoobjects* (office, industrial buildings, warehouses, residential objects—"trailers," parking lots, etc.) and other territories (in particular, for the disposal of specialized waste).

Thus the territory of the WLO and its AE can be represented in the form of a map consisting of many layers. For the WLO map, the Torbeevo landfill is one of the layers—dividing it into the main zones. You can create other layers, for example, "cluttering the vicinity of the WLO" (**Figure 4b**), "transport system" (**Figure 4c**), "anomalous zones," "territories with a homogeneous texture," etc.

In **Figure 4c**: (1) access roads to the landfill (outer part of the transport system), (2) main road, (3) serpentine, (4) secondary roads, (5) road junctions of the economic zone, (6) roads on the surface of the landfill, (7) transportation nodes. The transport system establishes routes, first of all, for garbage trucks, bunker trucks, scrapers, and other garbage equipment. Each road leads in different ways, one of which is optimal in length (see the theory of dynamic programming and other applications of the theory of optimization), from the external environment to this or that object, be it building, cluttering, sand mounds, etc.

The *WLO card* of a *private area* is a map of the land surface on which an WLO array is located within the territory of the possession of individuals or legal entities (enterprises, organizations, cooperatives, etc.) and relationships with infrastructure objects (roads, fences, buildings, structures, etc.). **Figure 5** shows examples of WLO maps showing the WLOs within the general and internal boundaries of a private area. The locations of the landfills in the observation area are marked in red tags: the territory of the business park to the west of vil. Motyakovo, northern (a) and southern (b) parts.

2.3 The dynamics of WLO and the environment of the WLO

The state of the NSO from the point of view of visual detection can be estimated in various ways, for example: (1) areas occupied by vegetation and their variation over time; (2) soil degradation—bogging, salinization, etc.; (3) changes in the object

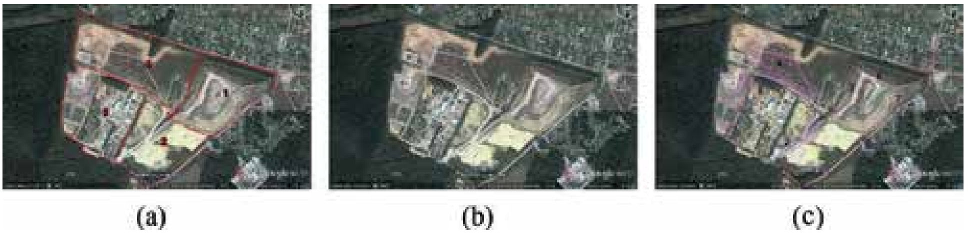

Figure 4.
Structure of the Torbeevo landfill: (a) the division of the territory in the first approximation, (b) the main dumps in the vicinity, and (c) transport system (Google Earth).

Figure 5.
Maps of the WLO of private territories on the example of industrial zones near the Motyakovo village, Lyubertsy district of the Moscow region (red tags) [Google Earth].

composition of the territory; (4) anomalous zones in the vicinity of the WLO; (5) compliance with the rules of the POR of the WLO; and (6) quality of vegetation.

To study the state of territories, not necessarily WLO, in addition to the "visual" method, methods of *inductive* and *deductive analysis*, combining space and field visual detection, etc., are used.

We will analyze the state of AE on the example of a WLO Kuchino landfill, Moscow region, the Balashikha district, in the common people—the Fenino dump in honor of the adjoining inhabited locality of the Fenino village.

Figure 6 shows the areas of general changes in the vicinity of the landfill: (1–4) vegetation reduction, (5–8) vegetation increase, (9–13) landfill expansion (breadth and height), and (14, 15) expansion of the Fenino cemetery. Every change has its own cause. For example, changes 3 have anthropogenic reasons: the need for deforestation to prepare additional areas for the development of soil for backfilling. Then the working zone can be conditionally divided into the current (4) and reserve (technologically still unchanged natural areas in the vicinity of the landfill). Changes (5–8) have a natural (natural) cause: overgrowing of the slopes of the landfill by vegetation. In general, *overgrowing* is one of the protective functions of the environment from various negative impacts on it, such as WLO.

The warehousing section itself has a lot of structural elements, the so-called storage cards (see **Figure 7**). Waste is filled in by cards "line by line," i.e., successively first in width, and then filled to the next level of height. The structure of cards of one level differs from the structure of the maps of the other—like brickwork, where the bricks of the lower level are lapped by bricks of the uppermost for greater stability of the structure. Due to the duration of the filling of certain cards, other cards (already filled) begin to overgrow with vegetation (see **Figure 6b**)

Figure 6.
Changes in the vicinity of the Kuchino landfill site from June 11, 2003 (a) to July 13, 2014 (b) (Google Earth).

Figure 7.
Structure of the landfill site for the Kuchino landfill, August 16, 2011: (a) on the map (Google Earth) and (b) schematically.

and change their texture. But—for a while, because subsequently, the overgrown map will be covered by a new storage map. So at different periods of the life of the landfill, it consists of the current storage zone and the overgrowing zone where storage does not occur.

Parallel to this, the filling of the landfill takes place in the queues of storage. This explains the unevenness of the polygon contour, more precisely, the fragments of the storage site carried out in different directions (see 9 and 10 for **Figure 6b**). These fragments, mainly, are caused by the queues of storage—new territories adjacent to the landfill, planned and prepared for a new "portion" of waste disposal. Knowing these "bulges," we can assume a story, i.e., the order of waste storage in retrospect. In **Figure 6a**, the storage in site 9 is at the initial stage—this state of the site can be called an extension of the landfill boundaries.

By the principle of storage queues, not only NEOs are expanding but almost all anthropogenic objects, such as populated areas, cemeteries, agricultural and park areas, etc. In particular, the Fenino cemetery for 11 years has expanded in two directions: to the northwest and southeast—see plots 14 and 15 in **Figure 6b**.

Many anthropogenic objects are close to each other and in structure (**Figure 8**). In particular, the structure of the cemetery (a) is similar to the structure of the settlement (b).

In the figure, for example, three classes of objects are distinguished: (1) ownership areas, (2) plantations, and (3) access roads. The difference is only in the sizes of structural cells—for cemeteries these areas are smaller than for settlements.

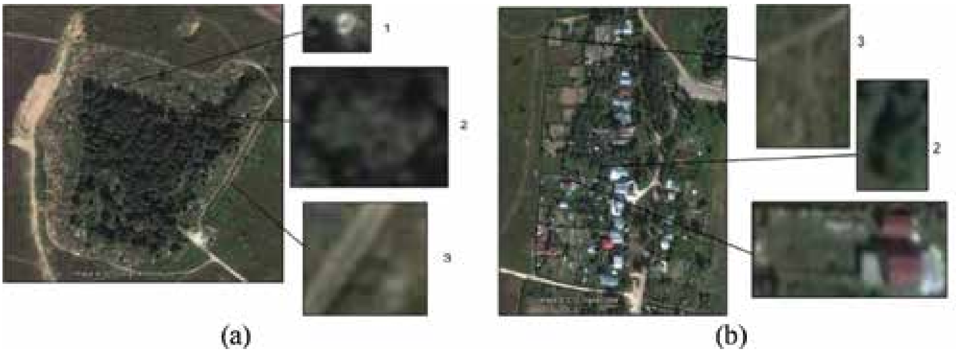

Figure 8.
Structural objects: (a) Fenino cemetery and (b) the Fenino village (fragment) [Google Earth].

From the point of view of visual detection, the state of the soil is characterized by (1) technological changes in the territory (changes in infrastructure); (2) the state of vegetation as a sign of the state of the soil; (3) change in the state of the soil, improvement (enrichment) or deterioration (degradation); (4) the surface state as a sign of internal processes in the soil; and (5) abnormal zones on the surface as a sure sign of a negative impact on the soil.

The landfill arose in the 1960s, but satellite imagery of high resolution arose only in the 1980's. And it is not possible to investigate the landfill from space at birth from the very beginning. Therefore, historical references and opinions of history eyewitnesses (in particular, the residents of Fenino) are resorted to. According to their opinions, the dump is formed on the site of the former clay quarries. And the quarry was deep water and represented a resort zone, popular among the inhabitants of the Moscow region (in **Figure 6a**, the rest of the former water quarry is visible). It was an ecologically clean and favorable area.

The Fenino village is an ancient landfill, at least because the formation of a village on the site of an already existing landfill is less likely than the formation of a landfill in place of an already existing village.

If we confine ourselves to a narrow interval of time (from 2003 to 2014), then **Figure 6** shows that a number of technological changes occurred. And most intensively technologically the neighborhoods of the landfill have changed and not the remote neighborhoods. This range includes the expansion of the village and the landfill, the emergence of new buildings (in the expansion zones and former village areas and landfills), new roads, etc.

Technological degradation, we believe, occurs where the natural root system of the soil is disturbed (see Sections 2 and 4 in **Figure 6**). In general, the forms of degradation associated with the WLO include (1) technological (including deforestation), (2) bogging, (3) salinity, (4) desertification, and (5) littering. But unlike other forms, technological degradation arises abruptly. The source of technological degradation may be utilities or the private sector. In the first case, technological degradation occurs on a large territory and in the second—on an insignificant (e.g., within the limits of its garden plot).

Different forms of soil degradation are shown on the fragment of the AE landfill—**Figure 9**: (1) *water logging*, (2 and 3) unknown forms of degradation

Figure 9.
Forms of soil degradation in the vicinity of the Kuchino landfill, July 5, 2010 (Google Earth).

(presumably *desertification* and *salinization* of the soil), (4) *littering*, and (5) *technological* degradation. For the degradation of the soil is characterized by an unnatural color of the earth's surface, violet (1), white (4), or brown (2, 3, 5). The presence of brown shades, especially in the summer season, against the background of green, means a reduced density of vegetation, i.e., inability of its full reproduction by soil.

Dilution of the vicinity of the WLO is caused, first of all, by the release of the filtrate to the surface of the earth, due to the excess of moisture in the soil and low reproduction of vegetation by soil. As can be seen from **Figure 10**, the filtration water flows from the base of the landfill and spreads in certain directions in the environment. In addition to the filtration reservoirs (1) and streams (2), they form traces of their current (3), and on the shores (4) of these reservoirs, virtually no vegetation grows (see also photo 2 in **Figure 11**). To reduce waterlogging, the soil is loaded with an additional layer of soil (5), which gives a temporary effect, due to the continuous accumulation of filtration in the soil (6). The filtration liquid can also take the form of channels (7), along the bottom of the storage site. Even in winter, numerous traces (8) of filtration processes remain on the surface of the earth (see **Figure 10**).

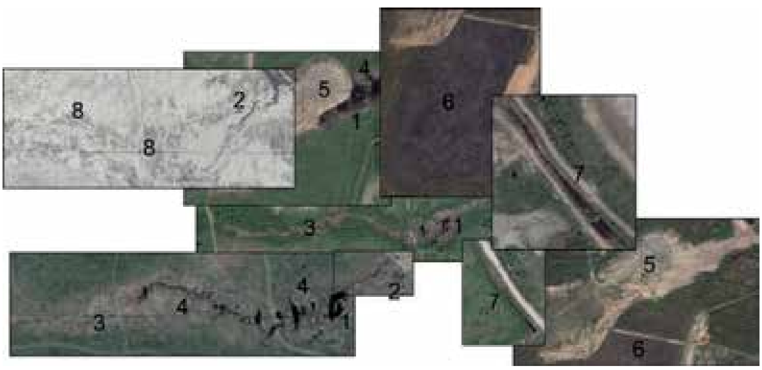

Figure 10.
Components of filtration processes in the vicinity of the Kuchino landfill (Google Earth).

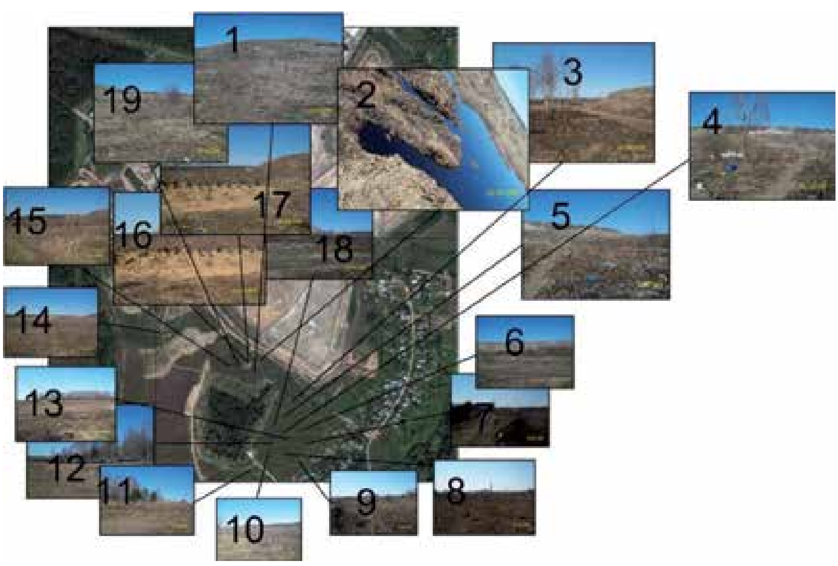

Figure 11.
Photographs taken around the vicinity of the Kuchino landfill.

Visual observations on images can be verified by conducting verification, i.e., comparison of space and field (terrestrial) visualization data. For example, you can take a picture of the neighborhood of the landfill at its various points and compare the information obtained with the visual detection data in the Google Earth (**Figure 11**).

Figure 11 shows photographs of two anomalous areas: surface filtrate (2) and unknown graves with number plates (16 and 17).

3. The method of deductive analysis of space images

3.1 Features of the method of deductive analysis of images

Most, if not all, image processing methods and algorithms solve a very limited range of space monitoring tasks. In particular, in problems of region detection, some developed algorithm selects objects of a given type located in a certain territory at a certain point in time from the source image. In addition, automated and automatic algorithms are associated, mainly, with the detection, allocation, marking, and mapping of land surface areas and are not associated with the analysis of information on these images. Because types of natural and anthropogenic objects are huge, for each of them, algorithms are developed that are loaded onto cosmic images or their series, and a full and complete analysis of the space image and the given field of observation does not take place.

The advantage of classical algorithms of space monitoring is the automation of image processing, i.e., a large-scale survey of the area of observation using space images. But the reverse side of this "coin" is their main disadvantage—the limited possibilities for examining the area. Most of the information is not extracted from the image.

To solve this problem, we propose a technique of *logical* (*deductive*) *analysis* of cosmic images, using the principles of logical reasoning on images and normalization of the results obtained. The proposed technique for the study of space images is based on visual observation of the image (using your own vision and reasoning for its interpretation). Logical analysis is obtaining the maximum amount of information from the minimum of initial data on a space image without the use of image processing algorithms.

The merits of the method of deductive (*logical*) analysis of space images include the following: (1) the implementation of the methodology which does not require knowledge of programming, theory, and practice of image processing; (2) extraction of information that cannot be obtained by modern methods of image processing; and (3) no binding to the type of images; deduction methods are the same for images of any kind.

The disadvantages of the technique are (1) individual work with each image and the impossibility of partial or complete automation to date, (2) the need for manual and detailed image viewing, and (3) the inability to obtain the distribution of surface state parameters, which is achieved by image processing.

The purpose of deductive analysis is as follows: (1) restoration of the history of the image; (2) restoration of information about the current picture; (3) predicting future processes on the surface of the earth, based on the given image; and (4) restoration of intermediate information (between neighboring shooting dates). Otherwise, the goal is some expansion of the space-time boundaries of the image.

3.2 Image information

Each image has several *types of information* (see **Figure 12**): (1) visible information, (2) invisible information, (3) information obtained by image processing, (4)

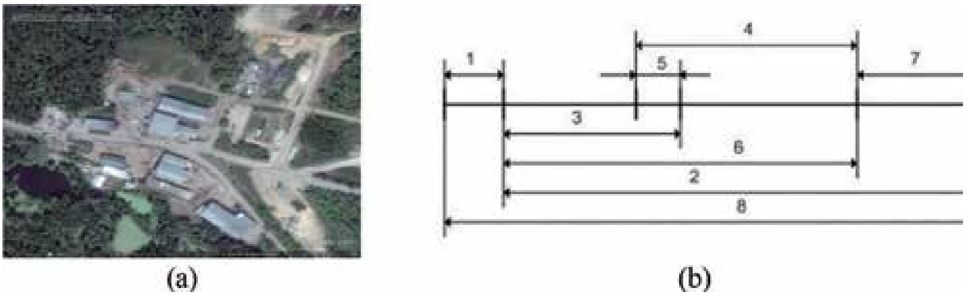

Figure 12.
Image information: (a) information field (economic zone of the Timoshovo landfill, Noginsk district, Moscow region, Google Earth) and (b) types of information in the image.

information obtained by deductive analysis, (5) general information obtained by image processing and deductive analysis, (6) recoverable information, (7) non-recoverable information, and (8) all image information.

Deductive analysis is obtaining the maximum amount of information on a space image without the use of automated and automatic image processing algorithms.

To obtain visible information, *reasoning* is not required, but *logical thinking* itself takes place in any case. For example, in order to *see* a house in the image, it is necessary to have different images of houses in the mind, in the limit—a full *spectrum of types* of houses ("manual" method of managed classification). We assume that information 3 and 4 do not include information 1: that something can be simply seen; it is not necessary to resort to additional costs. However, to see something on a large number of images is less advisable than automating the process.

The reasoning behind deductive analysis has the following characteristics: (1) *Variability*—offers options for explaining a particular fact (details on the image). (2) *Distribution*—reasoning has a probabilistic and statistical character. (3) *Chain character*—one detail and one reasoning lead to another detail and another reasoning, etc. (4) *Detailing*—when interpreting one area of reasoning, they pass into its internal subdomain or conjugate domain. (5) *Algorithmization*—reasoning can be carried out on certain algorithms that allow to restore information. (6) *Schematization*—the system of reasoning is filled into some "vessel," i.e., takes the form of some model.

Deductive analysis (recovery of the maximum amount of hidden information from the image through its detailed observation) is the development of conventional image surveillance.

Deductive analysis is variable—options are offered for explaining a particular fact (details on the image). Those reasoning have a probabilistic-statistical and a chain character, because one detail and one reasoning lead to another detail and another reasoning and so on.

Processing of space images allows you to extract information hidden from the eyes. Human eyes are seen mainly in the visible spectrum, and information in the invisible spectrum is mostly hidden from the eyes. If a person had also seen in an invisible spectrum, he probably could have uncovered all the same information as when processing images but using only logical thinking (vision) and deductive analysis. But the processing would be required to speed up the extraction of information from the images by means of automation.

Deductive analysis, for the most part, allows you to obtain information that cannot be obtained by modern image processing methods. We believe that this "extension" can be used to interpret visible images or images on which most of the objects can be distinguished. However, there is some general information obtained by both methods. The boundaries of deductive analysis end where the boundaries of image processing begin and vice versa.

Information can be visible or invisible and recoverable or non-recoverable. In the process of combining all the modern methods of image processing and *deduction* methods (and *induction*), some of the information on the image remains, in which it is impossible to extract for today—it is non-recoverable information. The limit of deductive analysis is the complete interpretation of the image, the possibility of explaining any details on the image in space and time.

Information field of the image is introduced: information sources (S_i), information objects (O), informational AE of source (IAE), boundary of AE (C) of some radius (r), information signals from the sources to the objects (u), and internal (I) and external (II) objects of a source. The *source of information* is some object in the image, which is known for the most information; it can be seen and recognized. These objects are highlighted in the first step of the analysis. A lot of information sources form an information basis of the image—these are the reference objects of the image, to which all information is bound to the information field. The information is identified in the vicinity of the region $S_1S_2...S_n$, where n is the number of sources. Each source has a certain *neighborhood* (IAE). Internal objects relative to the source belong to its AE and have a *connection* with it; external objects are on the contrary. The boundary separates the internal objects from the external ones. The connection of the source S_i to the object O_{ij} is expressed in the presence of the information signal u_{ij}.

3.3 Objects and events

In the language of *object-oriented programming* (OOP), the Earth model is programmed with objects and classes, events over objects, properties and methods, the principles of OOP (polymorphism, encapsulation, inheritance), etc. are established for it [5]. WLO and AE can be decomposed into many objects at one or another level of accuracy, each of which, in turn, decomposes into objects of a higher level of accuracy, etc. Each object changes its state in time, forming the so-called those or other *events*.

The structure of the event in space images is shown in general in **Figure 13**: A, the earlier *actual state* of the object (or system of objects) O; B, the later real state; e, the *actual event* that transfers the state A of the object O to the state B; t, the moment of time (according to the "space" measures—the time interval with some average value); t_i, the i-th reporting time; n, the number of reports; B_i, the *imaginary state* of the object O in the future with the known past state A; A_i, the imaginary state of the object O in the past at and the future state B; a_i, the *imaginary event* of the object O in the future, taking the state A of the object O to the state B_i; b_i, the imaginary event of the object O in the past, transferring the state A_i of the object O to the state B; and E_i, the latent state of the object O for which there are no pictures, somehow identifying him.

The "drive" of the state change A of the object is internal and/or external *factors* acting on the territory of the object. Internal factors operate from within, and it is difficult for them to identify the source of space images (favorable weather

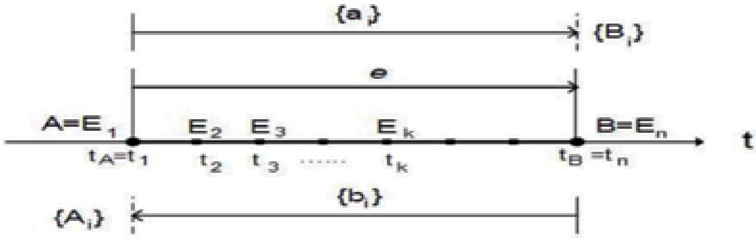

Figure 13.
Events and states on the time axis.

conditions can lead to a thickening of the vegetation cover). External forces act from the outside, and for them a source (impact of a neighboring object) can be identified.

Two events have a *cause-consequence connection* (CCC) A⇒B, if one of them (A) is first before the other (B). If some "quantities" are known, the remaining ones can be calculated: the examples of the calculation schemes are shown in **Figure 14**, where A and B are known events; X, Y, and Z are unknown events; and a, b, x, y, and z are logical connections (known and unknown). In (a) for two known events A and B of object O on two cosmic images taken at different times, it is necessary to find an unknown CCC x that transferred A to B. At the same time, the design scheme can have more than one solution x. It is similar for the remaining examples of schemes. In scheme (b) from the known A, one must find the set of solutions {x, Y}, i.e., assume future events Y and the corresponding connections x. In the scheme (c), on the contrary, according to the known event B, it is necessary to restore the past (X, y).

The connection A⇒C⇒B forms a simple logical chain of three events A, B, and C (d–f). It is assumed there is one unknown intermediate event C that occurred chronologically between events A and B. It can be specified if the logical connection between A and B is not "felt" and a link is required. It is similar for more than one intermediate event.

On space images, an event is expressed in a change in the state of an object or system of objects, i.e., some territory. Knowing the two states, we can assume an event (event) that resulted from an earlier event in a later event. Thus the change in the state a⇒b of the object O in **Figure 16** is probably caused by the slippage of waste from the slope of the Timoshovo landfill site (Noginsk district of the Moscow region) into the water during the year. If the changes on the left side of the reservoir were due to the crushing of the reservoir, then it would be updated from other sides, which did not happen (on the right the contour of the shore line of the reservoir did not change). In addition, the slippage of waste into the reservoir according to Archimedes' law could not lead to a decrease in the water level; for this there would be other reasons, such as a prolonged absence of precipitation. Thus probably the physical meaning of changes in the texture of the reservoir on the left is the immersion of a part of the waste heap to the bottom of the reservoir.

The picture of events on the time interval [t_1, t_2] can be reconstructed, considering both the main variant of the flow and the less probable one. So, if the height of the landfill was large, the waste could spontaneously fall off the slope (e.g., under wind). But the height of this landfill is small; in addition, the area of the blade is large, i.e., more likely the deliberate littering of a natural object (pond). After the filling of the territory beyond the coastal line of the reservoir, some of the waste spontaneously falls into the reservoir, including to the bottom, leaving room for

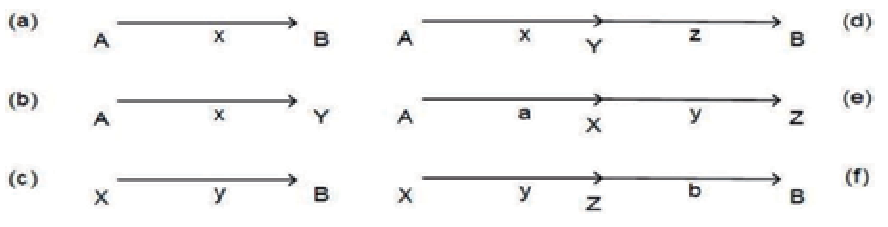

Figure 14.
*Event (state) equations. The CCC model A⇒B, in which only A is the cause of B and only B is the consequence of A, differs from the real CCC in which there are background connections (***Figure 15***): A and B are events related to each other; C is external event-consequences A; R, external events-causes B; and a, b, and c, logical connections. "a and b" are "scattering" connections, for which the consequences of event A and the cause of event B are difficult to determine, or these consequences and causes are probabilistic. Estimating the probability of a logical connection between A and B by eye, p = M/N, where M is the number of logical connections that lead to B and N is the number of all logical connections flowing from A. Depending on the probability value, place such links as "only A led to B," "from A follows only B," "although A, but B," "if A, then B," etc.*

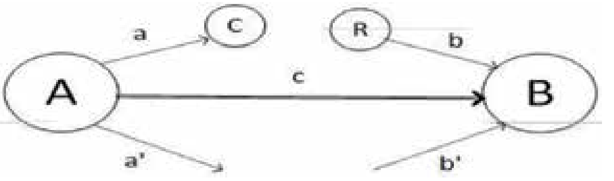

Figure 15.
The structure of the logical connection of real events.

new waste receipts. Under given conditions of survival, this reservoir is practically not suitable for complex life forms; proceeding from state b, one can assume its overgrowing and disappearance as a habitat.

For the possibility of *analyzing events* from images, including in the neighborhood of the interval $[t_1, t_2]$, it is necessary to know at least two different states of the same territory. The more known states, the more accurate the picture of events. Outside the working interval, the construction of the picture of events has greater uncertainty than inside. The wider the neighborhood of the image, the more events in the neighborhood of time ($t < t_1$ and $t > t_2$) can be restored.

Marking objects on the workspace and asking them a lot of event-causes and event-effects (probable, since only part of the event-causes occurred, and event-effects occur), the information picture is analyzed. Because objects and events "fight" on the same information field, it is necessary to establish links between them.

The relationship can be analytically represented as the formula A o B, where A and B are objects or events, o is the operator (link), and A o B is the result of the operation (some statement).

Links can be divided into *spatial*, *temporal*, and *logical*. Many of them are verbally given in the form of prepositions, prepositional words, and word combinations, for example, spatial (**Figure 17**).

The time links are A "to" B, A "after" B, A "at one time with" B, "before A, B," etc. Temporary communications are established not only by the temporal gradation of the images but also by the basis of a single image over spatial relationships. For example, in **Figure 18**, buildings appeared before the objects attached to them (lawn, clutter, parking lot, access roads, outbuildings, entrances, etc.); the fences were installed "on" the parking lot after its asphalting (concreting). In some cases, communications may not be defined in space, time, or cause-effect.

The spatial arrangement of objects in the image allows the image to be set in motion, i.e., restore its history and predict its future. Those on the spatial arrangement of objects, you can set events over these objects, as well as the sequence of events.

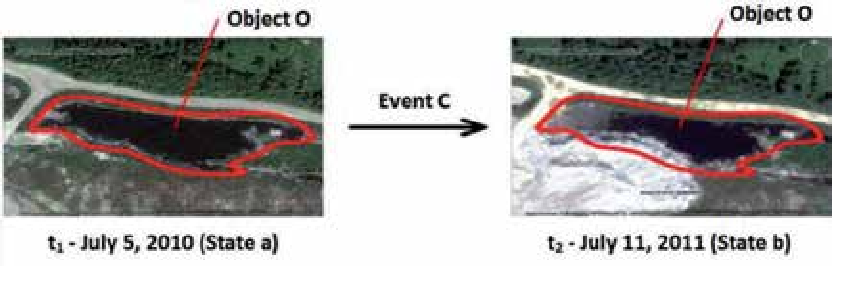

Figure 16.
Event on the image (Google Earth).

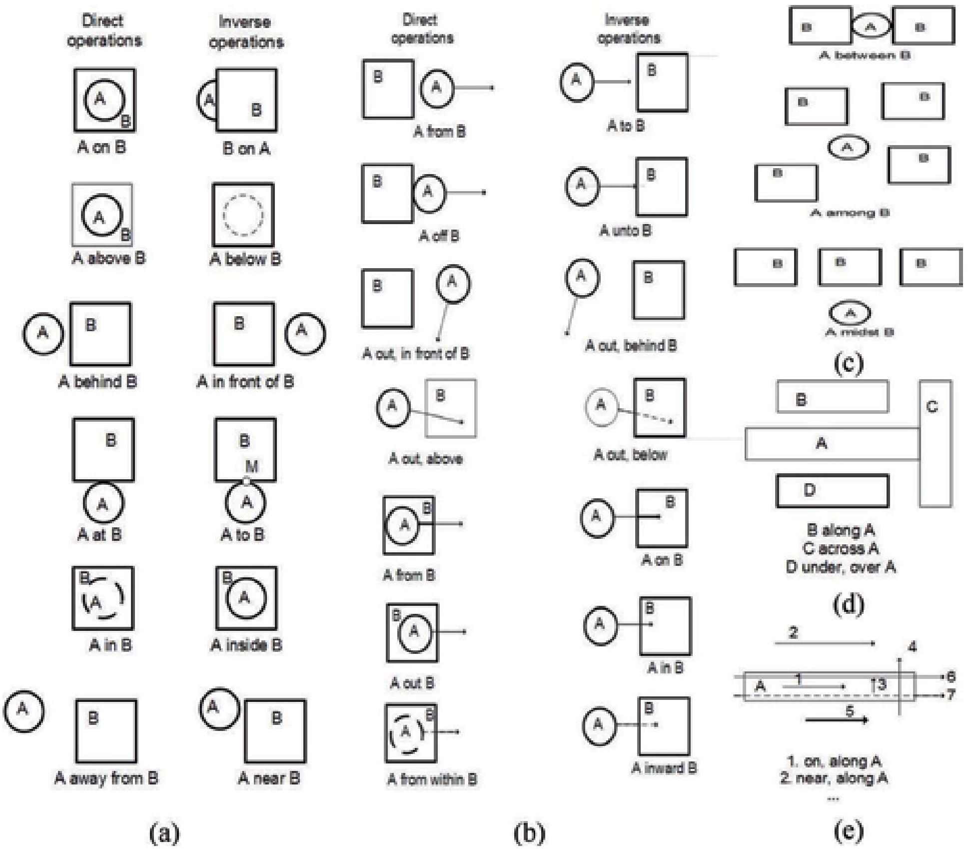

Figure 17.
Relationship of the objects and events: (a, c, d) the relationship of objects in space and (b, e) moving one object relative to another.

Figure 18.
Spatial relations of objects on the image (neighborhood of the building of the economic zone, Timoshovo landfill, Google Earth).

Because logical connection implies a temporal, establishing the chronological state of objects, their individual *event-causes* and *event-consequences* can be “crossed” in pairs and distinguish among them plausible logical connections that can occur with one or another probability.

Each link has an inverse link to it, which is expressed through opposite prepositions such as "on" and "-incl.", "Above" and "-above" = "under", etc. *Opposite operations* correspond to "opposite" prepositions, for example, "above" and "under," "because of" and "from before," etc. Accordingly, we obtain straight lines A o B and inverse B o A operations on the image.

The object O is a section of the image that is different from its background, i.e., it can be associated with a set of *determinants*, concepts {Ii} i = 1…m, one of which is true (most probable), while others have a lower probability.

From the point of view of images of an event (operations on objects), there are (1) the *appearance* and *disappearance* of an object, (2) growth and decrease of the object, (3) changing the site of the object, and (4) changing the state of the object. For specific types of objects, the type of event is confined to more specific manifestations of it, for example, "appearance"—growth (plants), building (building), movement (car), etc. Each object is "capable" of its own group of events.

3.4 Deductive analysis of images in Google Earth

Let us give an "introduction" to the deductive analysis for a specific WLO—the Timoshovo landfill, the Elektrostal town, the Moscow region. You can conduct (1) at a different level of detail, (2) for a specific image, and (3) for a time series of images.

This test site is one of the largest in the Moscow region and throughout the world. It is much larger than the Kuchino landfill and is located 4 km west of Elektrostal (**Figure 19**). In the first approximation, there are more natural areas in the vicinity than man-made ones.

The objects adjoin the landfill with parts of their borders: natural, large (in the southeast) and smaller (in the northwest) reservoirs; vegetation cover (forest and grass); anthropogenic, economic zone of the landfill in the west of the storage site; and road that fringes the landfill. In the vicinity of the landfill located settlements: cottage cooperative (in the southwest), the village Mechta (in the southeast).

The landfill has a fairly regular shape and a complex transport system installed on the active zone (in the Google Earth). The same overgrowing zone exists for a long time, so the "paths" overgrow on it. The outer part of the transport system is convenient for transport: the entrance to the landfill from three directions, i.e., from different settlements (sources of garbage), and a circumferential road giving access to the entry point (from the side of the economic zone) to the landfill from different directions, along and counterclockwise. From the point of view of visual detection, natural objects differ from anthropogenic ones in that they have an irregular shape—**Figure 20a** and **b**, whereas anthropogenic ones are correct

Figure 19.
Timoshovo landfill, and its surroundings, Elektrostal town (Google Earth).

Figure 20.
Examples of objects: natural, (a) natural forest (internal forest) and (b) a natural water object; anthropogenic, (c) building and (d) pond (artificial pond) [Google Earth].

(**Figure 20c** and **d**). Accordingly, the signs of natural and anthropogenic operations are reflected on the surface in the form of irregular and regular figures.

Consider a small "piece" of the vicinity of the landfill—**Figure 21a**.

We will give an assessment of how these or other details appeared on the image (in particular (1–8)) and in what order. It would seem that the site is simple enough and understandable (interpreted), but, in fact, the more you delve into its essence, the more questions arise, but more information can be "obtained" from the site. Indeed, everything and every detail in the image, in particular, has its own *causes*, *signs*, and *consequences*. If you pay attention to a specific image of the Earth's surface and mentally go over all its details, you can understand how many causes and consequences are on the image, and they all connect with each other in a complex system of cause-effect relationships hidden from the eyes. "There" can only be penetrated by reasoning.

For convenience, let us imagine deductive analysis schematically. Because lines and structures of reasoning are many, at least part should be reduced to a certain table. The diagram of the analysis of a pair of pictures is made differently; one of the variants is **Table 1**. The table shows the scheme for a *chronological pair*: two objects 1 and 2, one of which appeared before the other (1 before 2—straight pair, 2 before 1—reverse). The columns are added to the table: "arguments for" and "arguments against" the corresponding chronological sequence.

Figure 21b comments on some points in **Table 1**: (1) the epicenter of the group of trees (early trees), (2 and 3) the directions of the group's growth from the epicenter (the trees grow later), (4–6) the epicenter and the direction of growth (trees grow simultaneously), and (7) elementary trees (grow after 1). Different types of growth of trees on the slope also have their own causes and are due to the features of the soil, the illumination (8), the same slope angle (9), the soil state (10), etc.

The processing of a large amount of information based on chronopairs was carried out, including at a deeper level of chronopairs 1⇔2.

One of the assumptions is that on both sides of the road, the plantation formed in the process of its design—from the field—exists now; from the landfill it has disappeared when the landfill has grown but has grown on its slopes. This is due to

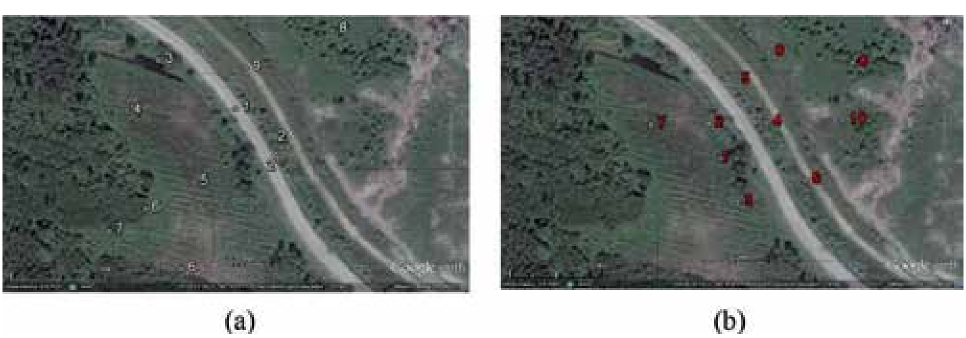

Figure 21.
Analyzed region: (a) the section of visual detection and (b) feature sites (Google Earth).

The direct order (1⇒2)
Trees are not elements of road design, because on visible signs are formed by growth and form the wrong (natural) form. Before the design of the road, the trees occupied a larger area than at the time of the survey, but some of them were cut down in the course of the land works for designing the road and the landfill. However, over time, the area of growth expands, and on the slope their age and growth rate are lower than on flat terrain, since on the slope, they began to grow after its formation arbitrarily, whereas at the base of the landfill the trees were not removed and grew simultaneously with the development of the landfill. In addition, the growth rate of trees on a slope is on average lower than on flat terrain (due to the difference in light conditions, properties of the soil structure and its relief).
The inverse order (2⇒1)
Trees are elements of road design, acting as protective screens, just as a body of water is an accompanying element of road design and accumulation of leachate from a landfill, assuming the correct shape. The rate of their growth at the base is lower than on the slope due to the fact that soil pollution by the filtration waters of the landfill spreads more at the base and level terrain than on the slope. Before designing the road, the trees formed an "island" among the field, but with the formation of a landfill and then girdling the road, the main part of the field was cut. This explains the different nature of the growth of trees on the slope (forest belt parallel to the road) and at the base (random distribution of forest area elements).

Table 1.
Chronological pair (1, 2).

the fact that the landfill could not exist without a road (**Figure 21b**), i.e., the road was created before the landfill, and in its place was something else—for example, the continuation of field 5, which was cut off by the road and, in the future, replaced by a testing range. It was a field (an artificial object), not a meadow (natural), because the forest under it was cut along the right lines 6, and in some places the forest grew over the edges and took a less correct form (e.g., line 7). But the agricultural field could not be so small. It turns out that the landfill was formed in an environmentally friendly place. Before the agricultural field, there were meadows, there was more forest, and there were probably water bodies, because on the edges of the landfill, there are many small and cut ponds, as well as elements of the water system regulation (dams, canals, dams, etc.). Accordingly, all elements of the landfill, including vegetation on its slope 8, a path along its perimeter 9, arose after its formation.

The chronology of events (month and year) can be assumed based on a series of events, known times of occurrence (e.g., of dumps), the size and density of trees, the correctness of their shaping (e.g., boundaries), etc.

Thus a certain *chronological chain* of formation of objects is built, which can be represented in the form of a scheme with the designation of the main arguments of *chronological links* (one visual argument)—**Figure 22**.

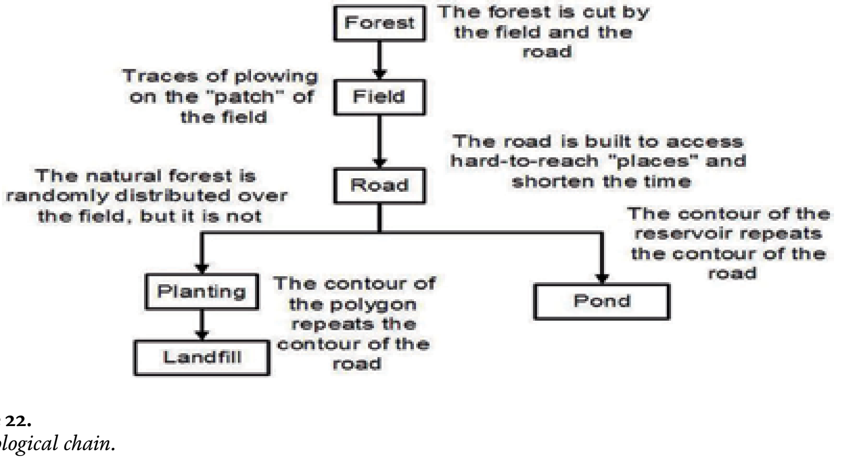

Figure 22.
Chronological chain.

Object identification			Connection of events		
i	p_i	Statement	j	p_j	Statement
1	80	Water object	1	70	Formation of the agricultural field
2	10	Shadow	2	5	Carrying out the road
3	5	Forest mass	3	20	Expanding the boundaries of the landfill
4	40	Rattle, moat	4	5	Cutting out sick trees

Table 2.
Probabilistic scheme.

General arguments are given only for a specific variant of the *chain of events*. Theoretically, there may be other chains in which the appearance sequences of objects will be different. But in many cases the reasoning will be much more complicated, i.e., for a chronological pair, much more reasoning is required.

In deductive analysis, you can use many other algorithms and schemes, such as the *probability scheme* (**Table 2**). It shows (1) the formalization of the probability of "eye" of any of the identifications of the object 3 in **Figure 21a** and (2) the events logically associated with the event of felling trees (6, 7). If a complete group of n events (assertions) is given, then the probabilities p_i of this events are reduced to probabilities q_i, the sum of which is 1: $\sum_{i=1}^{n} q_i = 1, q_i = \frac{p_i}{s}, s = \sum_{i=1}^{n} p_i$.

4. Conclusion

The solution of the problem of littering will belong to more than one generation of humanity, as its relevance will only grow with time. But it is possible to begin the solution of this prolonged emergency situation right now by setting a point of support inside (i.e., changing the inner world, consciousness) and outside (i.e., changing the external world, i.e., the environment around us).

Internal change is purely individual, and the external one can be given a logical explanation. The second, in particular, includes the monitoring of the WLO with a certain power impulse (at the physical, economic, social levels).

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Chapter 6

Services Six Sigma: Knowing the Debates and Failure Modes to Drive Better

Sajit Jacob and Krishnamurthy Kothandaraman

Abstract

The challenges in lean Six Sigma implementation start from terminology to applicability to actual application and finally in terms of experiencing the change. Six Sigma projects are being used as an event response antidote rather than as a culture in organizations. Could there be a debate on your "X sigma" versus my "Y sigma"? Should lean practice be the front end or the back end or somewhere in the middle embedded in the Breakthrough Strategy has been a matter of debate among practitioners for many years now. Ego centric debates, a reason to justify failures, a failure to identify the purpose are contributors to the dilemma. Historically, the genesis of Six Sigma carries a setting of manufacturing yards, so should that be a reason to brand it as unsuitable for services, or is there a need to "dilute" the rigor in methodology or search for alternative techniques to facilitate application in a pure services context? Now, in an era of Industry 4.0 and Big Data Analytics, does Six Sigma continue to have a relevance? Should machine learning algorithms remain in the ever evolving list of tools and techniques within the Six Sigma book of knowledge? This chapter aims to address the above questions and more number of questions that we experience on a day-to-day basis in Six Sigma applications in the real world.

Keywords: business excellence, lean Six Sigma, breakthrough strategy, industry 4.0, big data analytics

Chapter learning objectives: understanding of evolution of TQM, lean, Six Sigma in the industry, application issues in services sector, financial and overall evaluation of application, failure modes & critical success factors, emerging trends in application.

1. Introduction to TQM and lean Six Sigma evolution

Tracing the history of quality journey up to the age of total quality management, it was a period of promises such as enterprises being strongly committed to customers and their problems being of utmost priority for the senior management. People of the firm realize that they are there because of the customers, hence it becomes imperative that customer problems are be resolved. Also ways and means to be found out to make sure, problems do not recur. But, the obvious fact is assurances never satisfy a professional management, unless tangible achievements are showcased. Thus, managers slowly started withdrawing any long term support to such total quality management initiatives as they found nothing that contributes directly

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to their success. As business milieu became competitive with the entry of products and professionals, the demands on quality also underwent transformation.

A professional manager is looked upon as a sophisticated engine that leads, creates strategies, solves problems and generates revenue. Out of the outcomes expected, revenue and profitability end up as the most difficult mounts to surmount due to the dynamic nature of the target and quantitative measurements associated with it. As always, a resourceful manager finds cost savings as a possible strategy to overcome this mount. Cost savings promote the thoughts of waste reduction in the system, which indirectly forces organizations and management to concede to the fact that there exist systemic wastages. If quality efforts are identifying wastes and enables subsequent management of waste, then eventual reduction in waste will curtail the quality spend. Thus, savings too emerges as a form of revenue; then, it promotes the objective of the managers. This realization has actually led to convergence of quality and economics.

Cost accounting of wastage reveals prevention costs, failure costs, and appraisal costs. But reduction in cost is possible only with a deliberate, determined and systematic series of interventions. This is where breakthrough methodology of Six Sigma comes handy. It is a combination of a methodology and classical total quality management tools, where selection of the tool and its appropriate use will influence the outcome [1]. Because of its disciplined methodology, strict data orientation, innovation methodologies to generate solution, alignment to business this makes it a strategic intervention.

2. Lean-or/and-Six Sigma: the right medicine for services sector

Lean or Six Sigma, which is better? Is there a scope for argument? At least, there is a visible trend in organizations, to promote lean in a major way. The advantages people tend to present for lean include—Lesser time to prepare a resource for a lean engagement, lower competency demands due to lesser mathematical content to understand the lean principles and techniques, shorter cycle time of projects due to logic based driving, lack of data rigor are cited as reasons. But are we considering convenience over appropriateness while choosing the methodology?

People saw lean as a spectacle to find waste, but that is a very narrow view of the methodology. Lean can bring change only with end-to-end visibility of the system. Thus, many times lean takes the blame that it is not outcome focused, but that is not all that true. Lean focuses on flow, which means, lean creates the channel, maintains uninterrupted channels, and enables swiftness in the flow of material and information through the process channel. That philosophy, underlines the innate intend of lean to bring in acceleration. But during the times when scientific developments are exceeding the speed of thought, lean takes up the initiative to adopt and adapt organization to latest scientific and technological developments. Thus, customer, the end beneficiary starts seeing value and velocity while meeting their expectation.

Six Sigma is intended to be strongly customer driven and aspires for near perfect output. The mainstay of this strategy is methodological discipline underpinning the philosophy. It embraces data analytics to extract information out of the process and utilizes rigorous causal analysis techniques to unearth the failure modes proactively at a critical sub-process level. Thus scope is well dissected. The competency needs are stringent and hence it is a costly process. The systematic methodology definitely induces a bureaucratic approach. Size or business is not the criteria for deciding suitability for Six Sigma, rather existence of processes determines suitability for the methodology.

The objective of introducing Lean Six Sigma [2] is to enable organizations to reach the desired state of excellence. A state of performance excellence is a by-product of achieving highest level of performance in effectiveness and efficiency in a process. The term effectiveness is a metric traditionally being associated with reviews, tests and audits. Rather, the term means effectiveness of a work performed. From that angle of thought, the performance of a reviewer or tester or auditor who is inherently being despised as defect mongers, their output indicates the perfection of the business process they verify. In other words, defects detected in a product is indicative of the performance of the process quality underlying it. Defect reduction and reaching near zero defects is the self-adopted motto of any Six Sigma project as its performance metric upholds the unit of DPMO (Defects per Million Opportunities).

The service business is an outcome of globalization and liberalization [3]. Let us consider the case of out-of pocket expense management in a typical multinational corporation. The reports are created in a software tool, and then hardcopies are deposited in office. This box will be shipped to another nation to do scanning, the scanned files will be exported to a second country to verify its quality, a third country does accounting entries, in a fourth country expense audits take place and finally a fifth country will conclude the funds transfer. Teams and processes are spread out in five countries, they have their own business goals and objectives to achieve, the process implementation styles are different, operational metrics and their definitions too are different. Now, implementing a Six Sigma methodology in a segment will not create a huge impact on the final outcome and implementing methodology in end-to-end process is not practical as it is not under the eye-sight of a single master black belt.

Most of the services business running on time-and-material with a budget cap would insist on shorter turn-around-time with zero defects. Shortening turn-around-time, demands reduction of effort wastages to remain with shorter life cycle, more value adding activities, and increase in agility. Being agile is necessary to augment productivity and ensure efficiency in the system. But, many of the techniques in lean prefers to remain superficial, more logic centric, believes in low hanging fruits and cannot assure a prevention. Sometimes, even professionals tend to adhere to the count in technique name to find the stopping point. For example, the 5Y analysis, despite its inherent reluctance to approach a problem from diverse dimensions to find out potential root causes, practitioners impose the restriction of seeking “why” to fifth level, thus bringing out a suboptimal outcome.

Service projects are time sensitive. A caller to a call center wants the agent to attend to his call in the first ring, customer wants the call to be resolved in the third minute, and finally solution applied must be defect free. For an IT super market that serves maintenance, enhancement and different kinds of support, productivity is measured through metrics such as calls attempted (a measure of productivity), turn-around-time per call (a measure of efficiency), call reopen-rate (a measure of effectiveness). So an engagement is assessing the success of the deal with service provider on the basis of a combination of metrics that suggest a balance of effectiveness and efficiency.

Thus, if state of excellence is a combination of efficiency and effectiveness, then lean and Six Sigma has their own territories and both carries with them a role to play in the process improvement journey. Thus, there is no significance in the debate on lean or Six Sigma, as both are necessary to play their specialized roles and process remains as the ultimate beneficiary. The choice of methodology is only secondary to the decision to pursue with the state of process excellence in the debate.

Case 1:

A mechanical engineering service company trying to reduce the invoice process cycle time and reduction in invoice errors. This helps avoid huge accounts receivables that impacts operating income. In this situation, Accounts receivables became CTB, the CTQs are errors and invoicing time. Value stream studies performed. An exploratory regression was conducted to ascertain the phase that significantly contributes and followed up with a Ishikawa’s fish bone analysis to identify root causes. An action plan created to mitigate all root causes. At the end, cycle time improved from 16 to 8 days, and errors reduced from 40,000DPMO to 100,000DPMO.

3. Six Sigma: actual application versus definitions

If all what is said about Six Sigma is true, then the Six Sigma benchmarking is for a process which may translate to a function of a department. For example, procurement is a department where vendor management, processing of purchase requisition, and supply of products are connected but well dissected process that has ability to remain independent. Thus, organizations claiming sigma status at enterprise level or even for a department brings out the dichotomy in understanding. Sigma level is for a process and that identity needs to be necessarily protected.

Your three sigma is my Six Sigma—an argument that we may not regularly see but definitely not a rarity. The context of this claim is, the criticality of the product or function must determine the sigma level that must be targeted. In other words, all need not fancy achieving Six Sigma status, if the product is not critical. A patient going under the knife of a surgeon may not be happy about the fact that surgeon is operating at Six Sigma levels, or a patient approaching a pharmacist supplying medicines with Six Sigma assurance, so as an astronaut in a space vehicle made to Six Sigma standards. Those are situations where a Six Sigma level becomes inadequate. But, a balloon manufacturer need not aspire to operate at Six Sigma level. This is not because a higher quality for balloon is not a necessity, but for achieving the optimum cost-returns balance, a lower sigma level will not impact the health and safety of its consumers, and at the same time, sales may not drastically improve due to that one sigma level improvement from 3 to 4 sigma.

Six Sigma is not an initiative without a cost, hence striking the optimum sigma level that provides the necessary balance in quality that justifies the cost and revenue at the same time without impacting the well-being of consumers is a good business sense. That is a well sounding, realistic argument. But, the claim of Six Sigma status while the statistical performance matches with a lower degree on sigma performance scale on the ground of a business justification is not an acceptable situation. This is due to the same argument given above, that the benchmark Six Sigma level matches with a performance that equates to 3.4 Defects per Million Opportunities, which is statistically derived.

Irrespective of the stories around the origin of Six Sigma, there lies a fact that there exist a computation and sound statistical basis for fixing the sigma level for process performance. Process performance is assumed to follow always a normal distribution. 3.4 defects per million opportunities is a statistical computation, where the area of rejection region beyond the specification limits imposed on normal distribution is its basis and 1.5 times standard deviation shift of the distribution is an empirical observation. Process shift with time is a reality due to umpteen reasons that are associated with factors that determine a process in operation. The debate over the constant is insignificant considering the benefits the proponents of the methodology has demonstrated across the world in various leading industrial houses.

Case 2:

A leading automobile manufacturer while assessing the customer satisfaction levels of after sales services realizes that their highway breakdown service cycle time is around an hour. On analysis of the phases, it is found that the interval between ticket creations to dispatch of service engineer consumes the most of the time. Process flow was created, Value Added-Non Value Added analyses performed, for the NVA, a detailed causal analysis also conducted. Ultimately, linear regression study finds selection of mechanic and dispatching are the two activities that contributes most. A causal analysis revealed significant findings, for which corrective and preventive actions were planned and implemented. Using X-mR charts the time intervals are plotted and compare for significant changes before and after implementation of actions. The CSAT improved from 53 to 70%, and proportionately revenue increased as customers started relying on the company's service center rather than third party service stations.

4. Lean to begin or end or remain within

There are arguments favoring conducting a lean project and then sustain with Six Sigma method, or conduct a Six Sigma project and sustain with lean, or let lean techniques remain alive throughout and apply wherever relevant without a definite role. This debate is circling around the reluctance to assign a definite role and absence of a definite idea on the outcome expected. Lean must be seen not as an easier option to Six Sigma, rather as a methodology to skim the wastages in the system.

Waste is a term with the widest scope in quality science. Industry wide for many years now, waste is a term that encompasses many activities and by-products that does not directly contribute to the final deliverable. Indirectly, learn philosophers concluded them as non-value generating outcomes, rather to make it straight, something for which a client is unable to pay the service provider. In a typical IT environment now a days, we observe, hundreds of mails being send across cubicles transporting huge amount of bits, the IT professionals continuously complaining of inadequate disk space to store the huge amount of files, think about the bandwidth and energy being consumed. Most of the day, an IT professional moves from one floor to the other participating in not less than five meetings, assume the waiting time before elevators and traveling time and finally meet to decide again to meet. End product has many functions to elate the customer, but the essential needs demanded remains incomplete. Every stage goes to multiple iterations of rework to achieve the requisite quality, because defects injection and detection turned out to be specialized jobs. Then most of the scenario has an underlying issue called defects, over use of energy, excessive time spent, etc., so needs a more intrusive methodology to unearth the hidden causal elements to prevent the occurrence, else, this waste reduction ends up as a regular routine job as operations. So lean needs to be planned and must be part of life, rather than a stereotypic engagement. Else, it leads to a state where one fails to plan, ended up planned to fail.

If lean has to be a deliberate and structured engagement, then what approach is beneficial? The lean tools and techniques enables to identify the waste in the system. If lean operation is conducted and then move into a Six Sigma methodology, many wastages, may return to system under the banner of essential non-value adding activities. Therefore, it is more appropriate to preserve the benefits realized in Six Sigma projects then further promote with reduction and prevention of wastage to provide an enhanced value to the stakeholder. Both approaches are far better than sprinkling lean techniques within Six Sigma methodology which will fail the team from recognizing the benefits realized out of those techniques and many times even fail to understand the failure of the techniques as well and eventually, process may not reap the right benefits due to inappropriate and inadequate usage of lean techniques. Thus, we agree with Bendell in [4] conclusion that lean and Six Sigma can be effectively integrated.

> According to Taiichi Ohno, waste reduction must be planned only when company is profitable, as any trimming during difficult times becomes risky, as none will be sure about the appropriateness of the action and its impact.

5. How methodology gets defeated

Invariably, the motives for application of Lean Six Sigma spans from meeting a target in terms of number of projects or to achieve targeted savings need not build a culture. While, becoming a culture, the methodology actually must become part of the genetics of the organization, which means it becomes an institutionalized approach, rather a day-to-day behavior. In the run-up to meet the count target, there will be attempts to force fit a breakthrough methodology on to a resolved problem, even wrong choice of problems for LSS intervention, and finally sub-optimal performance change will end in blaming the methodology. When cause is unknown and demand is a breakthrough performance, then a lean Six Sigma is the approach to try. But, if the scenario changes to a routine continuous improvement while causes are known, a pure lean intervention too is a good try.

Now, what constitutes a breakthrough and what definition it carries and who authorizes it? Breakthrough is radical performance improvement. A continuous improvement journey is a process of steady and gradual ascend in performance over a time period. But such a growth path will not create substantial improvement from baseline performance. Therefore, it became necessary to puncture continuous improvement journey with periodical breakthroughs to make sure while maintaining a steady performance growth, there is periodic transition to higher plains that leads to achieving a high performance level compared to continuous improvement highway. Typically, statisticians identify a step function with continual improvement journey that would yield a higher performance after a pre-determined time period when compared with a continuous improvement journey during the same interval is treated as breakthrough performance.

The gold standard of a Six Sigma project lies in the revenue it generated. The revenue could be savings by plugging financial leakages, or even a fresh source of income. However, it may be, the financial officer who upholds independence with respect to the operational process, and as the custodian of the cash chest, best suited to vet the financial benefit. Then, a natural counter argument is if source is out of scope of the LSS but revenue is earned, will the credit goes to the project executed. Naturally, no. Unless the source of revenue is verifiable and can be tied to the performance variable that acts as critical to process and quality metrics, the benefit of the funds cannot be tied to the project.

6. A post-mortem examination of DMAIC

Many LSS projects fail to begin with a phase to recognize the problem. This is the phase to realize the damage, relate with the financial outcome, and reiterate the importance after careful introspection. A business case is the outcome. When a case is documented, it must highlight the necessity of the project by explaining the gains out of the project and loss if project is not undertaken. Unless there is a statistical proof around the performance parameter and its causal association with financial performance parameter, a conviction cannot be generated. But the problem that manifests need not to be the real issue one must try to resolve with a LSS methodology. That is where an operational drill down is required. But, a systematic operational drill down and statistical association verifiable with a sound logic is consistently missing now a days in Six Sigma projects.

7. Relating to financial outcomes

A significant financial outcomes demands sufficient improvement in product overall quality and process performance. Overall quality is determined by process quality and output quality that gets revealed by the verification and validation activities on the process outcomes. Thus, process quality is more to do with compliance, hence could be measured by non-conformances (NC) from process appraisals and process adequacy satisfaction surveys, but output quality is essentially defects. But defects in itself may be caused by factors such as quality of input, complexity of work products, quality of safeguards in the process, competency of the reviewer or tester, etc. Thus overall quality could be represented by cost-of-quality metric.

Financial performance could be modeled as below:

$$\text{Financial performance} = f\,(\text{process performance, quality}) \tag{1}$$

Then,

$$\text{Process performance} = f\,(\text{variations, efficiency, productivity}) \tag{2}$$

$$\text{Variations} = f\,(\text{size of work, processing speed, complexity, competency}) \tag{3}$$

$$\text{Efficiency} = f\,(\text{input quality, processing quality, competency}) \tag{4}$$

$$\text{Productivity} = f\,(\text{input quality, processing speed, technology, competency}) \tag{5}$$

Hence,

$$\begin{aligned}\text{Process performance} = f\,(&\text{size of work, processing speed, complexity,}\\ &\text{competency, input quality, processing quality,}\\ &\text{processing speed, technology})\end{aligned} \tag{6}$$

Similarly,

$$\text{Quality} = f\,(\text{process quality, work} - \text{product quality}), \tag{7}$$

that is,

$$\text{Process quality} = f\,(\text{NC, process adequacy satisfaction index, defects}) \tag{8}$$

Then, work product quality can be termed as defects, therefore

$$\begin{aligned}\text{Defects} = f\,(&\text{input quality, work} - \text{product complexity,}\\ &\text{process quality, competency})\end{aligned} \tag{9}$$

Thus,

$$\text{Quality} = f\,(\text{NC, process adequacy satisfaction, input quality, work} - \text{product complexity, process quality, competency}) \tag{10}$$

Therefore,

$$\begin{aligned}\text{Financial Performance} = f\,(&\text{size of work, processing speed, complexity,}\\ &\text{competency, input quality, processing quality,}\end{aligned}$$

technology, NC, process adequacy
satisfaction, input quality, work
–product complexity, process quality)   (11)

Here financial performance is otherwise called as critical-to-business parameter. This is a lagging indicator as we get to know its status only after the event. To control this lagging indicator, we need leading indicators that are there as part of the transfer function (Eq. (11)). All transfer functions must be transformed to statistically valid linear regression equations, so that we get only a set of statistically valid causal variables (leading indicators) to act. But all statistically valid leading indicators will not be useful for Six Sigma, we need to identify the most significant process related contributors from the leading indicators. Only those indicators that are controllable yields a Six Sigma project. Probably, process adequacy satisfaction may provide process improvement change requests handling process improvement, incoming inspection process improvement will enable better input quality, processing error reduction of different critical sub-processes, process optimization to reduce the turn-around-time, competency enhancement process improvement to increase competency development are typical green belt projects that can support in the above specimen.

8. Who is responsible for driving improvement?

The quality of product and process, and process performance improvements could be responsibility of black belts and financial performance ultimately is the responsibility of master black belt. Thus, belt system is aligned to the metrics architecture to achieve an improvement roll-up from critical sub-process performance enhancement leading to critical quality and process performance improvement leading to breakthrough financial gains. This means, a swarm of green belt projects in parallel driven to achieve critical quality and process performance objectives at a higher plane and finally meets with the business objective at the apex of the architecture. Such a system will reflect Six Sigma true to its definition that includes terms such as focused, strategic, disciplined, critical problem management and high intensity engagement.

Recognizing problem to the level of the relevant process and there on to identification of critical sub-process set the stage for defining the problem. Thus problem, finds its expression through a performance metric (objective) on the critical sub-process. Here, choice of the metric becomes critical. The goal with which we are measuring the critical process must decide the facet of measurement we make on the process. But, the question is problem itself, without knowing it, a definition is not possible. Here, problem is the gulf between the target set and actual performance. Then a more fundamental question arises, if target itself is unscientifically set, then its relevance to engage in identifying the gap is unreasonable. Therefore, the target for the performance objective must be such that achieving that target must automatically ensure achievement of higher goals, which means, the target setting has to start from top and must percolate down.

The only target that is imposed will be the financial performance target. Financial target will be derived from the targets for the chief executive so that it remains consistent with the higher objectives of the organization and will enable a reporting to the board. Now the question is, to meet the financial performance target, what targets must be there for the process performance and quality objectives, this must be statistically derived. Then, for the set targets for process performance and quality objectives, what targets needs to be set for their leading indicators also must be derived statistically. So that, the targets are consistent and it enables and ensures transmission of benefits from lower order to higher order. This logic finds support from Antony et al. [5], where a consistent explanation of achieving financial goals is explained.

Pilot baselines created with data collected (and not what is anticipated or perceived) from the process for a short duration and utilizing statistical process control techniques to understand the triplets of stability (Upper Control Limit, Central Line, Lower Control Limit) and twins of capability (Cp, Cpk) subject to nature of data type. Find the gap between target and mean, where target is the center of specification limits and mean is the actual performance average. It is equally necessary to decide on variance reduction by comparing the intended standard deviation and actual standard deviation. Thus, this article emphasizes the fact that the concept of improvement is realized only when mean and variance improves. Thus, a typical problem statement will accommodate facts such as nature of distribution, actual average and standard deviation values, percentage of improvement computed with the aid of targeted values for average and standard deviation, committed count of days to turn around the situation, targeted date of Six Sigma project closure and committing that other performance parameters of the process will not be negatively impacted due to this project. Every performance objective must have a problem statement that includes the financial performance parameter, quality and process performance objectives, and their leading indicators pointing to the critical sub-processes. Thus, a LSS project run on critical sub-processes to improve the leading indicators, such that benefits cascade till financial performance measure.

When it comes to process mapping in LSS, a hierarchical approach is advisable where a high level process map with many sub-processes, then every sub-process being exploded to understand the series of activities, thus drill down till we reach a set of tasks. Only a mapping at task level will enable us to investigate for root causes, identification of waste, and dissection of value stream blockers. Thus, a typical LSS project must create thorough process drawings for all relevant processes and drill down till task level drawings are created for the critical sub-processes that are represented in the linear equations generated for the final transfer function (Eq. (11)).

9. Nuances of Six Sigma application in a services context: critical success factors

In a service environment, the problems being investigated as per LSS may not be prevalent across all engagements, therefore, uniformity of the service process being followed across needs to be ascertained. The tools and technologies involved also needs to be identical. The business process being serviced needs to identical in nature and complexity. Then the most critical item arises, the measurements. Here, if individuals are involved in data collection, we can safely assume that will be the biggest challenge as humans are the weakest link in a data collection process. We have identified situations, where in service industry data mix-up due to reasons such as, collecting data from unintended process steps, data units are widely different, even derived metric formulae differing. Most of the occasions, we have observed there is no rationalization of competencies among data collectors before data collection. The best example, is the defects data itself, the problems start from even determining a defect, then goes to misunderstanding in identification of source of defects, categorization of defects such as technical classification of defect, operational classification of defect severity, etc. are results due to absence of a descent data definition document and a measurement system analysis. After collecting the data, in case of data storage, the practices related to privacy, security, integrity, and completeness of data needs to be validated and ascertained else there could arise allegations of data manipulation and theft. Without plugging this failure mode, no reliable data collection is possible in measure phase.

The analytics part of measure phase is yet another area where too many questions, too many personal biases and many assumptions and practices are observed. All project reports carry the customary descriptive statistics possibly it is easier to get as a software output. But, invariably interpretation and inferencing part is mostly inadequate. For example, classical mean, standard deviation, skewness and Kurtosis need not carry any relevance when data type is discrete. When data is continuous, reports fails to present an understanding the statistical significance of the mean, tolerability of standard deviation, the presence of skewness. Since samples are used for the study, and when multiple samples of data are available from different engagements, without an inferential statistics proves identical mean and standard deviation, samples cannot be mixed, even when all other environmental and data specific factors are identical. When samples needs to be compared for their descriptive statistics, their appropriate derived metrics for measures of central tendency and dispersion may have to be employed to enable a comparison. Applying inferential statistics and statistical process control techniques without statistically concluding on the data type of the variable will lead to wrong choice of tests and charts leading to wrong inferences.

In analyze phase, invariably we find either a 5Y analysis or a fish-bone diagram and rarely a Failure Modes and Effects Analysis (FMEA). Just because a number five exist, there are no demands to stop our Why-Why analysis at the fifth Y, as long as we have not hit the root of the cause. To be true to the technique, it should be "5Ys and 4Whats," which means every time a Y is answered, its impact gets documented as "what" but most unlikely practiced that way. Also, this technique drive the root cause analyst with blinders such that only a single cause gets identified and excavated to five levels. A fish bone diagram, by its facilities allows multi-dimensional exploration. But then people takes pride in their experience and knowledge without examining to a subset for exploration. Hence, it is advisable to explore all the 7M (Man, Money, Material, Method, Measurement, and Milieu) dimensions, at least as a minimum criteria should be examined to plug the possible recurrence of assignable cause associated variation. Even a rigorous technique called FMEA can be defeated by half-hearted approach. A thorough process FMEA is performed at task level, where each task is examined for all the 7M dimensions to unearth the possible failure modes of that step. Unless all kinds of failure modes are listed, including hypothetical possibilities to plug corrective and preventive actions, controlling common cause variation becomes impossible.

Control phase is denoted by the application of statistical process control to monitor the stability and capability of the evolved process. An improved process, need to display stability and substantial variability reduction. It is equally demanded that the improved process must have a Cp and Cpk, greater than 1 or around 2 Defects per Million Opportunity to grade a process as significantly improved with LSS methodology. But, all improvements deteriorate if process is not properly maintained. Therefore, without sustainability plan concluding a LSS project will be a hasty move.

Sustainability plan is a combination of standardization and institutionalization phases. A stable and capable process delivering near perfect outcome is devoid of all defects. Hence, a value stream mapping at this stage on the reformed process will identify non-value added and essential non-value added activities for which an impact assessment will clarify the risks in eliminating each of them. In a controlled environment, non-value additions can be eliminated step by step after evaluating. At the end, an optimized process needs to be made the culture of the organization, there techniques such as 5S, visual mistake proofing, Gemba and other lean techniques will assist.

10. Emerging trends in application

As part of Industry 4.0, even if Cyber-Physical Production Systems take over, still micro computers will react to signals from sensors by sending signals to mechanical systems, but the underlying service with mechanical systems still will be prone to have the same failure modes. Overall, the failure modes could increase due to interface complexities. Robotic automation in the manufacturing and service industry will allow preventive measures and bypassing algorithms to continue the process but failure of machines, electronics and processes driven by people will continue to be the reality. The intelligence of the machines is limited by the quality of input training algorithms utilized for self-learning. Therefore, Six Sigma will find relevance in providing a complete learning feed into the training algorithm, preventing identical failure.

Big data from Industry 4.0 systems needs machines learning algorithms to support the analysis. Machine learning algorithms will aid in failure pattern recognitions, which will trigger preventive Six Sigma operations. So it is well in conjunction with Antony in [6, 7], that the Six Sigma tool box will continue to grow with emergence of applicable management and statistical techniques.

11. Future research potential

Lean and Six Sigma have permeated into every industry. In spite of a plethora of success stories, still maturity in LSS usage as a breakthrough methodology to achieve business excellence in a sustained manner is yet to be ascertained [8]. There are Six Sigma professionals in practice who make a range of inappropriate choices from selection of problem to choice of methodology.

It remains to be seen how Six Sigma application helps in the innovation process. The classical methodology and tool set can be made more vibrant by integrating LSS methodology with methodologies that provides innovation techniques to overcome constraints and speed [9, 10].

There are corporate organizations which do not adhere to the principle of monetary performance as the basis of determining project success [11, 12]. There are professionals who believe that application of design of experiments, Markov's switching models are adequate to qualify a black belt project. Utilization of this methodology in corporate strategy building and corporate leadership creation is an area to be further explored. Therefore, a LSS implementation maturity model is essential to provide a highway for improvement and segment the corporates into different levels of maturity [13].

Since there are many practitioners who still think that this is a management philosophy created by mixing many aspects of past trends with statistics, fewer academicians are venturing into scientific research in this area. Unless scientific research happens, an efficient implementation methodology cannot continuously evolve. Till that point application of Six Sigma will remain as per the beliefs and based on the appetite for trial and error studies. This will result in a large share of projects not yielding the expected results and finally leading to a premature conclusion that the methodology ineffective and inefficient. One of the key factors that prevented aggressive academic research in this area is the branding of Six Sigma as management fad, but over the last three decades, the methodology survived its critics, pervaded into different industries to solve a range of problems from customer satisfaction, productivity, defects, etc., thus it showed its potential [14, 15].

Being a disciplined methodology rooted in a trained army of resources, creates two parallel organizational hierarchies, one for business and other for process improvement. This creates stress on the organization to do capacity and availability management and competency management for two streams separately. Managing resource conflict in a LSS organization is a research area to be further explored.

Since LSS is highly prescriptive in approach, mechanical organizations with repetitive processes will find it appealing, but a service industry which would prefer to accommodate flexibility at the cost of a few defects will find LSS as a conflicting paradigm. So DPMO or DPMU or something else should be the benchmark of performance. Studies are possible in this conflicting territory [16].

There are arguments that stereotypic methodology of Six Sigma impedes innovation and rather relies on cluster of improvements that solves few of the pressing problems to get the desired output. Thus, exploration or exploitation, what is the priority of LSS methodology? [17, 18]. Of course, Schroeder et al. [19] provide evidence for ample number of patents to prove explorations as well happens with exploitation. This is a topic for further research across global context.

Should Six Sigma remain as a stand-alone initiative or be part of the day-to-day operations is a vital question. That is an area of study in itself [20].

12. Concluding thoughts

There could be many more failure modes and criticisms on lean Six Sigma, but as a methodology it has helped many companies to earn quality savings and thereby become a benchmark for business excellence. Definitely, this is not a methodology that will yield a solution for a problem overnight as methodology needs to complete full life cycle. Success of this methodology is dependent upon the culture organization builds, for which a large sets of professionals need to be trained at various competency levels to occupy different belt positions. The training time is a significant investment as it is not practical to master process and required quantitative skills in a short time.

As a practical impact in implementation, Six Sigma could instill the must needed knowledge of systems and variations in the minds of leadership. Most importantly, a Six Sigma project is most likely to fail, when methodology is improperly implemented with wrong choice of tools and techniques that leads to poor inferences. But lean Six Sigma, armed with open tool box, will always find newer management techniques to resolve the problems of the modern times and the new generation methodologies of innovation also finding a place in improve phase will significantly cap the criticism around creativity in such implementations. Data analytics being the new buzz word, the methodology will continue to remain relevant in the intense digital era of Industry 4.0. Machine learning will enable pattern recognition to identify precise possibilities of failures, and design of corrective actions driven by data out of DMAIC when loaded into AI will allow their application at the most opportune moment to make sure failure modes are adequately mitigated and even might allow for extreme positive sigma performance in services context.

Academic community has enough to further their research interests in this field. Failure studies on LSS projects can create vital case studies for training material. It is possible to look at integration with methods from specialized areas that augments the effectiveness and efficiency of current LSS methodology. Studies around institutionalizing Six Sigma practice and integrating with corporate strategy planning, organizational leadership competency building, etc., can be undertaken to further the knowledge of LSS.

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Chapter 7

Implementation of SPC-EPC Scheme to Lessen and Control Production Disruptions in Chlor-Alkali Industry

Walid Smew, Bader Al-Mutawa and Ali Issawy

Abstract

The quality of products in the industry can be improved by monitoring the manufacturing process and adjusting/optimizing the process input variables based on the output deviation from the target. SPC stands for statistical process control, and it is used to monitor processes in order to identify any assignable causes of variation. EPC stands for engineering process control, and it is concerned with adjusting systems inputs to keep the system output on target using different types of controllers such as integral controllers and PID controllers. Combining SPC and EPC as a unified framework proved to be effective in reducing production disruption in manufacturing industries. The main objective of this project is to redesign the production and quality control system in a chemical batch processing company, anonymous company, by developing an engineering process controller (EPC) in order to adjust the chemical process inputs to keep the output chemical concentration on best optimized target while monitoring the system using the sensitive time weighted control charts (SPC), in order to eliminate the process assignable causes of variation, improve system elements life, and reduce overall system wide costs.

Keywords: batch processing, production disruptions, engineering process control (EPC), integral controller, statistical process control (SPC), time weighted control charts

1. Introduction

Statistical process control (SPC) and engineering process control (EPC) are two very different approaches to improve the process efficiency by reducing the process disturbances or variability and achieving a much better product quality which will lead to customer satisfaction and increase in sales [1]. SPC works by monitoring the process by utilizing different types of control charts and tries to identify any points located outside the control limits [2, 3]. Points located outside the control limits are commonly referred as assignable causes which mean there is a specific cause that caused the point to be out of the control limits [4]. It is sometimes difficult to differentiate between common cause and assignable cause, furthermore just because the points are within the control limits, it does not mean the process is under control [5]. The points sometimes generate a suspicious pattern which will indicate there's something wrong in the process and must be fixed. Now for the EPC it's a continuous process of manipulating the process input controls in order to keep the output on target [6]. EPC utilizes different types of controllers that work by feedback adjustment such as the integral controller and the PID controller [2, 6]. These controllers will work in conjunction with a certain type of control chart where if a point falls outside the control limits then it will automatically trigger the controller to take corrective actions to bring the process back in control. The SPC and EPC unified framework has been proven to be very effective at significantly reducing the process variation and drastically improving the product quality. Aljebory and Alshebeb [7] presented how effective to combine both techniques and implemented a unified framework of SPC and EPC into a chemical manufacturing industry and managed to reduce the process standard deviation by 30%. Out of the many types of statistical control charts, the cumulative sum control chart (CUSUM) and the exponentially weighted moving average control chart (EWMA) are very good at detecting small mean shifts in many quality characteristics and can easily be devolved and analyzed using software such as Minitab. In order to develop an engineering controller, one must first mathematically model the process and identify the important inputs, outputs, flow rates ...etc. and then translate them into programming code to be run and analyzed using software such as MATLAB.

This work considers three research parts: chemical batch processing monitoring and control, integration of SPC and EPC, and a case study to demonstrate the unified scheme to lessen and control the production disruptions in Chlor-Alkali industry. This book chapter is organized as follows: Sections 2–4 illustrate the theoretical background and derivation of the basic relations from literature for integrated SPC-EPC systems. Next, Sections 5–7 describe and explain the case system, key input variables, the problem, and the proposed unified SPC-EPC scheme implemented in Chlor-Alkali industry. Finally, Sections 8 and 9 present the results, findings and conclusions of this research work.

2. Statistical process control (SPC)

The idea of statistical control charts is that a reference distribution that can be attained by simply combining observations from rational subgroups where they are taken over short periods of time in which that the process is considered to be stable [8]. A continuous comparison of the current process observations will be compared to the control limits that is calculated based on the reference distribution can lead to a detection of assignable causes such as out of control points and patterns.

In order to implement a control chart successfully, a practitioner will ask three main questions [8]:

- Is the control chart an important tool for this application?
- Which type of control charts must be used?
- Where should be the control limits be placed?

To develop a statistical control chart, it all depends on whether or not a reference distribution exists. If a reference distribution does not exist then an effective alternative approach would be plotting individual data subgroup means or variances onto run charts and those run charts must be presented clearly to the individuals that are responsible for the process. Control limits will not be used, however if the process means exhibits a drifting behavior then an Engineering process control strategy should be implemented in order to reduce process variation [8].

The answer of questions two and three depends on why the charts will be used. There are three main uses for a statistical control chart: (1) real time process monitoring, (2) problem solving, and (3) assessment of process stability. Uses 2 and 3 are more important than 1. Long-term process improvement is way more important than just process monitoring and detecting [8].

After determining the main use for a control chart, a specific and suitable control chart must be chosen to monitor the process. If the process noise is white noise and the objective is to detect a spike, then a Shewhart chart should be used; if a step change, then a cumulative sum (CUSUM) should be used; and if an exponential change or increase, then an exponentially weighted averaged should be used [8]. CUSUM and EWMA control charts provide faster detection in small shifts in the process mean where the regular unmodified Shewhart control charts might fail to detect small step changes in the process which would result in a higher process variation [8].

2.1 Time weighted control charts

All control charts have the same basic format with a center line, an upper control limit, and a lower control limit however, time weighted control charts uses weighted averages as a performance measure, where they take in consideration the current and the previous process observations in order to make the control chart more sensitive to small process shifts especially in phase II process monitoring [9]. They can be used as an excellent alternative to the Shewhart control charts which uses only the information contained in the last sample observation. There are three types of time weighted control charts; the exponentially weighted moving average control chart, the cumulative sum control chart and the moving average control chart [10].

2.1.1 Exponential weighted moving average (EWMA)

The exponentially weighted moving average control chart is a time weighted control chart which uses the weighted average Z_i, as the chart statistic rather than the sample number i [2, 11]. The weighted average can be calculated by using the following equation:

$$EWMA_i = Z_i = \lambda X_i + (1-\lambda)Z_{i-1} \tag{1}$$

The EWMA control chart control limits can be calculated by using the following equation:

$$UCL = \mu_0 + L_\sigma \sqrt{\frac{\lambda}{(2-\lambda)}\left(1-(1-\lambda)^{2i}\right)} \tag{2}$$

$$CL = \mu_0; UCL = \mu_0 + L_\sigma \sqrt{\frac{\lambda}{(2-\lambda)}\left(1-(1-\lambda)^{2i}\right)} \tag{3}$$

The factor L, that is shown in Eqs. (2) and (3), is called the width of the control limit and the λ is called the weighting factor. The common values of λ ranges from $0.05 \le \lambda \le 0.25$ [6]. Generally, using a smaller weight would be better at detecting small shifts in the process mean. The boundary value L is usually determined from an engineering decision based on the costs of being off target and the costs of making the adjustment [7]. Montgomery proposed the following equation (Eq. (4)) to estimate $\sigma EWMA$ [2, 11].

$$\hat{\sigma}EWMA = \sqrt{\frac{\lambda}{2-\lambda}}\hat{\sigma} \tag{4}$$

3. Engineering process control (EPC)

Quality control engineers frequently need to adjust different processes. Control charts such as Shewhart control charts are inefficient and inappropriate in adjusting processes. Simple principles provided by EPC could be easily put to use [12]. Principles such as feedback adjustment using a discrete proportional integral (PI) control can be easily implemented and understood [8]. PI controllers are not only simple and effective, but it's also very robust and versatile, which means it could be implemented in different industries [13]. Discrete PI controllers can easily replace, much more complicated control schemes with only a slight loss of efficiency [14].

When adjustments cannot be done automatically, there usually a cost factor that goes with every process adjustment that is done [15]. The fixed cost that goes with every feedback adjustment is often not economical to make adjustment at every opportunity [8]. However, in cases like this, using and EWMA control chart that uses bounded adjustment could give minimum cost in feedback adjustments, where the adjustment is only made when the process observation exceeds the upper or lower boundary [16]. Appropriate tuning can be done on the bounded adjustment scheme where it would minimize three main costs:

1. Cost of being off target

2. Costs of adjusting

3. Cost of sampling and testing

EPC will use feedback adjustment to remove any assignable cause that the SPC approach failed to remove [2]. The Integral control approach works by adjusting the process input variables based on the error that started to accumulate over a certain period of time. Usually, integral controls are used in conjunction with a proportional controller which is responsible for making corrective adjustments to the proportion of error in the input, so it can adjust faster and more accurate [6]. The combination of the integral controller and proportional controller is referred as the PI controller where they use feedback adjustment to reduce the deviation from the target [2].

3.1 Process control by feedback adjustment: integral control

The main objective in feedback adjustment is to make the output as close to the desired target as possible. Let us say the process at period time t has an output of y_t and a singular input process variable of x, so changing x will affect the output y. $y_{t+1} - T = gx_t$, where T is the desired target and g is a constant called the process gain. The process gain is basically relating to the magnitude of change in x_t to the magnitude of change in y_t. It basically acts like a regression coefficient [2, 6]. In any process, there will most likely be some disturbances, we will denote the disturbance in the process with N, so $y_{t+1} - T = N_{t+1} + gx_t$. This equation shows that at period t + 1, the output deviation $y_{t+1} - T$ will depend on the disturbance in period t + 1 plus the input variable x_t which is our chosen set point. By forecasting the disturbance, we would know the optimal set point to cancel out the disturbance [17].

$$x_t = \sum_{j=1}^{t} \left(x_j + x_{j-1}\right) = -\frac{\lambda}{g}\sum_{j=1}^{t} e_j \tag{5}$$

The actual set point for variable x_t at the end period t is the sum of all adjustments through time t, where λ is the weight and is e are the predicted error [2]. This type of process adjustment scheme is called the integral control, where it uses feedback control to manipulate the variable input x_t, to reduce the process deviation from the target.

3.2 Process control by feedback adjustment: proportional integral derivative controller (PID) controller

A PID controller has the optimum control dynamics as it has zero steady state error and would eliminate the overshoot and oscillations of the output [6]. Moreover, it has a quicker response time compared to the integral controller or the proportional integral controller. Choosing the manipulative variable for a PID controller is calculated as shown below:

$$x_t = k_p e_t + k_i \sum_{i=1}^{t} e_i + k_D(e_t - e_{t-1}) \tag{6}$$

k and c are constants that are chosen based on the tuning of the controller [6].

3.3 The adjusting chart

Most feedback adjustment schemes adjust the process automatically, utilizing many different combinations of sensors and computers and finally actuators to physically implement the adjustment [2]. When the feedback adjustment adjusts the process automatically, it is called the automatic process control. In some processes, the feedback adjustment is done manually by the operators, where the process deviations are routinely observed to know how much adjustment needed to keep the output closer to the target.

4. Integrated SPC and EPC systems

SPC works by continuously plotting and comparing a statistical measure of certain variable with a user generated control limit [18]. If the plotted statistic exceeds the upper or lower control limit, then the process is considered to be out of statistical control. Corrective action is then applied to the process in order to eliminate the assignable cause thus reducing process variation [18]. Matos et al. [19] integrated SPC and EPC into a unified framework and investigated a pulp and paper industry through three phases and found that:

- Phase 1: fitting several single input and single output (SISO) transfer function models in order to identify any possible relationships between the input and output variables.

- Phase 2: merging of three data sets in order to achieve the main goal which is obtaining a better profile of the bleach pulp process; phase 1 was then repeated.
- Phase 3: a multiple input single output (MISO) transfer function will be developed based on the results obtained in phase 2.

However, using this type of integration has two big concerns. The first concern is that the identified input and output variables must be monitored. The second concern is that a decision must be made on which type of controller should be used, whether an automatic controller or a manual controller. The decision will be made based on the adjustment costs and type of adjustment [19].

SPC and EPC are two techniques that complete each other as they both work together to reduce the process disturbances and improve the product quality. There is a relationship between the EWMA predictor and the integral controller, they both work hand in hand in order to make predictions. Using EWMA control charts in conjunction with integral controllers are frequently used because of their simplicity and efficiency. Jiang and Farr [20] proposed four different categories of the application of the two different quality control approaches, which are going to be illustrated:

1. The EPC scheme is not needed if the data is not correlated. The SPC will be used to monitor the process and identify any assignable causes.
2. The EPC control scheme should be examined if the data is correlated. The SPC control charts should be brought up to monitor the autocorrelation if no possible EPC control scheme exists.
3. Even though the EPC control scheme can compensate some auto correlation disturbances, however a single EPC control scheme will not be able to compensate all the different kind of variations.
4. The diagnostic process of the SPC will be used in conjunction with the feedback adjustment of the EPC control scheme, where the SPC will detect any sudden shift in the process mean and the EPC will take corrective actions based on the deviation from the target.

SPC and EPC originated in different industries, the parts industry and the process industry, and both approaches have been developed independently and they have they are on controversies, since the word control has different meanings depending on the approach. The word 'control' in SPC means process monitoring, while the word 'control' in EPC process regulation. SPC and EPC strategies are considered as two complimentary strategies for quality improvement [18]. There are three types of SPC and EPC unified frameworks: The Algorithmic SPC, Active SPC and the Run-to-Run.

4.1 Algorithmic SPC (ASPC)

ASPC is proactive approach to quality improvement that uses feedback and feedforward adjustments to reduce predictable variations [18]. This approach aims to reduce both short term and long-term variations by using a new discipline that replaces the traditional discipline 'monitor, then adjust when out of control' with 'adjust optimally and monitor [21].

4.2 Active SPC

Active SPC are statistical models that are used to define the control limits and develop control laws that suggest the exact adjustment needed to maintain the process under statistical control [18]. Thus, using this strategy would eliminate the need for an algorithmic automatic controller. As a result, active SPC would result in a saving in raw materials and utilities.

4.3 Run-to-Run (RTR)

RTR is a process control technique where a run is represented by a batch or any other type of grouping [18]. In an RTR process, control actions are only made or implemented between runs instead of during runs. The SPC acts as a supervisor [18] where it triggers the adjustments whenever needed.

5. Case study

Anonymous company is a locally based Chlor-Alkali chemical manufacturing company that was listed in Kuwait stock exchange in the year 2002 and is focused on continual growth and optimization. The anonymous company complies with many international standards such as ISO 9001: 2008 quality management systems, ISO 14001: 2004 environmental management systems and OSHA 18001: Occupational health and safety management. The anonymous company has a total equity of approximately $107,000,000, produces and exports many kinds of salt-based products such as sodium chloride, sodium hypochlorite, sodium hydroxide, hydrogen and chlorine. These products have many uses in industrial sectors as they play an important role in the chemical manufacturing industry and the oil and gas industry. The anonymous company suffers from production disruptions and is unable to keep the feed brine concentration on target. The production disruptions are causing the cell membranes lifecycle to decrease due to the high variability in the feed brine concentration. The cell membranes main function is to prevent any unwanted reaction to occur in the electrolysis chamber. The anonymous company has a total of 120 cell membranes with a total cost of approximately $600,000.

As in **Figure 1**, the current control system that the anonymous company follows to regulate the salt levels can be described as: firstly, sensors such as the hydrometer and the 2-wire conductivity transmitter will start measuring the acidity and the concentration of the feed brine solution in Tk102 and inputs them into a regression model in order to predict what the feed brine concentration will be in Tk151. The values of the feed brine concentration will be plotted on IMR—control charts, as in **Figure 2**, so the control engineer can monitor the process. If there is an out of control point then an alarm will sound in the control room and the control engineer will then manually manipulate the salt levels to bring the process back in control.

This current control system has many problems. First, the anonymous company uses IMR-control charts (which has low sensitivity and is unable to detect small shifts in the process mean. Second, the IMR-control chart lacks the ability to predict the next error, which is a big problem since predicting error is essential in control engineering. The third problem is that the adjustments are done manually by the control engineers in the control room. Now manually adjusting the process comes with many drawbacks. First, the control engineers may not input the exact adjustment. Secondly the control engineer must always be present and alert at all times, and that would cause cognitive fatigue whereby human error is more likely to occur.

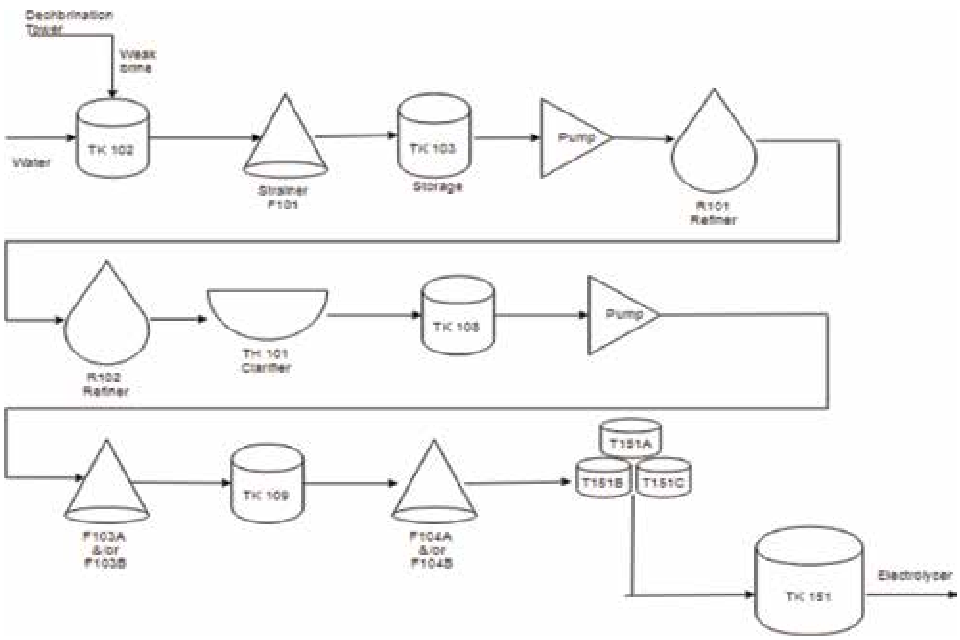

Figure 1.
Ferric treatment tank.

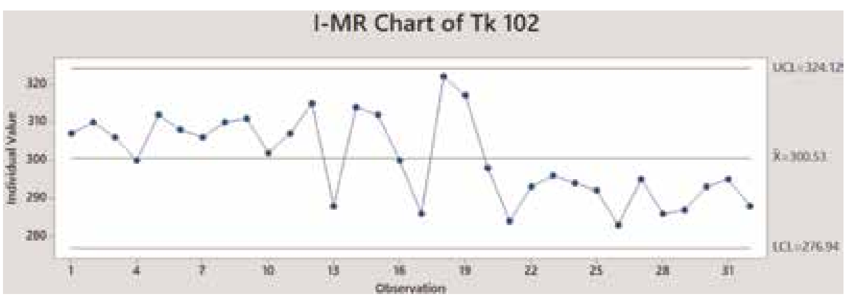

Figure 2.
I-MR control chart.

It's believed that by developing an integrated/unified SPC-EPC framework into the anonymous company Chlor-Alkali processing, it would drastically reduce the variation in the feed brine concentration and as a result would increase the cell membranes lifecycle.

6. Integrated SPC and EPC unified framework

The integration of SPC and EPC will be done in three phases which are the offline monitoring phase, the online measuring and detecting phase, and the integrated SPC and EPC phase. The offline monitoring phase focuses on analyzing the process flowchart, identifying key input variables, identifying critical to quality, collecting historical data and checking them for normality and autocorrelation. The online measuring and detecting phases focuses on generating control charts ensure all points are within the limits and there's no pattern present in the data. Also, the analysis of the current control system happens in this phase. The integrated SPC and EPC phase focuses on the implementation of the Concept of this research work.

Beginning with the offline monitoring phase and according to the process flowchart shown in **Figure 3**, the key process variables and the critical to quality will be identified. It can be seen that the he process starts by pumping in Sea Water which is then undergoes many multiple filtration steps to remove varies types of impurities that may be present due to sea pollution. The sea water will eventually be evaporated away until only purified salt will be left behind and it will be stored into super purified salt storage tanks. The salt will be mixed with purified water in the ferric treatment tank and it undergoes further filtration and re-saturation until we get super purified brine (pure salt dissolved in water). The purified brine then enters the Electrolysis Chamber shown in **Figure 4**, where the solution will breakdown into its elements to make hydrogen, chlorine and sodium hydroxide. These chemicals will then undergo further processing until they get their final product which is hydrochloric acid, sodium hypochlorite and sodium hydroxide. Finally, some of the feed brine will be recycled back into the treatment tank for re-saturation.

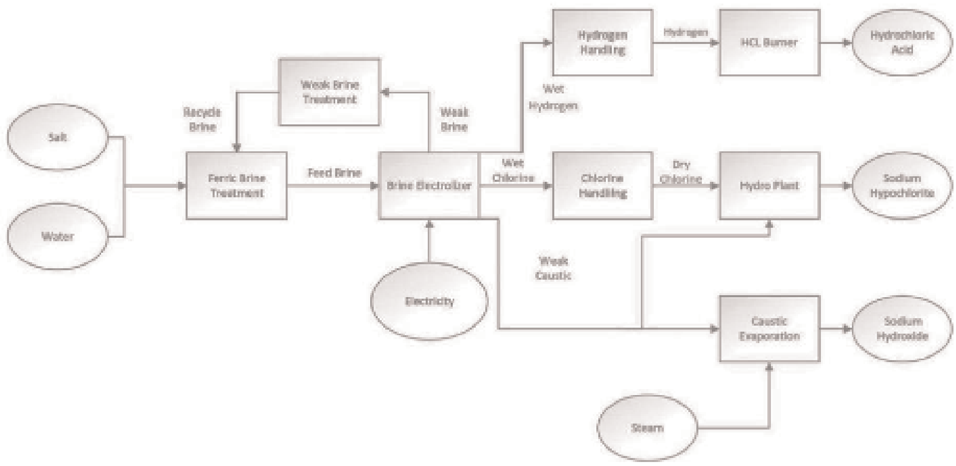

Figure 3.
Process flowchart.

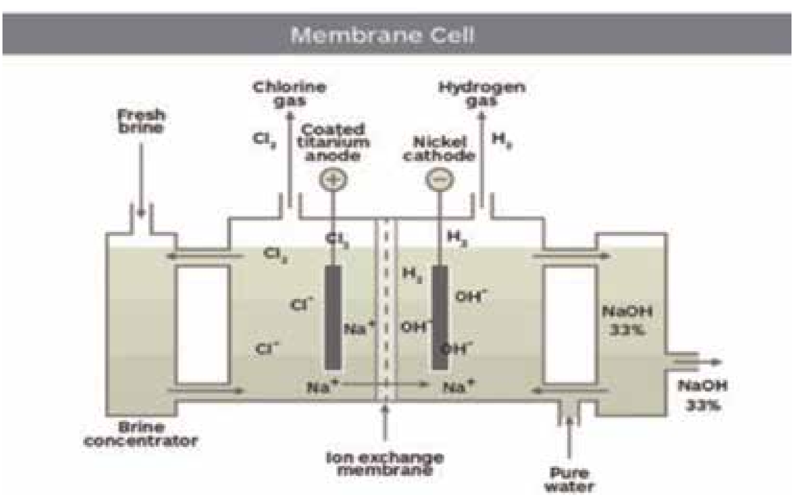

Figure 4.
Electrolysis chamber (electrolizer and cell membrane).

Varies things happens in the electrolysis chamber. First, when the feed brine enters the electrolizer, then the NaCl (salt) and the H_2O (water) will breakdown into their elements where chlorine ions will go to the positive electrode (anode) and sodium ions and hydroxide ions will go to the negative electrode (cathode) and hydrogen gas will also be formed. Both electrodes are separated by a cell membrane where it helps with ion exchange and also prevents any unwanted reaction to occur in the electrolizer.

Recall that the main purpose of the ferric treatment tank shown in **Figure 1** is to re-saturate the brine solution to the optimum concentration to make sure it does not affect the cell membrane located in the electrolizer. The treatment tank begins with the input tank Tk102 then brine goes through varies filtration steps until it reaches the refiner R101 where caustic soda and soda ash is added to the brine solution to remove impurities such as calcium and magnesium. The brine will then keep going through varies filtration stages in the treatment tank until it reaches the final tank which is Tk151 which is where the super purified feed brine is stored with a target concentration of 306 gpl. The feed brine will then exit the treatment tank and enter the electrolizer.

It has been found out that the cell membrane located in the electrolizer is very sensitive to the feed brine concentration and needs to be replaced every three to 4 years. The cell membrane has a current Lifecyle of 3–4 years, each cell membrane costs around $5000 and the company have 120 membranes with a total cost of nearly $600,000. Our objective is to increase the cell membranes life cycle to 6–8 years by reducing the variation in the feed brine concentration.

7. Framework demo

Our research Concept is proposing the use of the sensitive EWMA control chart in conjunction with the Integral Controller where we will have two arrays, one is the EWMA points and the other is the process observation. The Integral Controller will keep checking the EWMA points and once it exceeds the boundary limits then the integral controller would formulate an adjustment and send it to the process. **Figure 5** is a visual representation of the concept, where array 1 is the weighted averages and array 2 is the actual measured process values.

The boundary limit is an engineering decision that can be calculated based on equation (Eq. (4)). MATLAB have been used to develop a code that will continually

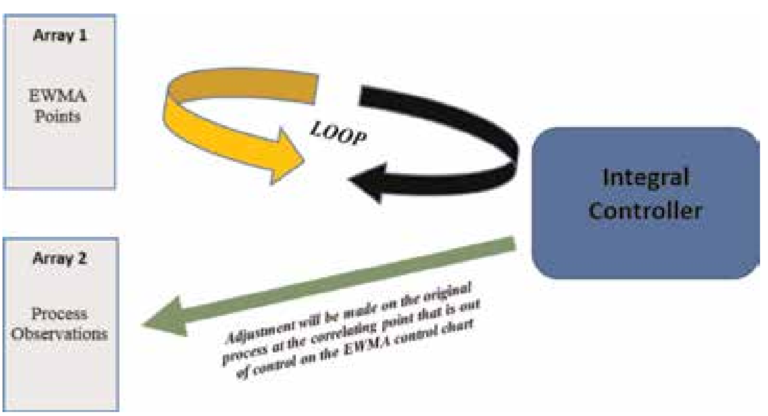

Figure 5.
Research concept.

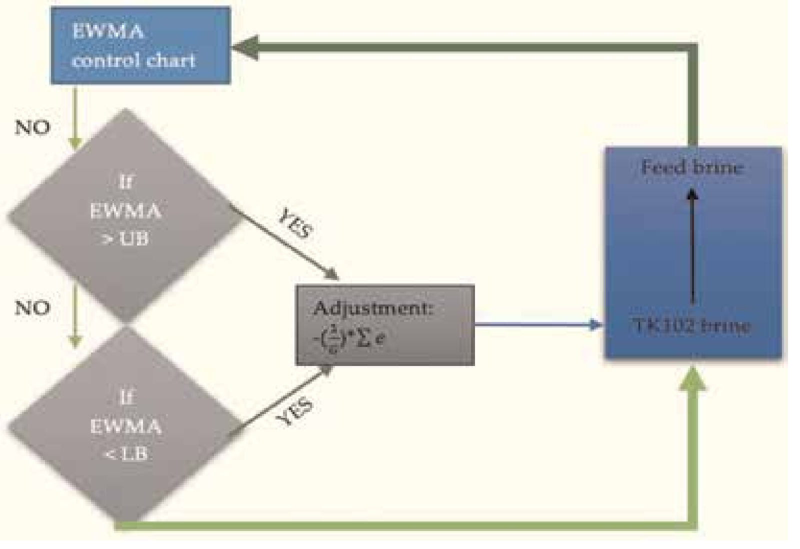

Figure 6.
Concept logic.

check the EWMA values in array 1 using MATLAB for-loops. When a point exceeds the upper or lower boundary, the Integral Controller will calculate the required adjustment (Eq. (5)) to keep the process on target and send the adjustment to the actual process as shown in the Concept logic, **Figure 6**.

A fitted regression model will be developed to understand the relationship and brine concentration levels in the output tank (Tk151) and input tank (Tk102). Also help to estimate the process gain (G) to be used in calculating the adjustment in the integral controller. The weight λ will be tested at different values ranging from 0.1 to 0.5 to find the best target with the minimum variation.

8. Results and findings

The upper boundary (UB) is equal to 311.78 gpl and the lower boundary (LB) is equal to 300.22 gpl. The weight value of λ was selected to be 0.3 which resulted in a process gain of 0.9795. A fitted regression model was developed as below:

$$\text{Tk151} = 6.31 + 0.9795\ \text{Tk102} \tag{7}$$

Figure 7 shows the fitted regression model plot between the brine concentration levels in the output tank (Tk151) and the input tank (Tk102).

The EWMA control chart will plot the feed brine concentration which is located in Tk151, and then the integral controller would continuously check whether or not the observation exceeds the upper or lower bound. In an event where the feed brine concentration exceeds the bounded limits, an adjustment will be formulated and sent to the input tank Tk102. **Figure 8** shows the EWMA control chart for the input tank Tk102 and **Figure 9** shows the EWMA control chart for the output tank Tk151 where bounded control limits are used. The control scheme will be using this control chart to formulate its adjustments. **Figure 9** shows 11 out of control points, each out of control point will trigger the integral controller to formulate the exact adjustment needed to bring the process back in control.

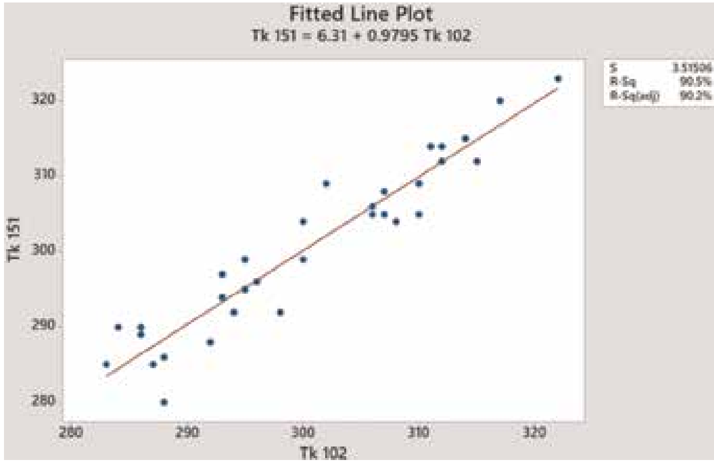

Figure 7.
Fitted line plot for Tk102 and Tk151.

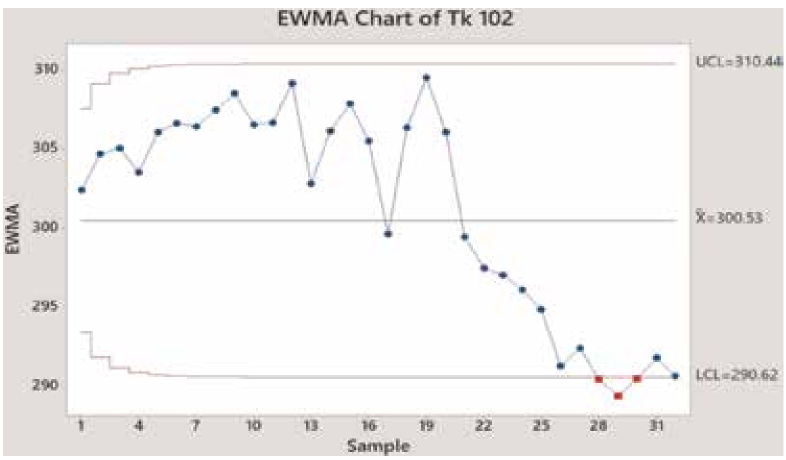

Figure 8.
EWMA chart for Tk102.

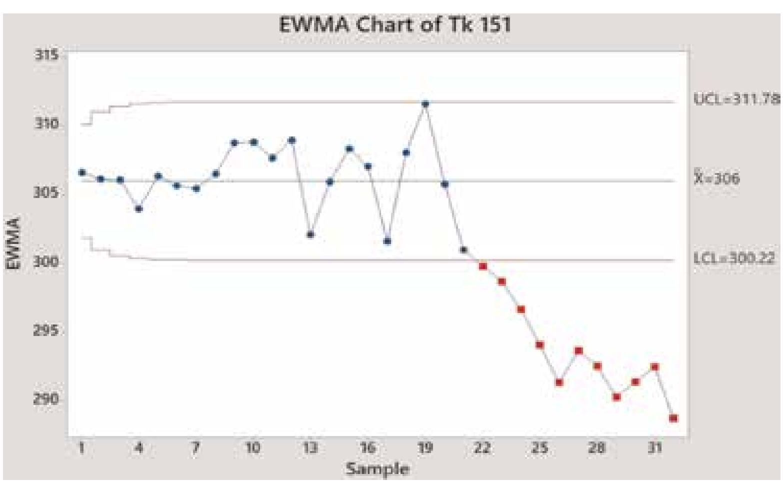

Figure 9.
EWMA chart for Tk151.

	Tk 102	Adjusted Tk 102	EWMA	Adjustments	Setpoints
1	307	307.00	306.60	0	0
2	310	310.00	306.12	0	0
3	306	306.00	306.08	0	0
4	300	300.00	303.96	0	0
5	312	312.00	306.37	0	0
6	308	308.00	305.66	0	0
7	306	306.00	305.46	0	0
20	298	298.00	305.74	0	0
21	284	284.00	301.02	0	0
22	293	293.00	299.81	3.98	3.98

Table 1.
Process data before and after adjustment.

	Before adjustment	After adjustment				
		$\lambda = 0.1$	$\lambda = 0.2$	$\lambda = 0.3$	$\lambda = 0.4$	$\lambda = 0.5$
Target g/lit	300.30	302.12	303.02	304.10	304.07	303.98
Variance	119.16	95.91	90.97	80.07	82.84	86.13
St Dev	10.92	9.79	9.54	8.95	9.10	9.28

Table 2.
Optimum λ.

Table 1 shows the adjusted and unadjusted values for brine concentration in Tk102. The third column in is setpoints and it's the cumulative adjustments done to the process. The first adjustment was made at observation 22 which exceeds the lower boundary and the integral controller calculated the required adjustment of 3.98 to bring the process back on target and reduce the deviation of the output from the target. The control scheme will continue this way where the integral controller will continuously calculate the required adjustments to bring the process under control and keep it within the boundaries.

After integrating the EWMA control chart in conjunction with the integral controller in the ferric treatment tank, the framework implementation managed significantly to reduce the process variation by 32.8% and reduced the standard deviation by 18%. By reducing the process variation and standard deviation, the process becomes continuously under control and the cell membranes lifecycle increased successfully. As in **Table 2**, different λ weight values have been tested in order to find the optimum that gives the least variation for after adjustment.

The high sensitivity of the EWMA control chart can be seen when compared to the I-MR control chart. It can be seen how the EWMA control chart was able to detect out of control points that I-MR control chart missed. **Figure 2** is showing that all points are under control however, the same points are out of control when plotted on the EWMA control chart as seen in **Figure 8**.

9. Conclusion

Many schemes of SPC and EPC integration had been proposed in literature with a view to complement each other's insufficiency [7, 12, 18–21]. While intensive work has been focused on developing various efficient and robust EPC controllers, some emphasized the crucial task of monitoring auto correlated processes and EPC systems. In this research work the objective was to create a concept in which we used the EWMA control chart in conjunction with the integral controller to keep the feed brine concentration on target in order to increase the cell membranes life cycle.

SPC and EPC integration approach was done in three phases; offline monitoring phase, online measuring and detecting phase and finally the integrated SPC-EPC phase. The first phase was about analyzing the process, identifying the critical to quality characteristic, identifying the key input variables and understating the process flow chart. The second phase involves analyzing the current control system. The third and final phase is where we introduce the concept which is the EWMA control chart in conjunction with the integral controller.

According to the proposed scheme and results and with the cooperation of the anonymous company, by keeping the feed brine concentration on target the Chlor-Alkali process variation is reduced, the cell membrane lifecycle is expected to be doubled, and monthly cost is minimized by 50%. The implementations of our effective concept drastically improved the product quality and reduce cost. The concept is versatile and applicable to different industries.

SPC and EPC unified framework has been proven to be very effective at reducing process variation and improving the product quality.

EWMA control charts are very effective and sensitive in detecting small processes means shifts and ability to forecast the next processes error which is essential in control engineering.

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Chapter 8

Lean Six Sigma and Performance Metrics

Kaouthar Lamine

Abstract

The intensification of competitiveness and the fluctuation of industrial market were pushing the companies to ameliorate their product's quality and services in order to maintain their place in the market. They have a tendency to integrate various methods such as total quality management (TQM), Six Sigma (6-σ), and Lean Six Sigma (LSS). The Lean Six Sigma method became the focus of academic researches. Hence, huge empirical studies have been raised in this field which enhances the visibility of this quality method. Some focused to identify its particular aspects, tools, and concepts. Others reveal its positive repercussions on reducing the defects, waste of time, and reworks. Others attempt to develop specific model related to Lean Six Sigma to facilitate its implementation. Regarding the literature gap reviewing and highlighting the specific features of Lean Six Sigma, the requirement of recognizing its particular aspects is needed. The focus of this chapter firstly is to identify the performance metrics then to underline the Lean Six Sigma metrics in order to seek its link with business performance. Also a guideline for the best integration of Lean Six Sigma is also offered.

Keywords: Lean Six Sigma, performance, metrics, process improvement, efficiency, customer requirement, profits

1. Introduction

The Lean Six Sigma (LSS) quality enhancement approach has obtained recognition in the previous few years as more and more corporations affirm its effectiveness in developing their bottom lines and shareholders (i.e., [1]). Companies need to focus on creating Lean Six Sigma projects that are aligned to the business needs (i.e., process improvement, efficiency, profits, customer loyalty, and reliability). Customers increasingly require on the quality of the supplied product which leads companies to strive excellence or at least to strive for perfection in order to satisfy more customers [2].

Lean Six Sigma is recognized as a combination of Lean and Six Sigma. It is "a business strategy and methodology that increases process performance resulting in enhanced customer satisfaction and improved bottom line results" [3]. It is considered as a strategic issue of quality improvement based on the increase of process capability and the development of company performance [2].

As we have just seen, many important questions have recently been raised in the Lean Six Sigma field and performance. Thus, the purpose of this Chapter is to investigate in the second Section the multidimensional aspect of performance and measurement dimensions. The Section 3 provides more details concerning Lean Six Sigma metrics and key steps for its best implementation. Section 4 represents discussion and conclusions. Section 5 stresses the managerial implications and future direction of Lean Six Sigma.

2. Performance concept

The performance concept has been the focus of abundant studies, investigations, and articles and is extensively renowned. Thus, various definitions and explanations have been addressed in this issue (i.e., [4]). The next subsection provides extra details concerning the multidimensional performance concept.

2.1 The multidimensional performance concept

Much confusion exists on the performance concept as [4] attempt to explain. The first explanation would be is that the performance is a construct, not a concept. The identification of all the variables related to the performance field allows the first clarification of construct (i.e., [5]). Performance is defined as "the art of doing the right things right" [6]. Briefly, it means the act of drawing the best of the available resources of the company to achieve its goal.

The performance concept is distinctly assimilated to efficacy, competitive capacity, efficiency, performance, and productivity. Venkatraman and Ramanujam [7] propose to represent the performance in three levels (financial, operational, and organizational performance). In this proposal they stress the idea of intermediate measurement of performance and distinct measures used according to the objectives pursued (see [7]).

2.1.1 Performance definition

An important number of researches converge in the notion that the performance has a global sense and implies efficiency and effectiveness (i.e., [8]). An organization is successful if it accomplishes its goals (effectiveness) using a minimum of resources (efficiency). Seashore and Yutchman entirely define organizational effectiveness from this perspective as "the ability to exploit its environment in the acquisition of scarce and valued resources to sustain its functioning" (see [9]).

From a strategic point of view, performance can be defined as the ability of an organization to implement its strategy. The purpose of the performance is to improve the torque value—cost [10].

2.2 Performance measurement dimensions and indicators

Given the rising interest accorded to study the performance measurement systems as tools for successful strategy integration, this part offers definitions of performance measurements, dimensions, and indicators. The performance measurement is defined as "the process of quantifying the efficiency and effectiveness of past actions" [11]. However, Moullin considers it as "the process of evaluating how well organizations are managed and the value they deliver for customers and other stakeholders" [12].

Neely et al. provided an important distinction between these three terms: a performance measurement, a performance measure, and a performance measurement system (see [11]). More clarifications are offered in **Table 1**.

Grafton et al. provide a constructive work assessing the role of performance measurement and evaluation in building organizational capabilities and performance. The results suggest to encourage managers to employ both the multiple financial and nonfinancial performance indicators increasingly included in current performance measurement systems (in [13]).

Therefore, the performance measurement refers to the use of a multidimensional set of performance measures which include financial measures and nonfinancial measures. Financial performance is generally defined as the use of outcome-based financial indicators that are assumed to reflect the fulfillment of the economic goals of the firm, and nonfinancial performance measures are often used for performance evaluation.

2.2.1 Organizational performance dimensions

The manner on which the authors perceived and measured the organizational performance is different. Arumugam et al. measured organizational performance based on quality performance specifically the quality of product and service, customer relations, customer satisfaction with product quality, and level of quality performance relative to industry norms (see [14]).

Deshpande focused on supply chain performance and organizational performance, outlining the financial and market components and customer satisfaction dimensions. The financial and market performance is determined by reference to market share, return of total assets, and annuals sales growth (see [15]).

Several works have treated the organizational performance dimensions; for example, Venkatraman and Ramanujam [7] identify three dimensions of firm performance:

- The financial performance: it contains criteria such as sales, turnover growth, profitability (return on investment, return on sales, and return on equity capital), profit by shares, the market value of the company, or the cost of asset replacement.

- The economic performance: it incorporates chiefly marketing measurements such as market shares, new products introduction, products quality, or marketing effectiveness.

- The organizational effectiveness: it consists of internal criteria having an overall image of organizational performance (see [7]).

The link between quality management practices and organizational performance is the focus of various studies (i.e., [16]). The results of these studies

	Performance
Performance measurement	Defined as the process of quantifying the efficiency and effectiveness of action. It refers to the use of a multidimensional set of performance measures. It includes both financial and nonfinancial measures [1]
Performance measure	"Defined as a metric used to quantify the efficiency and/or effectiveness of action"
Performance measurement system	"Defined as the set of metrics used to quantify both the efficiency and effectiveness of actions"

Table 1.
Performance aspects.

designated that there are a variety of measures (i.e., organizational performance, corporate performance, business performance, operational performance, financial and nonfinancial performance, innovation performance, and quality performance).

Based on the work of Scodanibbio, the key components of company's performance are highlighted in six elements which are commercial performance, operational performance, innovation performance, financial performance, economical performance, and cultural performance (see [17]). More explanations are provided in **Table 2**.

2.2.2 Performance indicators

The performance indicator has been the subject of numerous researches. Based on this literature review, the performance indicators acquired various definitions.

	Key performance components (KPC)
Commercial performance	Market penetration—market share/expansion • Effectiveness of marketing activities • Sales force effectiveness • Customer loyalty • Acquisition of new customers • Dealers/wholesalers performance • Brand identity level • Communication effectiveness • Reputation—image
Operational performance	• Operational efficiency (labor, machines, materials, indirect areas) • Economic efficiency (labor, materials, etc.) • Productivity • Quality of product and service • Value added • Plant/equipment performance • Personnel performance
Innovation performance	• Reactivity—ability to innovate • Time to market • Level of acceptance of new products/services
Financial performance	• ROI: return on investment • ROE: return on equity • ROTA: return on total assets
Economic performance	• Turnover • Profitability
Cultural performance	• Industrial culture level/modernity • Effectiveness of change management
Source: [17].	

Table 2.
Performance measures and indicators studied by different authors.

Author(s)	Measure	Indicators
[20]	Organizational efficiency Organizational effectiveness	Return on assets Share of deposits
[21]	Organization performance	Financial performance Operational performance Product quality
[22]	Operational performance Organizational performance	Internal operation performance Productivity improvement Financial and nonfinancial measures

Table 3.
The main components of company's performance.

Berrah et al. offered a performance indicator a quantitative aspect. It is considered as a quantitative data expressing the effectiveness and/or efficiency of all or part of a system (in [18]).

Performance indicators synthesize in qualitative or quantitative terms, some information to sit judgment on the performance evaluation:

- Indicator of objectives (or lagging [19]) that control the best achievement of strategic objectives

- Indicators on the stock variables and action plans (or leading [19]), which provide information on the means used to achieve these strategic objectives

Through there is an extensive literature review of performance measures, different indicators used for measuring organizational performance some of these are identified in **Table 3**.

3. Performance metrics

Performance metrics has been the focus of diverse studies in different fields. The present section highlighted the key Lean Six Sigma metrics presented in the literature.

3.1 Lean Six Sigma focus on metrics

Lean Six Sigma focuses on metrics; it is a combination of set of statistical tools as DMAIC of Six Sigma employed in order to define, analyze, measure, improve, and control process variability as presented in **Table 4** and critical-to-quality (CTQ) (Lean) for customer requirement [23].

The basic objective of Lean Six Sigma method is the implementation of measurement strategy focused on reducing the process variability and improving the projects to meet the customer requirement. This is realized through the combining of Lean and Six Sigma.

The main concepts of Lean Six Sigma are highlighted by Devane in these principal points: (1) the voice of the customer and "CTQ," (2) Six Sigma metric, (3) elimination of waste and nonvalue added activities, (4) process, (5) unintended variation which is the enemy, (6) value streams, and (7) "DMAIC" improvement process (see [24]).

Steps	Objectives/tasks	Expected result	Main tools
Define	• The need of the customer • The expected gain • The scope of the project • Responsibilities	• The project chart • Planning and allocation of the resources	• 5W1H • SIPOC
Measure	• Define the measuring means • Measuring variables • Collect data	• Detailed mapping process • Capability means and process	• Process analysis • Pareto • Normality tests • Study of capability • Statistical process matrix
Analyze	• Studying the relationships between input and output variables of the process	• Understanding the process	• Ishikawa diagram • Cause–effect matrix • Statistical tests
Improve	• Put the solutions • Select promising path for improvement	• Pilot process • Determination of the characteristics to sustain under control	• Design of experiments • FMEA, weighted voting
Control	• Put the solution selected under control • Formalize the process	• Drafting of procedures • Control charts • Performance index	• SPC

Table 4.
The DMAIC steps and tools.

The DMAIC structure with five modalities for intervention (define, measure, analyze, improve, control) is used to specify the problem of process variability to put the suitable solution in order to achieve a company performance.

We can give the example of some techniques related to Lean Six Sigma tools: "CTQ" companies focus on what the customer want by reducing wastes and nonvalue added activities in production process. Failure mode and effect analysis (FMEA) necessitates a step-by-step approach to identify all the possible failures in the design, manufacturing, product, or services. The aim of the FMEA is to adopt actions of removing or diminishing failures, beginning with the highest-priority ones, the suppliers, inputs, process, outputs, and customers (SIPOC), which is normally used throughout the defined stages of a process improvement project, as it helps to obviously understand the purpose and the scope of a process; a Pareto chart is defined as a series of bars whose heights reflect the frequency or impact of problems which are classified in descending order.

Based on diverse researches studies as [25], we have selected these principal tools of Lean Six Sigma illustrated in **Table 5**.

3.2 Guideline for the best implementation of Lean Six Sigma project

Before starting the Six Sigma implementation, it will be important to know these precious aspects mentioned as the antecedents of its implementation. It is necessary to create an encouraging environment and platform to succeed in its implementation.

Lean Six Sigma main tools	Literature review
CTQ	[25, 26]
FMEA	[26]
Control charts	[25, 26]
DoE	[27]
Pareto analysis/charts	[25, 26]
Taguchi methods	[27]
Measure capability	[26]
Regression analysis	[27]
Correlation studies	[25]
Process mapping, flow chart, SIPOC model	[26, 27]
Brainstorming	[25]
Root cause analysis	[26]
SPC	[25]
Capability index	[25, 26]
Probability plot	[25, 27]
Cause and effect matrix	[26, 27]
Descriptive statistics	[27]
Project selection and assessment matrix	[27]

Source: [25–27].

Table 5.
Lean six sigma focus on metrics.

The visions and point of view of authors concerning the success in implementing Lean Six Sigma are varied and valuable [28]. Jones et al. stressed the importance of strategy adopted, and the success of any organization is directly related to the effectiveness in implementation of Lean Six Sigma (in [29]).

The implementation of project should meet the objectives of firms and their ability to execute it. The project succeeds when it is able to achieve its goals. The objective of the Lean Six Sigma programs in any organization is the "project."

The importance of roadmap of project, process mapping, and team responsibilities explains the success of integrating such method. Indeed, the project charter identification, planning, and integrating steps, tasks, and recurrent milestones help to maintain track of progress and adjustment as required. Also, it creates a sort of dynamism for the project team.

Regarding the specificity of the project and its requirement, the focus is to answer these questions: "what," "who," "how," "when," and "how much." "What" refers to the customer needs. The higher the requirements are identified, the higher the probability of success will be. "Who" designs the allocation of the resources to achieve the project. "How" is the technological need that will convene to the "what" of the customer. "How" is very decisive to the project because if a connection between the project and the customer's expectations does not exist, there will be a gap in anticipations. "When" identifies "the schedule" and the tools of project management.

Montgomery and Woodall affirm that in "Aligning projects with both business-unit goals and corporate-level metrics helps ensure that the best projects are considered for selection strategic business objectives" (see [30]).

Tenera and Pinto's work provides a project management improvement of Lean Six Sigma in order to facilitate its development by reducing the potential problems (see [31]). One of the chief challenges of Lean Six Sigma implementation program is to succeed in the selection of the organization project, insuring the suitable identification of the critical-to-quality characteristics.

4. Discussion and conclusions

4.1 Discussion

It is important to know that Lean Six Sigma is not only a quality method for improving process and reducing costs. It is also an approach for engaging and implicating all the employees to achieve business goals, as well as to learn how to improve the effectiveness and efficiency of the company. Thus, this quality method develops the empowerment of employees and the share of responsibilities.

The Lean Six Sigma has positive repercussions in different levels, as social (company social responsibilities) and financial (boost of returns and profits) impact, employee empowerment (continuous training and culture), process improvement (reduce of process variability, wastes, defects), amelioration of product quality and efficiency, enhancement of customer satisfaction, and amelioration of competitiveness and brand image.

Furthermore, the assessment of Lean and Six Sigma link is important and has been the focus of diverse studies. Indeed, Lean Six Sigma or just-in-time goal aims to reduce as maximum as possible the stocks and outstandings. However, the Six Sigma objective is to eliminate variations and have as output coherent finished products without defects. It seeks to identify the defects, determine the causes, and eliminate them. Thus, we can state that both methods are complementary and independent. Undeniably, a process can be Lean, but it has a rate of change at the output, or it can have a rate of change at the output under control and is not Lean. Consequently, the Lean Six Sigma crosses simultaneously the Lean and Six Sigma advantages which give it a major substance.

4.2 Conclusion

This chapter is a prerequisite to understand the Lean Six Sigma specificities. It started by a brief explanation of performance concept, dimensions, and indicators in order to facilitate the second section, the assessment of the link between performance and Lean Six Sigma metrics.

Section 3 outlines the main Lean Six Sigma tools, objectives, and impact. It allows the improvement of the process capability by reducing defects and wastes which consequently impact positively on the company performance, outcomes, customer satisfaction, and loyalty. Also, it offers a highlight of the success steps for Lean Six Sigma project integration.

Studying the link between Lean Six Sigma and performance is precious. In terms of assessing the impact of Lean Six Sigma on organizational performance or in order to assess the factors that affect the company business performance, it is not advised to presume these factors on the financial evidence but to focus in the other factors that can have a relevant impact on Lean Six Sigma outcomes.

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5. Research implications and future direction

The originality of this chapter resides on its focus on the surroundings of Lean Six Sigma. Hence, regarding the lack of academics and empirical studies investigating in depth the real features of Lean Six Sigma, this chapter offers the chance of stressing the advantages and illuminating the Lean Six Sigma-specific concepts and tools.

From a managerial point of view, revealing a brief distinction between Six Sigma, Lean, and Lean Six Sigma can facilitate the decision for professionals hesitating to implement such methods within their quality management system. Also, the LSS is an available quality method in both manufacturing and service companies (as healthcare, financial, engineering) which attract the interest of the executives in the effectiveness way of Lean Six Sigma project integration in diverse sectors.

The implications of Lean Six Sigma are varied and touch diverse stages and area as well as the internal and external environment. Generally, it has positive repercussions on the product quality, enhancing customer satisfaction, faithfulness, and consistency, improving the business incomes, competitiveness, ameliorating its image, and bringing new stakeholders and investment.

This chapter can be a useful support for future researches interested in this filed. Therefore, future studies can focus in the assessment of LSS challenges and weakness in diverse sectors or develop comparative studies between LSS and other quality methods as Six Sigma, in order to seek out their similarities, dissimilarities, or complementarity.

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Chapter 9

The Integration of Six Sigma and Lean Manufacturing

Marcio B. Santos

Abstract

The Lean Manufacturing and Six Sigma methodologies are increasingly being executed together and what we have today is the united work of both, and companies have come to understand that their integration makes it possible to take advantage of the strengths of both strategies, becoming a comprehensive and effective, suitable for solving various types of problems related to the improvement of processes and products. Routine management, process standardization and the study of times and movements to eliminate waste are key features of Lean Manufacturing, while finding the root cause for problem solving requires further deepening and analysis in Six Sigma. The Lean and Six Sigma can be viewed as useful tools for the operation of the systems of improvement, innovation and routine management that integrate the system of business management. The companies have implemented Lean Manufacturing with the aim of improving the elimination of waste in the processes. Companies using Six Sigma have found that by selecting projects and assigning them to teams, after a monitoring, the results would appear. Companies that implement Lean Six Sigma often awareness of the teams, seeking projects from different scopes with the focus of improving the structure of processes and achieve the results.

Keywords: lean manufacturing, reference models, measurement systems evaluation, innovation, reliability, strategies

1. Why integrate?

The Lean Manufacturing and Six Sigma methodologies are increasingly being executed together and what we have today is the united work of both, and companies have come to understand that their integration makes it possible to take advantage of the strengths of both strategies, becoming a comprehensive and effective, suitable for solving various types of problems related to the improvement of processes and products.

Routine management, process standardization and the study of times and movements to eliminate waste are key features of Lean Manufacturing, while finding the root cause for problem solving requires further deepening and analysis in Six Sigma.

The Lean and Six Sigma can be viewed as useful tools for the operation of the systems of improvement, innovation and routine management that integrate the system of business management. For this reason, they are considered reference models. Santos et al. [1] points out that based on evidence about the potential of best practice approaches, different actors worldwide have been proposing and promoting different reference models. In general, these models serve as references for decision-makers in establishing practices to be used in operations and organizational processes usually associated with awards, certificates, or consultancies.

The companies have implemented Lean Manufacturing with the aim of improving the elimination of waste in the processes. Companies using Six Sigma have found that by selecting projects and assigning them to teams, after a monitoring, the results would appear. Companies that implement Lean Six Sigma often awareness of the teams, seeking projects from different scopes with the focus of improving the structure of processes and achieve the results.

Over time, companies have realized that these methodologies are complementary and since then, much has been written about combining Lean with Six Sigma as a process improvement approach, using best practices from each. For some authors like George [2], the union of these two methodologies maximizes the value of the company.

There are many ways to combine these two methodologies. According to Corrêa and Gianesi [3], in the Western world there has been a growing movement to recognize the strategic role of manufacturing in optimizing the production process and reducing its costs. Bendel [4] says that the way forward for implementing Lean Six Sigma depends primarily on the issues the company is currently facing and the nature of its business, as well as the aspirations of the company and its employees.

For Chaurasia et al. [5], the shift from traditional manufacturing processes to Lean Six Sigma processes (LSS) implies positive results for companies in relation to the generation of revenues, customer and employee satisfaction, increased productivity, reduced waste and design of a quality product at low cost, as shown in **Table 1**.

Features / Method	Six Sigma	Lean
View	Process Improvement	Value Chain Improvement
Approach	Defect Reduction	Waste Reduction
Goal	Decrease variability	Decrease Non Aggregate Value
Indicators	Effectiveness and efficiency	Efficiency and Effectiveness in time
Structure	Team formed by Belts	Small Group Activities (SGA's).
Nature of work	Projects defined with impact on the External or Internal Customer	Projects defined by observing the Value Chain Flow
Intrinsic Method	DMAIC e DMADV	Use of the 5 Principles
Deployment Strategies	Deploy by strategic projects to the company's business.	Implement Improvements in bottlenecks with dissemination of the Kaizen concept.
Model Association	ISO 9000, FMEA, 8D	QFD, Kaizen
Typical Coordination	Quality	Production
Initial Reference	North American Companies (GE, Intel, Auto)	Japanese companies (Toyota and production chain)

DMAIC *(measures the current performance of a process): Define, Measure, Analyse, Improve, Control;*
DMADV *(measures customer specifications and needs): Define, Measure, Analyse, Design, Verify;*
FMEA*: failure mode and effect analysis;*
8D*: eight disciplines;*
QFD*: quality function deployment;*
Kaizen*: tools that seek to bring about daily improvements, involving all employees of the company and in all existing areas;*
5 Principles*: specify value, map the value stream, deploy continuous flow, implement pulled production, seek perfection.*

Table 1.
Comparative table of methods.

2. Understanding Six Sigma

2.1 The beginning

According to Santos [6],

> *"The Quality model, which has long constituted a theoretical school as remarkable as the Scientific Administration (F. Taylor and H.Fayol) or the General Theory of Systems (L.Bertanllaffy and N.Wiener), preserves singular longevity for decades of evolution and conceptual updates. Far from being a bastion of contemporary truths, rooted in specific epochs, it further molds itself into a great umbrella that, as time passes, grows in size, incorporating and restructuring managerial concepts.*
>
> *It shows, for example, the change from Quality Inspection to CCQ (Quality Control Circles), from TQC (Total Quality Control), TQC to Total Quality Management (TQM) and to WCM (World Class Manufacturing), pointing to such broad concepts as Quality Management or world-class criteria of excellence.* Santos (pg 68, 2011)
>
> *Shewhart [7] set the starting point for the pursuit of Quality from 1925, when Bell Telephone Laboratories, New York, served the Western Electric Company (headquarters) in Chicago, where, in the manufacture of telephone sets, there was uniformity. He, analyzing the work process, initially verified the high volume of telephone scraps that were out of specification, found at the end of the production line... Deming [8] met Shewhart in 1927 who, in his view, gave the world a new perspective on science and administration. This professor of the University of New York, in turn, as eminent statistician, was able to implement and amplify, notably, the teachings of his tutor, so much that he was central figure in the uplift of Japan, after 2ª World War, considered one of the greatest expressions of Western and Eastern administration.*
>
> *In the course of its development, it has been structured in international norms that ensure reliable and expected management practices (ISO 9.000, 14.000, 18.000, TS, CMMI), methods (5 S, FMEA, FTA, MASP, QFD, BSC, TRIZ), techniques (Pareto, Cause–Effect, Histogram, Control Charts, 5W2H, etc.), and even in philosophical-strategic approaches (LEAN Manufacturing, 6 Sigma, Red X, MEG, among others) that for some companies are still another method and for others, another technique or tool, and still some professionals, with disdain, call them pills. As a school or current of the Administration, therefore, Quality has for decades had a non-trivial density of contributions to companies, with a great diversity of researchers, authors, books and works, but being mostly directed to the empirical results of its applications, without methodological concerns in the formulation of hypotheses, control of quantitative and qualitative techniques and broad repetition. For this reason, the marginal penumbra of science or Management Theory is added. Even "insurrections" (reengineering, chaos theory, constraints) have already occurred, which in fact, coeteris paribus, have further strengthened their principles and continuity in the timeline. -* Santos ([6], pp. 68–69).

2.2 Precision for large production volumes

With the expansion of the global consumer market in the late 1980s, especially through the breakdown of political barriers (iron curtain), quality no longer operates in thousands or hundreds of thousands, but in millions and hundreds of millions. This explosion imposes a new manufacturing standard on the world's major brand competition.

In addition, a new definition of Quality is focused by Harry and Schroeder [9], who built their 6 Six Sigma concepts from their work with Motorola in the 1980s, which was losing market share to competition for cost and quality reasons. For them, the traditional definition of Quality aims at complying with the standards that companies create for the quality of their products and services, even if this means reworking (raising costs) of a specific part of the product/service due to interaction between standards.

From the beginning, great emphasis was placed on the use of statistical tools for the treatment of variables in problem solving and reduction of process variation. The application of the Six Sigma approach is based on a standardized method for conducting the problem-solving process known as DMAIC, which is the abbreviation of the Define, Measure, Analyze, Improve, and Control phases. In each phase of this method, the use of some tools such as Process Mapping, FMEA, Hypothesis Testing, among others.

Six Sigma's creative management strategy extends the definition of quality by including economic value and practical utility for both the company and the consumer. It is a business relationship, where the incorporated value of the good means, on the company side, a certain expectation of producing quality products/services with the highest level of profits possible; by the consumer side, means that they have an expectation of buying high quality products at the lowest cost. In other words, the quality in the organization is greater when the costs are as low as possible for the company and for the consumer. The business strategy and philosophy built around Six Sigma show how changes in the organization must take place so that it can gain a new level of competitiveness by reducing defects in its industrial and commercial processes.

In traditional terms, 6 Sigma focuses on defect prevention, reduction of cycle times and cost savings. Unlike costly cost cuts, which reduce value and quality, 6-Sigma identifies and eliminates costs of waste, meaning that they do not add value to customers. In general, these costs are extremely high in companies that do not use it.

Companies operating at 3-Sigma or 4-Sigma levels usually spend between 25% and 40% of their revenue to repair or solve problems. This is known as the cost of quality or, more precisely, the cost of poor quality. Companies operating on 6-Sigma generally spend less than 5% of their revenue to fix problems.

The dollar cost of this difference can be enormous. General Electric estimates that the difference between 3-Sigma or 4-Sigma and 6-Sigma cost $8 billion to $12 billion a year. To achieve this goal, we use a set of proven techniques together with a cadre of well-trained, well-trained technical leaders known as black-belts to achieve a high level of efficiency in applying these techniques.

In other words, the number of Sigmas is a measure of process performance. The greater the number of Sigmas, the lower the variability of the process, the greater the process, the higher the probability of obtaining products that do not meet the customer's specification. Processes with little variability: More products complying with the specifications, as shown in **Figure 1**.

In short, the definition of the term Six Sigma contains three distinct elements [10]:

1. **A Measure**: The term derives from the statistical concept of standard deviation that shows how much a process deviates from perfection;

2. **One Target**: Refers to a fixed rate of 3.4 defects per million opportunities;

3. **Philosophy**: Six Sigma is a long-term business strategy to reduce costs by reducing the variability of products and processes.

But, we can add another fundamental element:

4. **Method**: the use of a critical path (DMAIC/DMADV) that will show and facilitate the use of statistical techniques in each of the stages.

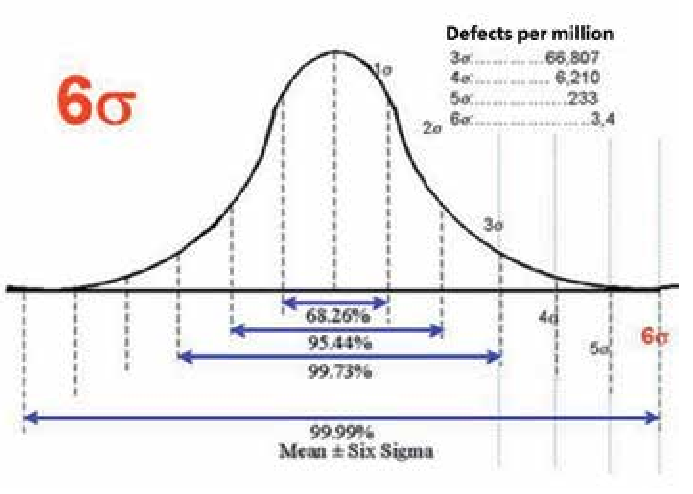

Figure 1.
Confidence levels in normal processes.

2.3 Team

The incorporation of the rigor and discipline of the martial arts in the learning of the personnel, as far as the statistical techniques are concerned, is of singular performance the involvement of the people (green belts, black belts, master black belt and collaborators), in the specific projects and general process of obtaining Quality 6 sigma.

Team building presents a differential compared to other approaches, considering the growing burden of statistical studies that participants should be trained. From basic statistics to models and simulations, from Green Belts to Master Black Belts respectively.

In this, the trainings of the specialists are divided by area and degree of knowledge. The success of Six Sigma is subject to the existence of persons with the appropriate profile and who will be transformed, according to **Figure 2a** and **b**.

2.4 DMAIC and DMADV

Six Sigma uses a variety of descriptive and inferential statistical techniques applied to the best performance of the process. It has intrinsic methods (**Table 2**) that allow it to establish a critical path in the use of these techniques, guaranteeing the best result.

3. Lean manufacturing

The concept of Lean Production emerged in Japan after World War II created by Japanese Toyota's Eiji Toyoda and Taiichi Ohno, aiming to overcome the challenge of cutting costs while producing small quantities of many types of cars [11].

The definition of the Lean Production system is given by Ohno (1988) as:

> *"The elimination of waste and unnecessary elements in order to reduce costs; the basic idea is to produce only what is necessary at the necessary moment and in the quantity required."* Ohno (1988, p.23)

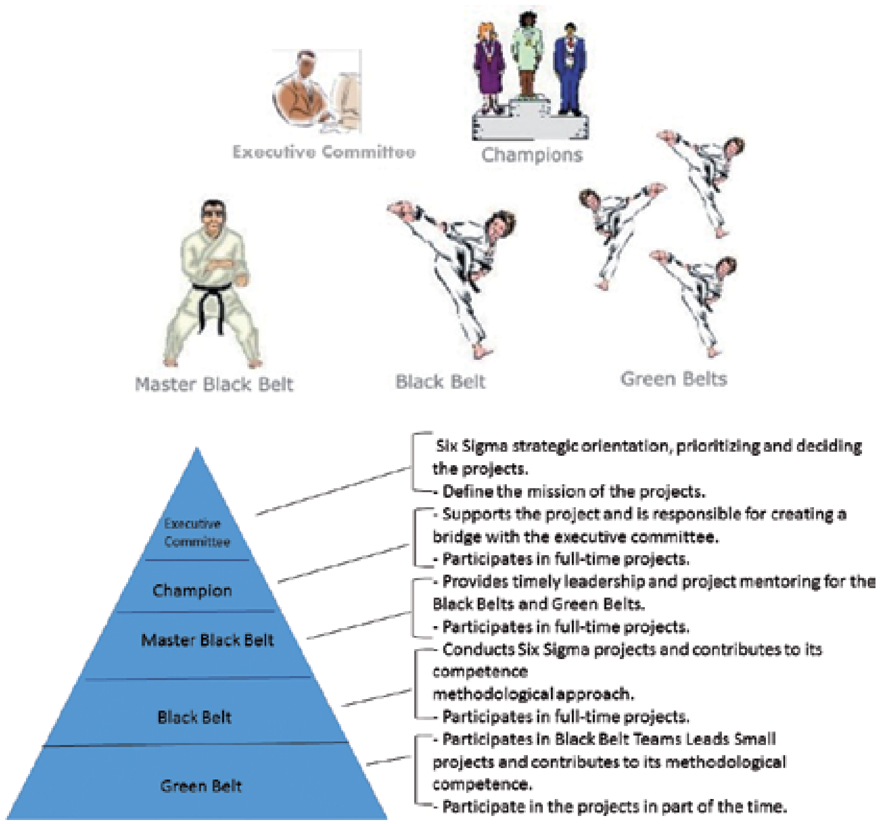

Figure 2.
6-sigma team roles (a) and responsibilities (b).

Intrinsic Method	General Feature	Phases	Specific Characteristics
DMAIC	Optimize existing processes by getting improvements in a business process to reduce or eliminate defects.	1) Define	Define the objectives of the improvement activity. Project aligned with corporate strategy. Define team.
		2) Measure	Establish metrics, measurement system, and current performance levels.
		3) Analyse	Identify differences between the current system performance and the desired goal; analyze the causes of defects and sources of variation.
		4) Improve	Improve the process to eliminate variations. Get responses from stakeholders by assessing the benefits
		5) Control	Plan to monitor process performance by controlling its variations, ensuring that improvements are maintained.
DMADV	Develop an appropriate business model to meet customer requirements, or design new product / process.	1) Define	Establish realistic and measurable goals important to the organization and its stakeholders.
		2) Measure	Critical factors for the quality should be measured as well as the requirements of the metrics.
		3) Analyse	What is the best design to achieve the goals? Analyze the project cycle
		4) Design	Develop project prototype or detail
		5) Verify	Make sure the design is acceptable. Conduct pilot studies and production scale.
Techniques of the Phases: 1) Brainstorming, Team Formation, Flowchart, PERT, QFD 2) Pareto Chart, Histogram, Normal Curve Analysis (a3, a4), Stratification 3) Diagram Cause Effect, Prioritization Matrix, FMEA, Experiment Design, Hypothesis Testing 4) Action Plan (5W2H), Dispersion Graph, Regression Analysis 5) Control letters, FMEA, International Standards (ISO 9000, 14000, 18000)			

Table 2.
Six Sigma and its intrinsic methods.

The general view of the cited author is that he considers seven types of production losses:

1. overproduction,

2. wait,

3. transport,

4. superprocessing,

5. handling,

6. defective products, and

7. stock.

Although initiated in manufacturing, the Lean concept can also be deployed in several organizational areas [12].

By aligning activities that create value by eliminating waste, the value stream is advanced smoothly and quickly according to the customer's request and not according to the producer.

Lean Manufacturing seeks process improvement by streamlining its flow, eliminating waste and emphasizing gains in speed and efficiency.

Womack et al. [11] present the five basic principles that can be used as a framework for an organization to implement the Lean methodology, these being:

1. **Value**: Precisely specifying the value is the starting point for Lean thinking. The value is defined only by the end customer. However, it is the organization that must identify what generates this value for the customer. Determining the value and defining the product, the next step is to specify the target cost based on the resources needed to manufacture the product with the specific characteristics;

2. **Value flow**: The value stream or value chain is the path traveled from the beginning of production to delivery to the end customer. Each step involved in the process is mapped on the premise that activities that cannot be measured cannot be managed and those that are not precisely identified cannot be analyzed and improved. With the mapping of the value stream it is possible to identify and eliminate activities that contain waste through waste elimination techniques;

3. **Continuous flow:** From the analysis and mapping of the value flow, it is necessary to make the activities that generate value can flow through the process without interruptions. The best way to make products flow is to stream them wherever possible by rearranging the sequence and equipment so that it does not act on waiting and inventory between activities;

4. **Pulled production:** Pulled production aims to decrease the lead time for the consumer. Implementing the pulled system means producing a good or service only when the request is made by the customer and not pushing the product to the consumer;

5. **Perfection:** When the four principles are followed clearly, that is, the organization declares the value accurately, maps the flow of value so that products flow continuously or when customers pull these products, it is possible to achieve perfection of processes by eliminating losses and waste. Continuous improvement must always be sought to achieve this perfection. To the Lean Thinking, the most important thrust to perfection is to maintain transparency among everyone involved in the system so that it is easier to identify ways to create value.

The main management techniques used to implement the Lean principles are: Value Stream Mapping, Evaluation System with well-defined metrics, 5S, Kaizen, Kanban, Standardization, Visual Management and TPM (Total Productive Maintenance).

4. LSS: the Lean and Six Sigma integration

Before beginning the integration between Lean and Six Sigma, it is prudent to understand their similarities and divergences, according to Antony [13], to enhance the work of the team in the reality of the organization:

1. Similarities:
    - Core processes in the organization,
    - Applicable not only in manufacturing activities,
    - Management support is essential,
    - It has customer focus,
    - They are made up of multifunctional teams, and.
    - The tools are complementary to each other.
2. Divergences:
    - Six Sigma requires more intensive training compared to Lean Manufacturing,
    - Lean Manufacturing focuses on waste reduction while Six Sigma in reducing variability,
    - Six Sigma requires more investment compared to Lean Manufacturing,
    - Lean Manufacturing aims to streamline the flow of processes while Six Sigma seeks to increase capacity,

- Lean Manufacturing does not present a systematic methodology for implementation, and
- Six Sigma presents specific designations as team empowerment.

It should be noted that Six Sigma supports Lean Manufacturing while it does not have a structured critical path (intrinsic method) for troubleshooting. But Six Sigma, in turn, does not focus on improving process speed, reducing lead time and eliminating waste, which are aspects of Lean Manufacturing.

4.1 Roadmap

The strong point for company culture is that statistical tools assist in the work of methodologies, reducing variability and making processes more stable and reliable.

According to Werkema [14, 15] there are steps for organizations to follow, aiming at the union of Lean and Six Sigma. It is a roadmap for an integrated implementation:

1. **Assess performance**: Establish the need for change and assess how well the organization is prepared to make that change.

   Results: Initial list of opportunities, including financial benefits, for subsequent prioritization and implementation.

2. **Plan the improvements**: Establish and communicate the goals of the implementation of Lean Six Sigma (LSS).

   Results: LSS Steering Committee, Method for selection and prioritization of projects, Standard for calculation of financial gains, Procedure for selection and training of LSS sponsors and specialists.

3. **Enable execution**: Develop, disseminate and implement procedures and policies to establish the infrastructure for change.

   Results: Training of sponsors and specialists, Establishment of internal communication channels for the dissemination of LSS, Integration of other improvement programs in force with LSS.

4. **Execute the projects**: Execute the projects (DMAIC and Kaizen) prioritized.

   Results: Achievement of financial gains (validated by the controllership), Development of the "hard and soft skills" of the sponsors and specialists, Replication of projects.

5. **Maintain improvements**: Ensure the perpetuation of the gains achieved and the consolidation of "LSS Culture", conducting periodic audits and re-energizing the program.

   Results: Continuous improvement of LSS.

4.2 Strategies for integration

Therefore, it is necessary to keep in mind the importance of choosing the Lean Six Sigma implementation strategy that best suits the characteristics of the company and its business.

Lean and Six Sigma to be integrated into a broader system of organizational improvement, the potential of which would be far greater than the sum of these two initiatives. In this line, some companies have already created their own integrated systems, called business improvement systems.

Thus, according **Table 3**, some authors cited Busso and Miyake [16, 17], emphasize the importance of adopting strategies to implement the Lean Six Sigma methodology, so that it is aligned with strategy and strategic manufacturing decisions, in order to more effectively harness the potential of both methodologies for improvement of the company business.

The strategy of manufacturing/services and its strategic decisions with the business strategy positively impacts the performance of the company improving productivity and profitability, when the organization has a management model. It is possible to say then that for the competitiveness of the company, it is important that the choices made in the production of goods or services in relation to the use of resources, skills and improvement methodologies, for example, should be guided by business strategies and selected reference models.

Author	Implementation Strategy	Features
Elliot (2003) There are 4 ways to implementation of Lean Six Sigma as a strategy for manufacture	Lean before Six Sigma	It eliminates unnecessary complexity and establishes a starting point. Manufacturing is the main problem and does not focus on solutions to variation problems.
	Six Sigma before the Lean	Eliminates variation and establishes process capability by creating focus. The problems are not need to be necessarily of manufacture. Care must be taken not to optimize processes that do not add value.
	Lean and Six Sigma separately	Comprehensive solution to solve all kinds of problems, the organization must be able to tailor the right methodology to the problem and take care that it does not resource competition.
	Lean and Six Sigma combined	Comprehensive solution to solve all kinds of problems when there is a map application of each tool.
George (2002) Companies that do not have neither methodologies. The methodology is chosen after identification of the problem and alignment with the objectives of the company.	Lean and Six Sigma combined	a) **Start:** Involvement of leadership, definition of goals that are related to the company's objectives and exposure of possible gains from the implementation and launch of the project, thus involving all employees. b) **Selection of Project and Resource:** selection of pilot projects that will serve as examples for the development of culture in all areas. One of the necessary resources is people specialized and trained for the development of activities. c) **Implementation and Evolution:** implementation of the project solutions. The author states that the Lean tools are part of the solution implementation and the mapping to discover opportunities. The Six Sigma methodology is based on organization of work and processing of data and information, in addition to problem analysis tools.

Table 3.
Strategies for Lean and Six Sigma.

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Chapter 10

Lean Six Sigma in Manufacturing: A Comprehensive Review

Hari Lal Bhaskar

Abstract

Lean Six Sigma is a systematic approach to reduce or eliminate activities that do not add value to the process. It highlights removing wasteful steps in a process and taking the only value added steps. The lean six sigma method ensures high quality and customer satisfaction in the manufacturing. The main purpose of this chapter is to explore the Lean Six Sigma (LSS) in the manufacturing sector. This chapter focuses on the different critical aspects of LSS. The core sections of this chapter are Introduction; Key lean six sigma principles; Tools and techniques; Lean six sigma methodologies; Critical success factors; Lean six sigma framework; Lean six sigma strategy; Implementation of Lean Six Sigma in SMEs; significant benefits; Significant barriers to implement lean; Assessment of Lean Six Sigma Readiness; Emerging trends in Lean Six Sigma; and Successful examples/stories in the manufacturing industry. The final section of the chapter contains the conclusions and suggestions. It is important for practitioners to be aware of Lean six sigma benefits, impeding factors, Tools and techniques, methodologies etc. before starting the Lean six sigma implementation process. Hence, this chapter could provide valuable insights to practitioners. It also gives an opportunity to Lean six sigma researchers to understand some common themes within this chapter in depth.

Keywords: lean, six sigma, lean six sigma (LSS), manufacturing, comprehensive review, methodologies, success factors, principles, lean six sigma examples

1. Introduction

In recent years, Lean Six Sigma have become the most popular business strategies for deploying continuous improvement [1] in manufacturing sectors, as well as in the public sector. Continuous improvement is the main aim for any organization in the world to help them to achieve quality and operational excellence and to enhance performance [2, 3].

It has changed manufacturing forever and from every aspect of the industry: from the people and the machinery to the logistics and administration. According to SAIL engineer Srivastva, “Machines mean nothing; if they are not efficient and calibrated—this is where the Six Sigma Methodology and the Machine Industry marry their goals for the betterment of the business industry”.

There is a misconception that Lean and Lean Six Sigma methodologies are only applicable to manufacturing or supply chain processes [4, 5]. However, these tools can be used within all aspects of a business [6]. The essential foundation needed for Lean and Lean Six Sigma methods succeed within all areas of a company is the capability to recognize waste, decrease the waste, and forcefully attempt to eliminate all activities that do not add value or increase customer satisfaction both within the company and outside.

These methods are not a new phenomenon. In fact, the Lean methodology has been an effective tool since the dawn of the industrial age [7, 8]. The idea of improving performance and meeting the expectations of customers while still improving the bottom line has always been the goal of businesses [9]. The evolution of Lean and Lean Six Sigma is based on understanding what methods or mixture of methods should be used to ensure the biggest impact to the business. The Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) foundation is the base for our Lean training and service programs [10, 11].

Six Sigma basics are designed to improve manufacturing [12, 13]. This is a type of quality control that was originally developed for large scale manufacturers. It was intended to enhance processes and eliminate the amount of defects found within them. The Lean method is a philosophy centered around eliminating waste and providing the best customer experience [14]. According to the Lean manufacturing subject matter expert, there are eight kinds of waste: defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion, and extra processing.

Researchers believe that it is very important to conduct a comprehensive review in manufacturing field to understand the each aspect of Lean Six Sigma. Research on "Lean Six Sigma in manufacturing" is limited and state that no standard work done for such a combination exists.

Hence, the aim of this chapter is to address such gaps within Lean Six Sigma (LSS) and manufacturing that allow them to achieve the most benefits from this strategy, as well as to identify the gaps and give recommendations for future research. To achieve the overall aims of this chapter, the author has comprehensively reviewed the literatures in second section.

2. Comprehensive review

2.1 Lean and six sigma

The concept of lean thinking can be traced to the Toyota production system (TPS), a manufacturing philosophy pioneered by the Japanese engineers Taiichi Ohno and Shigeo Shingo [15, 16]. The development of this approach to manufacturing began shortly after the Second World War while employed by the Toyota motor company [17]. Lean manufacturing extends the scope of the Toyota production philosophy [18] by providing an enterprise-wide term that draws together the five elements of "the product development process, the supplier management process, the customer management process, and the policy focusing process for the whole enterprise" [17]. Lean Six Sigma has been defined as "a business improvement methodology that aims to maximize shareholders' value by improving quality, speed, customer satisfaction, and costs: it achieves this by merging tools and principles from both Lean and Six Sigma" [19]. Gershon and Rajashekharaiah [20] point out that "leading texts fail to define Lean Six Sigma as a unique methodology".

Laureani and Antony [21] stated that "Lean Six Sigma uses tools from both toolboxes in order to get the best from the two methodologies, increasing speed while also increasing accuracy". Both Lean and Six Sigma require a company to focus on its products and customers [19]. According to Stoiljković et al. [22], the concepts of lean and six sigma are intertwined in that Lean speed enables Six Sigma quality and Six Sigma quality enables Lean speed. Pepper and Spedding [17] and Ferng and Price [23] similarly identify that Lean thinking may be used to identify areas of improvement

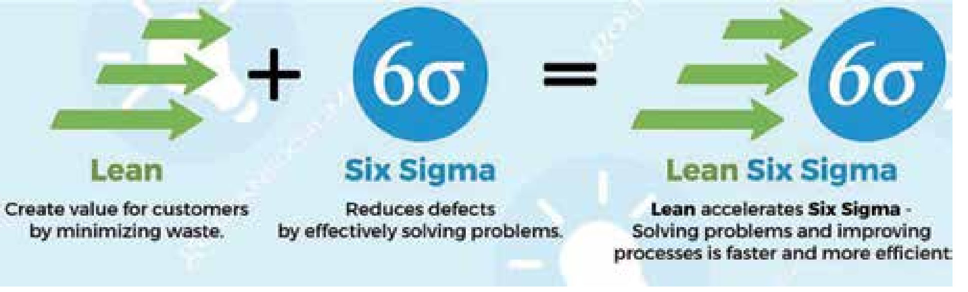

Figure 1.
Lean, six sigma and lean six sigma. Source: [27].

and set standards, while the Six Sigma methodology may be used for targeting them and for investigating deviations from said standards. The foundation of the lean vision is still a focus on the individual product and its value stream (identifying value-added and non-value added activities), and the main target of lean thinking is to eliminate all waste, or muda, in all areas and functions within the system [16, 17].

Lean Six Sigma is a combination of two powerful process improvement methods: Lean and Six Sigma [24–26]. It decreases organization's costs by:

- Removing "Waste" from a process: Waste is any activity within a process that is not required to manufacture a product or provide a service that is up to specification [36, 37].

- Solving problems caused by a process: Problems are defects in a product or service that cost your organization money [36, 37] (**Figure 1**).

2.2 Integrating lean and six sigma

Lean and Six Sigma are the two most important continuous improvement (CI) methodologies for achieving operational and service excellence in any organization [29–33]. LSS is the fusion of two most powerful process excellence methodologies, namely, Lean and Six Sigma [24].

According to Sokovic and Pavletic [34] *Lean* means speed and quick action (reducing unnecessary wait time) and *Six Sigma* means identifying defects and eliminating them. As well as *Lean Six Sigma Engineering* means best-in-class. It creates value in the manufacturing or service organization to benefit its customers and saves money without capital investment [34].

Six Sigma is a well-established approach that seeks to identify and eliminate defects, mistakes or failures in business processes or systems by focusing on those process performance characteristics that are of critical importance to customers' [35]. It is a statistical methodology that aims to reduce variation in any process, reduce costs in manufacturing and services, make savings to the bottom line, increase customer satisfaction, measure defects, improve product quality, and reduce defects to 3.4 parts per million opportunities in an organization [35, 36].

The high cost of Six Sigma training is a barrier for many organizations to deploy this methodology [37, 38]. In fact, deploying Six Sigma in isolation cannot remove all types of waste from the process, and deploying Lean management in isolation cannot control the process statistically and remove variation from the process [35]. Therefore, some companies have decided to merge both methodologies to overcome the weaknesses of these two methodologies when they have been implemented in isolation and to come up with more powerful strategy for continuous improvement

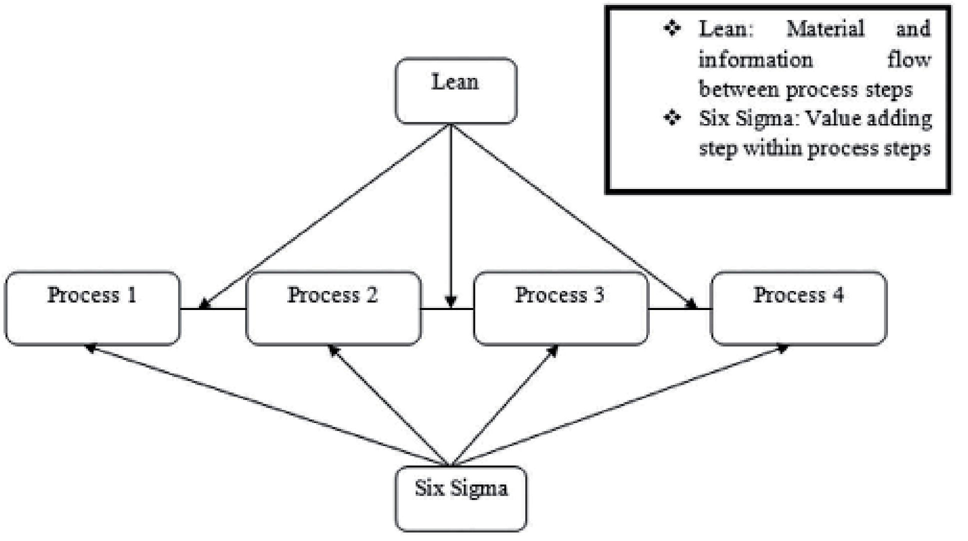

Figure 2.
Concept of lean six sigma. Source: [28].

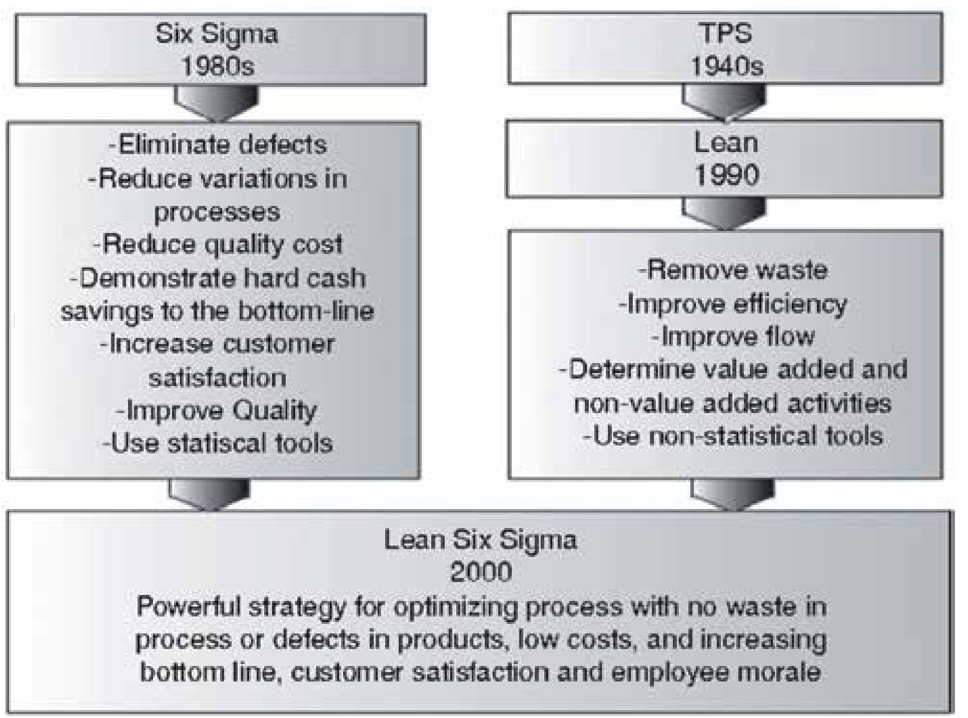

Figure 3.
Lean and six sigma popularity and integration. Source: [35].

and optimizing processes [35, 39, 40]. In fact, LSS are completing each other and there is an obvious relation between both methodologies, which makes it possible for the synergy of the two methodologies (see **Figures 2** and **3**). Therefore, the integration of these two approaches gives the organization more efficiency and affectivity and helps to achieve superior performance faster than the implementation of each approach in isolation [30, 35, 41].

Salah et al. [30] has indicated that the integration of lean and Six Sigma is the solution to overcome the shortcomings of both, as they complete each other. This integration helps companies to achieve zero defects and fast delivery at low cost. According to Bhuiyan and Baghel [42] the combination of this two is the way for organizations to increase their potential improvement.

The integrated approach to process improvement (using Lean and Six Sigma) will include:

- Using value stream mapping to develop a pipeline of projects that lend themselves either to applying Six Sigma or Lean tools [34, 43].

- Teaching Lean principles first to increase momentum, introducing the Six Sigma process later on to tackle the more advanced problems [34, 43].

- Adjusting the content of the training to the needs of the specific organization—while some manufacturing locations could benefit from implementing the Lean principles with respect to housekeeping, others will have these basics already in place and will be ready for advanced tools [34, 43].

The following roadmap provides an example for how one could approach the integration of Lean and Six Sigma into a comprehensive roadmap (**Figure 4**).

Therefore, many manufacturing firms are looking for an approach that allows to combines both methodologies into an integrated system or improvement roadmap [44, 45]. However, the differences between the Six Sigma and Lean are profound (**Table 1**).

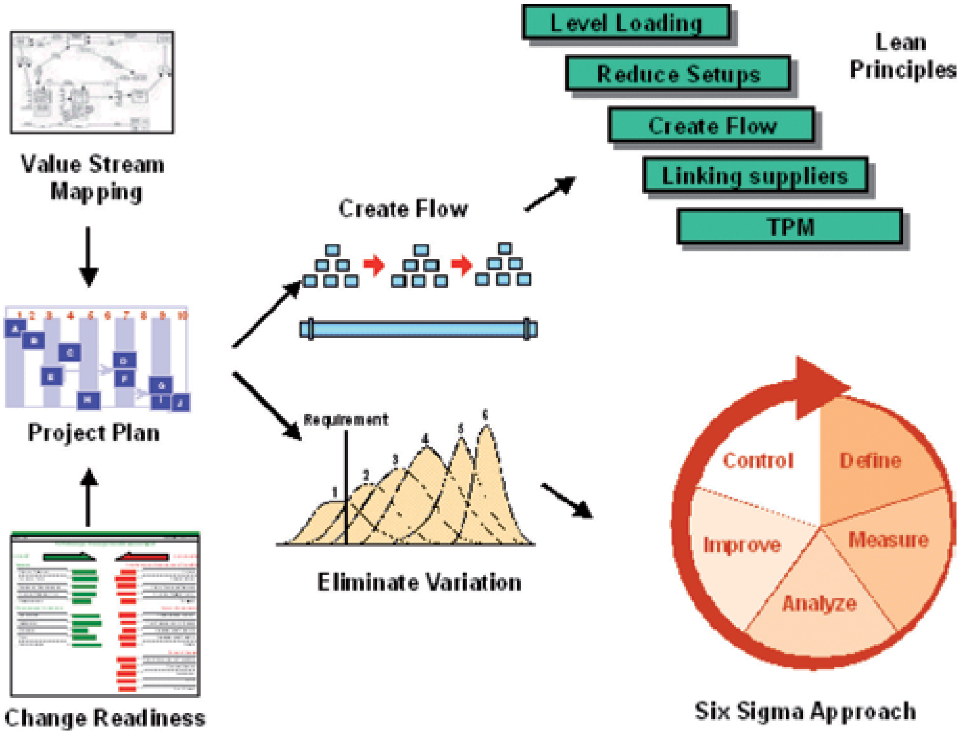

Figure 4.
Integrating lean and six sigma roadmap. Source: [44].

	Lean	Six sigma
Goal	Create flow and eliminate waste	Improve process capability and eliminate variation
Application	Primarily manufacturing processes	All business processes
Approach	Teaching principles and "cookbook style" implementation based on best practice	Teaching a generic problem-solving approach relying on statistics
Project selection	Driven by value stream map	Various approaches
Length of projects	1 week to 3 months	2–6 months
Infrastructure	Mostly ad-hoc, no or little formal training	Dedicated resources, broad-based training
Training	Learning by doing	Learning by doing

Source: Prepared by the author.

Table 1.
Comparing lean and six sigma.

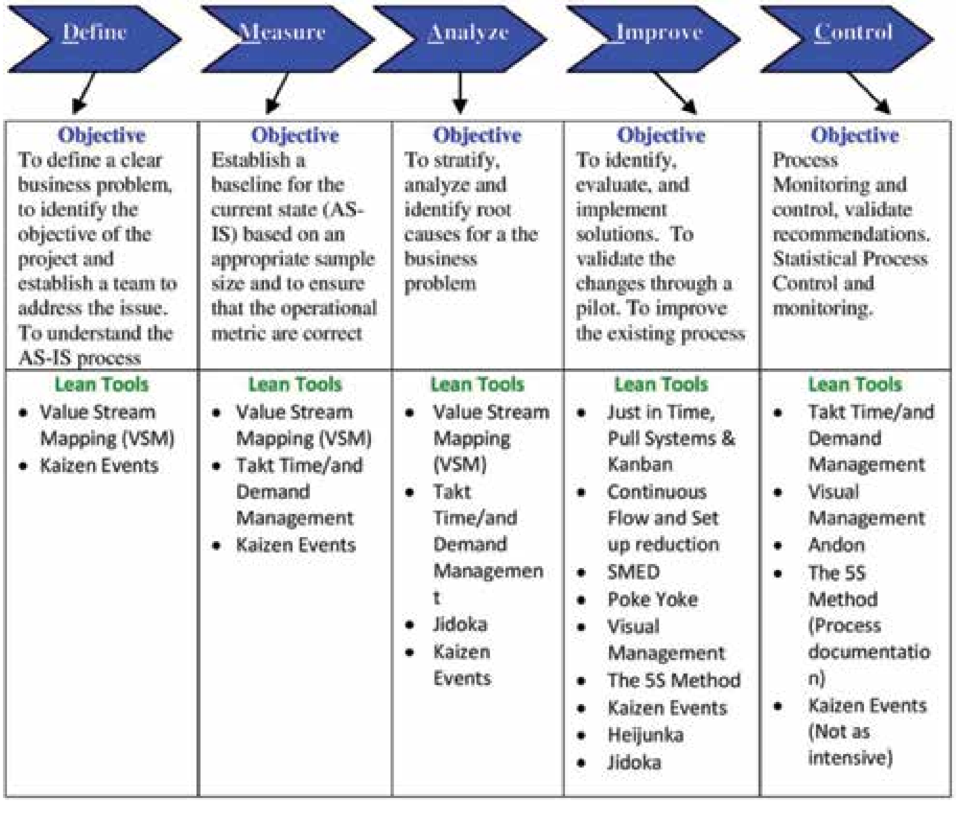

Figure 5.
Integrating lean tools and six sigma DMAIC cycle. Source: [46].

Duarte [46] identify that Lean Six Sigma has become a widely recognized process improvement methodology and has been adopted by many companies like Ford, DuPont, 3 M, Dow Chemicals, and Honeywell etc. At present, the methodology of Lean Six Sigma has been carried out in 35% of companies listed in the Forbes top 500 [46]. He illustrates how Lean tools can be incorporated into the Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) cycle (**Figure 5**).

2.3 Basics of lean six sigma

In the efforts to draw nearer to customers, several manufacturers have lost focus on what ought to be a company's primary success factor—profitable growth. In today's competitive manufacturing environment, it takes more than quick fixes, outsourcing and downsizing for firms to systematically achieve their growth and profit objectives [47]. Whereas these choices could yield temporary financial relief, they will not lead the way to long-term growth and profitability. Therefore, they have to bring lean to grow and continually exceed bottom line expectations; and to bring lean they must master eight basics of Lean Six Sigma for manufacturing.

2.3.1 Software as the solution

In digital and cloud based environment, the physical database is replaced by a virtual database. Data are transferred throughout the cloud computing [48]. Organizations were led to believe that computerized systems would provide the solution to all growth and profit challenges. Material requirements planning (MRP) and enterprise resource planning (ERP) system gurus assured companies that if they implement their software programs at bottom line, would take care of itself. In a typical company, converting the quarterly financial forecast into reality still requires overtime, internal/external expediting, last minute "on-the-run" product changes and even some "smoke and mirrors" from time to time [49]. Results are scrap, rework and warranty costs that negatively impact profitability and quality, and shipment problems that deliver less than acceptable customer satisfaction [47]. Companies have spent thousands of dollars in pursuing MRP and ERP only to see growth and profits decline due to uncontrolled operating costs that produced non-competitive pricing [39, 40]. Thus, softwares can be a solution for these problems, and eliminate the root causes of ineffective systems and processes.

2.3.2 How to get to root causes

Manufacturers can get the root causes by in-depth understanding of the fundamentals of Six Sigma and then a total reliable commitment and determined execution of eight basics of Lean Six Sigma. Like renowned football coach Vince Lombardi, who achieved success by having his team focus on the mastery of football basics, manufacturing teams need to focus on the mastery of the Lean manufacturing basics. These basics require proactive planning and inflexible implementation that demands leadership above and beyond just satisfying day-to-day accountabilities. Some managers cannot imagine the benefits of mastering manufacturing basics. Others simply cannot find the time. Like practicing blocking and tackling in football, it is not exciting. And like most football heroes, managers prefer to run with the ball. But without the solid execution of Lean Six Sigma basics, companies will seldom achieve their full growth and profit potentials [44, 47]. Here are the eight basics of Lean Six Sigma which every manager should know and implement:

- **Information integrity:** It is common for front office management to become disappointed with computerized systems results when time schedules and promised paybacks are not achieved. It is a given that acceptable systems results cannot be achieved when systems are driven by incorrect data and inappropriate, uncontrolled documentation [44, 47, 50].

- **Performance management:** Measurement systems can be motivational or de-motivational. The individual goal-setting of the 1980s is a good example of de-motivational measurement—it tested one individual or group against the other and while satisfying some individual egos, it provided little contribution to overall company growth and profit. Today, the balanced scorecard is the choice of business winners [44, 47, 50].

- **Sequential production:** It takes more than systems sophistication for manufacturing companies to gain control of factory operations. To achieve on-time shipments at healthy profit margins, companies need to replace obsolete shop scheduling methodology with the simplicity of sequential production [51]. Manufacturing leaders have replaced their shop order "launch and expedite" methodology with continuous production lines that are supported by real-time, visual material supply chains…sequential production. The assertion that sequential production only works in high production, widget-manufacturing environments is a myth [44, 47, 50].

- **Point-of-use logistics:** Material handling and storage are two of manufacturing's high cost, non-value-added activities. The elimination of the stock room, as it is known today, should be a strategic objective of all manufacturers. Moving production parts and components from the stockroom to their production point of use is truly a return to basics and a significant cost reducer [44, 47].

- **Cycle time management:** Long cycle times are symptoms of poor manufacturing performance and high non-value-added costs [44, 52]. Manufacturers need to focus on the continuous reduction of all cycle times. Achieving success requires a specific management style that focuses on root cause, proactive problem solving, rather than "fire-fighting" [44, 47].

- **Production linearity:** Companies will never achieve their full profit potential if they produce more than 25% of their monthly shipment plan in the last week of the month or more than 33% of their quarterly shipment plan in the last month of the quarter. How linear does a production department produce to the company's master schedule? As companies struggle to remain competitive, one of the strategies by which gains in speed, quality and costs can be achieved is to form teams of employees to pursue and achieve linear production [44, 47].

- **Resource planning:** One of the major challenges in industry today is the timely right sizing of operations. Profit margins can be eroded by not taking timely downsizing actions, and market windows can be missed and customers lost by not upsizing the direct labor force in a timely manner. These actions demand timely, tough decisions that require accurate, well-timed and reliable resource information [44, 47].

- **Customer satisfaction:** Customer satisfaction is the main driver of loyalty. It affects company's financial performance and perception of the customers [53]. Perceptions are what a company needs to address when it comes to improving customer satisfaction. It does not good to have the best products and services if the customer's perception of "as received" quality and service is unsatisfactory. Companies need to plan and implement proactive projects that breakdown the communication barriers that create invalid customer perceptions [44, 47, 54, 55].

2.4 Key lean six sigma principles

Lean six sigma principles mainly refer to process improvements, although their practical implementation has different impacts according to different organizational models [56]. Leaders at all levels are working to integrate lean and Six Sigma principles into all business processes, including product design and development, integrated supply chain, marketing and sales, customer service, infrastructure, governance and strategy deployment [57].

According to Lucid chart Content Team, for a process stream that produces the best results; consider the following Lean Six Sigma principles for your organization.

1. **Focus on the customer**: Before you start making any drastic or even minor changes, establish the level of quality or requirements that you have promised your customers.

2. **Figure out your value stream**: You need to see the current state of your process before you can move forward and make improvements. Identifying value stream is unquestionably what makes Lean Six Sigma principles so effective. A value stream map showcases every single step, including purchasing parts, assembling them (and checking for quality assurance), and distributing the finished product. You must determine which steps add value and which do not.

3. **Take out the trash**: Remove any non-value-added activities or opportunities for defects. On value stream map, avoid highlighting areas that are working fluidly. If your value stream map does not clarify exactly where the problem lies, you can use several other diagrams to work through potential root causes of the issue. For example: Cause-and-effect diagrams.

4. **Keep the ball rolling**: Workers will keep performing (or not performing) the same tasks until management decides otherwise. The responsibility of business is to communicate the new standards and practices effectively and clearly. Be sure each employee receives training and feedback. Otherwise, why expect the problem to change? Thus, nothing will change until change is enacted.

5. **Create a culture of change and flexibility**: Lean Six Sigma requires a lot of change [58]. You need to welcome change and encourage your employees to accept change as well. As part of this cultural shift, your company should always look for new ways to streamline the process and remove waste. Keep your eye on the data, examine your bottom line, and adjust your processes where necessary.

Womack and Jones [59] has summarized five Lean Six Sigma Principles in "Lean thinking—banish waste and create wealth in your corporation" as follows:

1. **Specifying value:** "Value is only meaningful when expressed in terms of a specific product or service which meets the customer needs at a specific price at a specific time."

2. **Identify and create value streams:** "A Value stream is all the actions currently required to bring a product from raw materials into the arms of the customer."

3. **Making value flow:** "Products should flow through a lean organization at the rate that the customer needs them, without being caught up in inventory or delayed."

4. **Pull production not push:** "Only make as required. Pull the value according to the customer's demand."

5. **Striving for perfection:** "Perfection does not just mean quality. It means producing exactly what the customer wants, exactly when the customer requires it, at a fair price and with minimum waste."

Womack et al. [60] defined the five principles of Lean manufacturing in their book "The Machine That Changed the World". The five principles are considered a recipe for improving workplace efficiency and include: (1) defining value, (2) mapping the value stream, (3) creating flow, (4) using a pull system, and (5) pursuing perfection. The principles encourage creating better flow in work processes and developing a continuous improvement culture. By practicing all these five principles, an organization can remain competitive, increase the value delivered to the customers, decrease the cost of doing business, and increase their profitability. These Lean principles can be applied to any process to reduce the wastes (**Figure 6**).

2.5 Lean six sigma frameworks and methodologies

Lean six sigma is a systematic data driven methodological philosophy centered around eliminating waste, reducing process variation [61] and providing the best customer experience [45]. According to the Lean method, there are eight kinds of waste: defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion, and extra processing [62]. Lean six sigma is a structured problem solving methodology [63]. The lean six sigma framework aim at providing an effective approach to integrating lean and six sigma [65]. It uses the DMAIC phases similar to that of Six Sigma [32]. Problem solving in lean Six Sigma is done using the DMAIC framework. It has been implemented and verified at one engineering company in UAE [32]. The results show that the process "Make-to-Order (MTO) projects" has a long lead-time [32]. The main causes of the long lead-time are the subcontractors, the customers, and the company-implemented procedures [32].

Figure 6.
The five lean principles [64].

Using the framework, it was possible to identify the most significant reason for the long lead-time, analyze the root-cause(s), suggest three relevant solutions and select the most preferred one [32]. In this methodology framework application, lean-production, six-sigma, balanced scorecard, simulation and cost benefit analysis tools were used.

A study was conducted in India by Ben Ruben et al. [61] using DMAIC framework methodology and validated practically to provide both operational and environmental benefits. The framework is validated with an industrial case study conducted in an Indian automotive component manufacturing firm/organization located at Tamilnadu. The firm manufactures high precision transmission. On the successful deployment of the framework, the internal defects was brought down to 6000 ppm from 16,000 ppm and environmental impacts was reduced to 33 Pt from 42 Pt. Deployment of the developed framework helped in improving the firm's sigma level and also reduced the overall environmental impacts. In this research different lean six sigma tools were used at different level/phase like-Value Stream Mapping (VSM), 5S, Kaizen, Cause and effect diagram, Quality Function Deployment (QFD), High level SIPOC, Eco-QFD, Pareto chart, Environmental VSM (current level), life Cycle Impact Assessment, Brainstorming, Design of Experiments, Cost benefit analysis, Design for Environment, Life Cycle Interpretation, Environmental VSM (Future level), 7s practices, Standard operating Procedure (with environmental metrics) and Performance evaluation tools.

Thus, using the framework methodology the user will have a systematic approach for continues improvement. Because, this framework also allows the user identify the process problem(s) and solve them effectively [32]. There are five stages in this framework. They are Define, Measure, Analyze, Improve, and Control [66] (**Figure 7**).

Hill et al. [45] has developed an initial conceptual Lean Six Sigma Framework (LSSF) and undertook a series of iterative developments in an attempt to improve its effectiveness and suitability to Maintenance Repair and Overhaul (MRO) implementation. Hill et al. [45] describes the novel implementation of an integrated LSS framework and outlines how it was used to identify the factors that affect supply chain performance in an aerospace Maintenance Repair and Overhaul (MRO) facility. It shows how each of the Six Sigma DMAIC phases are applied systematically to each of the Lean stages. Stage (0) of the LSSF was the starting point of the implementation stage. *The phases are as follows:*

LSS Phase 1—Specify value by defining the CTQ issue.

LSS Phase 2—Align the internal operations through measuring the extent of the Problem.

LSS Phase 3—Create flow by identifying constraints in the system.

LSS Phase 4—Create flow through process improvement.

LSS Phase 5—Continuous improvement and control of future processes (**Figure 8**).

Hill et al. [45] outlined the application and measures the effectiveness of the integrated LSS framework through its ability to achieve new and enhanced performance through simultaneously reducing late material calls and reducing and stabilizing Order To Receipt (OTR) times.

2.6 Tools and techniques

Lean and Six Sigma both have their own set of tools and techniques that can enhance a company's objectives for value and profit enhancement [24]. Lean six sigma consists of many tools and techniques for continuous improvement such as the Kanban system, 5S, Cause and Effect analysis (C&E), Value Stream Mapping (VSM) and many others [35, 36]. According to Brazilian publications, there are

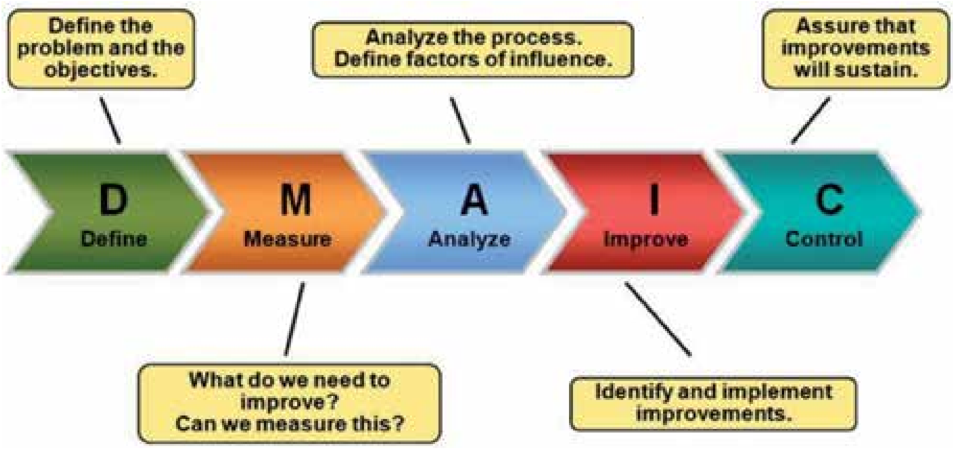

Figure 7.
Lean six sigma framework and methodology. Source: [66].

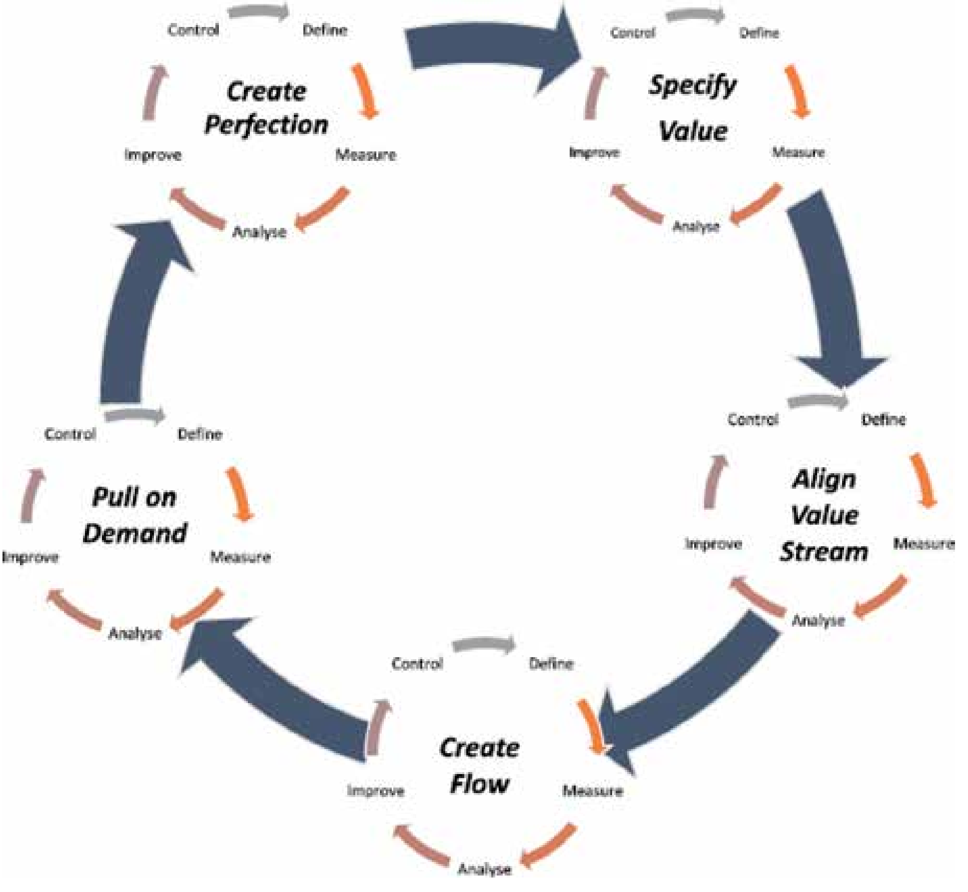

Figure 8.
Integrated generic lean six sigma framework (LSSF). Source: [45].

six most frequently tools used in LSS applications: “Control Charts”, followed by “Value Stream Mapping”, “DMAIC,” “Kaizen,” “Ishikawa Diagram,” and “Histogram;” and Control chart is the top ranking tool [33]. DMAIC is a five step

Lean Six Sigma (LSS) tools	Author(s)
Control Charts	[10, 24, 33, 67]
Value Stream Mapping (VSM), Box plot, Process mapping, Standardized work, Scatter diagram, Cause and effect matrix (C&E analysis), Kanban system, Hypothesis Testing, Process Flow Diagram, Quick, 7 waste analysis, Heijunka	[10, 24, 31, 35, 67]
DMAIC or DMADV	[10, 24, 67, 68]
Kaizen, Single Minute Exchange of Die (SMED)	[24, 67, 68]
Ishikawa Diagram, Histogram, Stratification	[10, 24]
Pareto Chart, E-Kanban system, SOP, Check sheet, VOC translation matrix, Three diagrams, Brainstorming, SIPOC Diagram	[10, 24, 31]
Current state map, Spaghetti diagram, Poka-yoke	[24, 67]
5S, 5 Whys, XY matrix, FMEA, ANOVA, Design of Experiments (DOE), Rootcause Analysis, Mistake proofing, VSM, Pareto chart, CTQ analysis, Root-cause analysis, Jidoka	[10, 24, 31, 35, 67]
Process Capacity Analysis, Cause and effect diagram	[10, 24, 31]
Changeover, Total Productive Maintenance (TPM), Line balancing; Cellular manufacturing,	[24, 67]
Critical to Customer Tree—VOC/VOB	[24]
OEE, DMADV, Autonomation (Jidoka), Visual management	[24]
5W1H, JIT, Regression analysis, QFD, Statistical Process Control (SPC), Kano Model, Gemba (Go & See)	[24, 31, 35, 39, 67, 68]
Confidence Interval, Continuous Flow, Benchmarking	[24]
Impact Effort Matrix, PDCA, DFSS, Production Leveling, Lean Office, Solution Prioritization Matrix, Matrix Diagram,	[24]
QCC (Quality Control Circle), Cellular Layout, Milkrun, Mizusumashi	[24]
Andon, QC Story, Routine Management, R&R, Gantt Chart	[67]
Relationship Diagram, Stratification, Cross-functional Team, Theory of Constraints (TOC) Principles, A3 Form, Affinity Diagram	[67, 69]

Source: Prepared by the author.

Table 2.
Identified lean six sigma tools and techniques.

method for improving existing process problems with unknown causes. DMAIC define and quantify the problems; identify cause of the problems; implement, verify and maintain the solutions. The DMAIC or DMADV toolkit comprises all the Six Sigma and Lean tools [10], and the success factors of lean six sigma is their ability to use the toolbox in a systematic and disciplined manner [10]. Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), Statistical Process Control (SPC), Design of Experiments (DOE), Analysis of Variance (ANOVA), Kano Model, etc. statistical tools and techniques reduce variation in any process, reduce costs in manufacturing and services, make savings to the bottom line, increase customer satisfaction, measure defects, improve product quality, and reduce defects to 3.4 parts per million opportunities in an organization [35, 39]. Some of these tools have adopted from TQM as Six Sigma in itself has derived from the TQM movement. All the tools and techniques are shown in **Table 2**.

2.7 Critical success factors

There are many studies have been conducted on critical success factors of LSS. Author has shown critical success factors that were identified by previous researchers. Some of the predominant CSFs are discussed in this section.

Most studies on critical success factors (CSFs) have found senior management involvement and commitment as a CSF in the implementation of lean six sigma projects [10]. Carleysmith et al. [70] and Mustapha et al. [10] noted that senior support as a critical factor that enables the process of LSS implementation. Mustapha et al. [10] also identified senior management supports as the most vital institutional factors which enable implementation of the LSS framework. Delgado et al. [71] says that the role of management is influencing the practice and guiding organizational culture to help the organization in closing the gap and proposing ideas for improvement.

According to Mustapha et al. [10] and Sharma [72] senior management involvement ensures the benefit of the program to the company by facilitating trust and communication. Senior management motivates to the team members, enables them to use procedures and methods for better quality. They also ensure recognition, which leads to effective and quicker change toward greater innovation [10]. Mustapha et al. [10] and Zu et al. [73] have also considered Management decisions and Organizational infrastructure in the lean critical success factors.

Näslund [68] frequently mentioned CSFs include the importance of a vision and strategy, top management support and commitment, importance of communication and information, and so forth. According to Mustapha et al. [10] linking business strategy with continuous improvement strategy is important. A clear and solid combination of LSS with the company's corporate strategy is the most critical factor for successful implementation.

Kumar et al. [74] and Mustapha et al. [10] note that stress on overall program success and short-term successes are important in the initial stages of LSS to ensure members' interest in the lean project. Apart from these LSS projects also need champion or sponsors who provide direction to the implementation team, find resources and plan for the project [10]. The readiness of the company is also a critical in lean implementation [10, 68, 75].

For the successful implementation of change effort, different education and training are also most required factors [68, 72, 74]. Education in a systems and process view of organizations answers the questions why the change of the system is needed, how it is supposed to change, and what the benefits will be to the system [68]. This education can also prepare the organization for change and create the readiness for change [68].

Customer satisfaction as the central goal of LSS, Cultural change and a transformation of attitudes of the employees [10, 74], productive teamwork [76], LSS working groups [74], duties and responsibilities of team players [74], Integration of LSS with the performance management process [10] and integration of human and process elements of improvement [10, 77] are the key element for the effective implementation of LSS programs. Because when these elements are combined with other aspects of LSS, it would produce its successful implementation in an organization.

2.8 Lean six sigma strategy

Lean Six Sigma combines the strategies of Lean and Six Sigma [30]. It has rapidly established itself as the key business process improvement strategy of

Deployment Strategy	Pros	Cons
Tops-Down Approach (Company Wide)	• Quick dissemination of knowledge • End to End projects • Large ROI	• Large initial Investment required • Higher Risk • Large Scope and Complexity
Partial Deployment	• Narrow Scope • Reduced Complexity • Easier to Navigate through organization – Change Management	• Narrow scope potentially sub-optimizes supply chain • Longer time to deploy • Smaller ROI
Focused Deployment	• Quick Wins • Address burning platforms	• Narrow scope potentially sub-optimizes supply chain • Smaller ROI

Table 3.
Lean six sigma deployment strategies. Source: [46].

choice for many companies [45]. In general, the approach has been to align Lean Six Sigma deployments with the strategy of the organization [46]. The strategy usually includes a plan that addresses the high level goals of the organization [46]. Strategic objectives are then broken down into routine metrics at the operational level. In classic Six Sigma terminology the "Big Y" is broken into "smaller y's" and plans are put in place to address each "small y" at the operational level. The majority of the companies use this approach in creating a Six Sigma portfolio that helps meet the strategic goals of the organization [46]. Both Lean and Six Sigma are key business process strategies which are employed by companies to enhance their manufacturing performance [78]. **Table 3** illustrates different deployment approaches that are used along with some of the pros and cons of using the approach [46].

Some companies use a top-down LSS deployment approach which is driven by strong governance [46]. For example: General Electric. This approach requires strong executive commitment and company wide acceptance to change [46].

The reasons for deploying LSS often include poor financial performance, retreating customer satisfaction, increased rivalry or the existence of a burning problem area [46]. There is not a single method that fits all Lean Six Sigma deployments. There are various deployment models that are broadly used in the industry today. **Figure 9** illustrates a deployment strategy that includes a few concepts presented above.

The strategy includes a pilot or proof of concept phase and ends with a companywide LSS deployment. In the pilot phase, specific problems are addressed to reveal the usefulness of the methodology and to gain buy-in. larger investments are made in infrastructure, education and training of yellow belts, green belts, black belts and master black belts [46]. Organizations must be aware of their toolset and enhancements needed to move forward. Many organizations train their Black belts on the theory of constraints and agile techniques to keep their toolset sharpened with a goal of including various manufacturing engineering methodologies. For truly successful LSS, the deployment must be tied into the strategy and be focused on the right parts of the business [46].

2.9 Assessment of lean six sigma readiness

Implementation of LSS is not a game of self interest. Thus, lean six sigma readiness must be assessed before its implementation in manufacturing organizations. Sreedharan et al. [79] recently designed an evaluation model in their quality paper

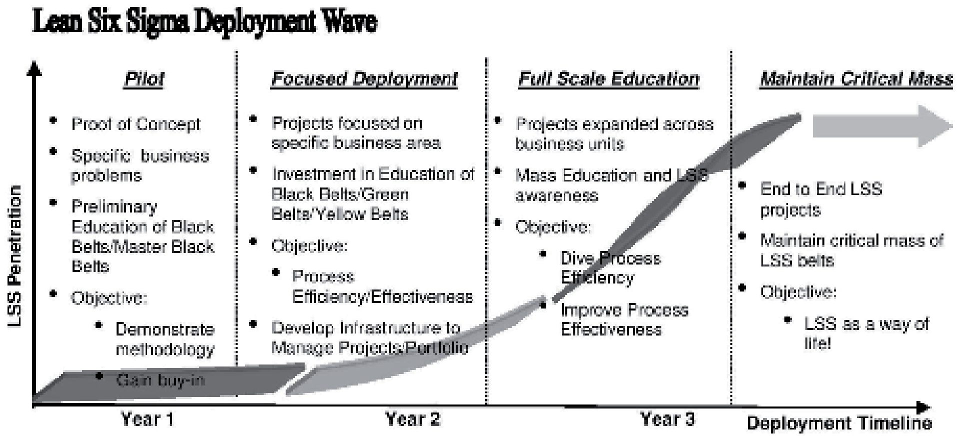

Figure 9.
Strategic goals and objectives in deployment wave. Source: [46].

"Assessment of Lean Six Sigma Readiness (LESIRE) for manufacturing industries using fuzzy logic". According to this evaluation model, the following criteria must be for readiness of LSS in manufacturing:

- Employee engagement
- Developing organizational readiness
- Establishing Lean Six Sigma dashboard
- Roadmap for project execution
- Infrastructure
- Top management commitment and Involvement
- Knowledge about Lean Six Sigma benefits
- Good leadership
- Clear vision and future plans
- Proper communication about future benefits expected from project by top management
- Experience in Lean Six Sigma deployment and implementation
- Lean Six Sigma facilitator Structure
- Alignment between the objective of the project and strategic objective of the company
- Customer focus
- Selection of candidate for Belt training
- Project prioritization

2.10 Implementation of lean six sigma in SMEs

Every organization is unique, without a common blueprint that universally applies. Lean Six Sigma implementation refers to a company's management philosophy and a long-term strategy [80]. It can be implemented in any SMEs in phases. The aim of implementation of LSS is finding wider application in many different environments. A successful implementation has several factors associated with it. Alkhoraif [80] has noted that Japanese automobile companies Toyota have a high implementation success rate due to their inflexibility in systematic planned management of employees, resources and equipment.

In a Lean Six Sigma SMEs, people deal with process improvement by conducting improvement projects as well as continuously improving daily routine. This requires an organization which understands the methodology.

According to Lokesh R, There are eight steps to a successful lean six sigma implementation in SMEs. Lokesh R is a certified Black Belt and general manager of process excellence at Firstsource Solutions Ltd. The first step in a Lean Six Sigma implementation is deciding to use the methodology. Once the leadership of a SMEs believes they can benefit from using Lean Six Sigma, they can follow eight steps—Step 1: Create a Burning Platform; Step 2: Put Resources in Place; Step 3: Teach the Methodology; Step 4: Prioritize Activities; Step 5: Establish Ownership; Step 6:

Figure 10.
Successful lean six sigma implementation steps source: Prepared by the author.

Take the Right Measurements; Step 7: Govern the Program; and Step 8: Recognize Contributions (**Figure 10**).

Step 1: Create a burning platform: SMEs must have a compelling reason for implementing Lean Six Sigma. For example "We are suffering huge quality losses; they account for more than 45 percent of our costs." and "Our competitors are gaining our market by 12 percent every quarter." Company leadership should become familiar with the burning platform, and understand how Lean Six Sigma can address the problems in the platform statement.

Step 2: Put resources in place: Do not hesitate to hire the right resource at right price. This is applicable to any resource, be it employees, material or technology. They must be able to work together as a team, and be empowered to carry out initiatives.

Step 3: Teach the methodology: For a lifetime survival, organizations need to train their team members to be powerful change agents. Yellow Belt, Green Belt and Black Belt training, along with skilled mentors, can help increase organizational awareness. The employees identified for training should share the organization's vision.

Step 4: Prioritize activities: Organizations must make a priority to: Listen to the customer, Identify critical-to-quality criteria and Ensure Lean Six Sigma efforts are linked to business goals. It is important to learn what to overlook and where to take risks. Activities must be assessed to ensure they are meeting the expectations of the organization's goals.

Step 5: Establish ownership: It must be clear who owns the Lean Six Sigma initiative. This may involve appointing a committee to find out who is responsible for the entire team. With ownership comes empowerment and a sense of pride, and team members who are more committed, accountable and engaged.

Step 6: Take the right measurements: What cannot be measured cannot be improved. By creating a measurement system, practitioners can determine baseline performance and use the data in objective decision making and analysis of variation. The key for measurement is to get the cost of quality right. Organizations also must find a way to measure process performance to ensure they receive data at a fast pace. Having too many items on a scorecard may shift practitioners' attention from the critical few metrics. They need to identify and measure the key leading indicators instead of measuring the many lagging indicators.

Step 7: Govern the program: A proper governance structure can help a program sustain momentum. Poor governance or too much governance can lead to the vision falling apart. Proper governance also helps practitioners create a best practice sharing forum, which helps projects to be replicated and can highlight common challenges. Without regularly scheduled, productive meetings or review sessions, the program can veer off course and employees may lack guidance.

Step 8: Recognize contributions: Rewards and recognition play a valuable role in making sure team members remain satisfied in their roles. They can help build enthusiasm for the program from a top-down and grassroots level. Rewards and recognition also can help drive innovation throughout the organization.

2.11 Significant barriers to implement LSS in manufacturing

Lean principles, tools and techniques have become a benchmark for manufacturing companies that have founded on the success of the Toyota Production System (TPS). Despite its popularity, companies are still struggling to achieve a successful lean implementation [81]. Many studies claim regarding the effectiveness of LSS in manufacturing and found that LSS practices is difficult and organizations encounter several roadblocks in this long continuous improvement journey. Some studies identified determining factors which make LSS journey either a success or a failure [82]. Existing research indicates some important organizational and technical barriers such as lack of management support and commitment, poor involvement of employees, and excessive confidence in lean tools and practices [81]. According to Navarro (a certified LSS Black Belt), there are five major barriers/obstacles/challenges to implement LSS in manufacturing:

- Insufficient management time to support lean
- Not understanding the potential benefits of applying lean
- Underestimating employee attitudes/resistance to change
- Insufficient workforce skills to implement lean
- Backsliding to the old inefficient ways of working

2.12 Significant benefits of LSS implementation in manufacturing

Many organizations have reported significant benefits after the implementation of LSS in manufacturing [79]. Lean and LSS is not just for manufacturing. It can benefit organizations of any size, in any industry. Because all organizations have problems to solve, all organizations have waste, and all organizations want to increase profits and reduce costs. It benefit to Healthcare, Financial services, Retail and hospitality, Education and Office-based businesses. LSS can also benefit organizations in Agriculture, Energy, Mining, Construction, Consulting, Design, Hotels, Travel and transportation, Law firms, Logistics, Government and Public services.

Albliwi et al. [35] has conducted a review research on LSS. They reviewed 37 LSS original research papers including 19 case studies had been published in the manufacturing sector in 11 different countries, which are: USA, UK, India, The Netherlands, China, Malaysia, Australia, Iran, Taiwan, Sweden and New Zealand. Albliwi et al. [35] identified more than 50 benefits (in 19 case studies). The top 10 benefits are:

1. Increased profits and financial savings;
2. Increased customer satisfaction;
3. Reduced cost;
4. Reduced cycle time;
5. Improved key performance metrics;
6. Reduced defects;
7. Reduction in machine breakdown time;
8. Reduced inventory;
9. Improved quality; and
10. Increased production capacity.

Other identified benefits are identifying different types of waste, development in employee morale toward creative thinking and reduction in workplace accidents as a result of housekeeping procedures.

Many other LSS practitioners, manufacturers, academic researchers have realized common benefits in manufacturing by applying a successful lean methodology are—Greater productivity, Smoother operations, Greater flexibility and responsiveness, Eliminates defects, Improved product quality, Reduced lead time, Increased customer satisfaction, Improved staff morale, Safer working environment and Boosts bottom line.

Ben Ruben et al. [61] identified that on successful deployment of the LSS framework in an Indian automotive component manufacturing organization, the internal defects was brought down to 6000 ppm from 16,000 ppm and environmental impacts was reduced to 33 Pt from 42 Pt.

Lean and Six Sigma offers a number of substantial benefits to organizations. Most importantly, Lean and Six Sigma Creates efficient processes so you can deliver more products to customers; Increases revenue by streamlining processes; Reduces costs by eliminating waste activities; Develops effective teams by empowering employees, staff morale and job satisfaction.

Singh and Rathi [28] have recently conducted a review research on LSS and covered papers from 2000 to 2018. They have selected a total of 216 research papers published in different countries on LSS implementation in various manufacturing sector such as automotive, micro small medium enterprises, health care, education, financial sectors etc. and observed major LSS benefits are: reduction in inventory; reduced costs of poor quality; improve customer highest satisfaction; reduced cycle time and lead time; defect free processes; and improvement in productivity.

2.13 Limitations of LSS in manufacturing

Many authors have argued that there are a significant number of limitations in LSS methodology. They have addressed many fundamental limitations [35]. These limitations can be a rich area for future research. The identified top seven limitations of LSS in the manufacturing sector are:

1. The absence of clear guidelines for LSS in early stages of implementation.

2. Lack of LSS curricula.

3. Lack of understanding of the usage of LSS tools and techniques.

4. Lack of a roadmap to be followed—which strategy first?

5. The limited number of practical applications of LSS integrated framework.

6. No globally accepted standards for certification.

7. Lack of expertise.

Thus, LSS practitioners need a clear guide for the direction of the early stages: which strategy should come first, Lean, Six Sigma or LSS, and what tools in the toolbox should be used first.

2.14 Lean and six sigma belts

A Lean and Six Sigma practitioner's "belt" refers to their level of experience. They may be a white, yellow, green, black, or master black belt. These roughly correspond to their hierarchy in martial arts.

Lean and six sigma master black belt—A highly experienced black belt.

Lean and six sigma black belt—Has expert knowledge of the DMAIC methodology, Lean methods and team leadership.

Lean and six sigma *green belt*—Has strong knowledge of the DMAIC methodology and Lean methods, but does not have experience with advanced statistical tools.

Lean and six sigma *yellow belt*—Has completed training in the fundamental concepts and tools of Lean and Six Sigma.

Lean and six sigma white belt—Has completed a small amount of Lean and Six Sigma awareness training.

2.15 Emerging trends in lean six sigma and agenda for future work

This study is the first comprehensive review of existing reliable literatures on different aspects of lean six sigma and the issues emerging in this field published during the period 1990 to 2019 and extract theoretical elements to develop the concept of LSS. The future of lean six sigma depends on the development needs of organization involved. These needs and opportunities are creating emerging trends in LSS which includes:

- The Big Data trend in lean six sigma
- Green lean six sigma
- Global Warming, Pollution and Lean's impact
- Lean and Six Sigma with environmental sustainability
- Lean's Impact on Resources
- Energy Conservation and management by LSS
- Factors affecting green lean six sigma
- Integration of LSS into educational systems.
- Assessment of LSS Readiness using fuzzy logic
- Green supply chain management

To encourage research in the field of lean six sigma and manufacturing, here we are highlighting gaps in the existing literature as a basis for developing a research agenda.

- Research gap 1 (performance measurement system for a particular organizations and processes);

- Research gap 2 (application of LSS in developing SMEs);
- Research gap 3 (integrated universal methods of manufacturing, frameworks, and models)

2.16 Successful LSS examples/stories in the manufacturing industry

As LSS was implemented world over for improving performances of various processes, developing countries have also started implementing LSS and got significant results in various sectors [83]. Lean Six Sigma (LSS) methodology was recently applied to an Auto ancillary conglomerate in India for achieving operational excellence. The root causes for the problem were identified and validated through data based analysis from LSS tool box. The application of LSS methodology resulted in reduction of drilling defects while machining injector bodies and reduced the Defects Per Million Opportunities from 38,000 to 5600. The application of this methodology had a significant financial impact (saving of about INR 1.4 million per annum) on the bottom-line of the company [83].

All type of manufacturing industry can increase profits, reduce costs and improve collaboration using LSS. For reference, below is Lean Six Sigma success examples in the Manufacturing industry organized systematically (**Table 4**).

General Electric	**Dell India Pvt. Ltd.**	**NALCO**
Xerox	Colgate Palmolive	Steel Authority of India
Ford	Al fanar	HP
Toyota	Alessa	Seimens
Durgapur Steel	Zuari Agrochemicals	3 M (American MNC)
BEML (Bharat Earth Movers)	Brother Gas	Acme Industries
ADCO (Abu Dhabi oil Company)	Gulf Gas	AEDC
AMRDEC	Wabash National Corp.	Gooch & Housego
Axalta Coating Systems	Fortress Paper	Ingersoll Rand
Barcoding Inc.	General Cable	Jabil Shanghai
Beverage Producers	GKN Sinter Metals	John Sisk & Son
Bosch	Milling Products	KushCo Holdings, Inc.
Celestica	Molded Devices, Inc.	Foster Threaded Products
Cummins	Real Alloy	Seegrid
Luvata	Reliable Plant	Spanbild
MC Assembly	Santana Textiles	The Jubach Company
Magline	Think Lightweight	The National Productivity Centre of Nigeria
Masonite	Topper Industrial	UTC Aerostructures
Metform Engineers	Universal Machining Industries Inc.	Vermeer Corp.

Source: Prepared by author (adopted from [84]).

Table 4.
Lean six sigma success examples in the manufacturing industry.

2.17 Conclusions and suggestions

Lean Six Sigma is a combination of two powerful process improvement methods: Lean and Six Sigma. It decreases organization's costs by removing "Waste" from a process and solving the problems caused by a process. Lean Six Sigma (LSS) is an emerging extremely powerful technology which is used to identifying and eliminating waste, improving the performance, efficiency and customer satisfaction to sustain in competitive manufacturing and nonmanufacturing environment. The focus of this chapter was to explore the each aspect of LSS in manufacturing. This systematic comprehensive review aims to synthesize, organize and structure the stock of knowledge relating to Lean Six Sigma and manufacturing. The identified lean six sigma tools and techniques, methodologies, frameworks, success and failure factors and strategies can be effectively used as a roadmap in manufacturing sector. This is also identified that the LSS has been implemented worldwide and in all type of manufacturing organizations for achieving the excellence. They have been successfully achieved their LSS objectives. But there are various challenges and barriers have been identified in the deployment of LSS. Assessments of lean six sigma readiness and implementation steps are most important that every practitioner must be aware. Basics of lean six sigma are discussed to get the root causes by in-depth understanding of the fundamentals of Six Sigma.

To bring lean in the organizations, every manager must be master and implement the eight basics of Lean Six Sigma for manufacturing. They should achieve their goal of satisfying/delighting customers by delivering higher quality service in less time by improving related business processes, eliminating defects and focusing on how the work flowed through the process.

This can be achieved only if the creativity of the people is used in team work on the processes with data and with an understanding of customers and processes. Therefore, the team members should work together to create real solutions for the organization. They should be from the different process areas, and their decisions should be based on data and facts.

Furthermore, for future direction, research and practitioners can be more focused on prioritization of significant barriers as identified in chapter and to tackle them during LSS implementation in manufacturing so that continuous improvement can be easily achieved [1].

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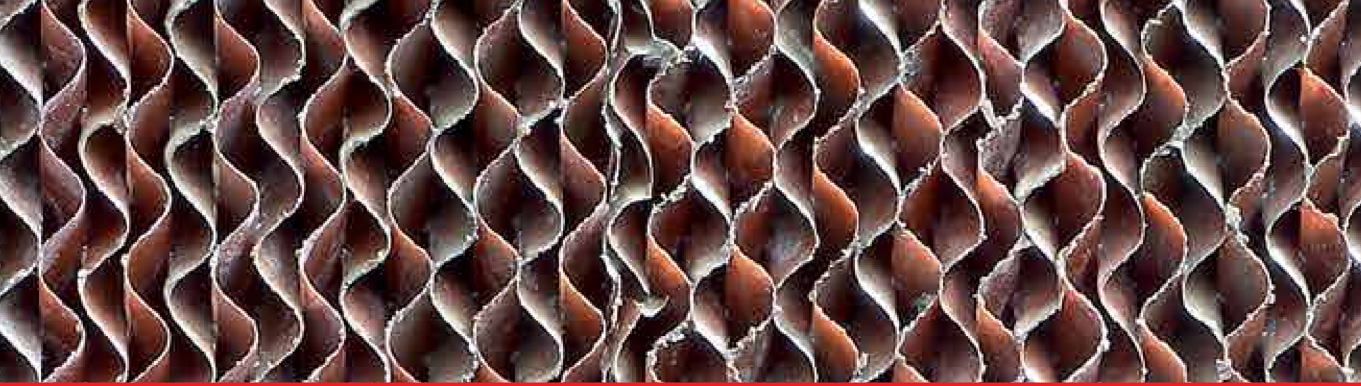

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Lean Manufacturing, also called lean production, was originally created in Toyota after the Second World War, in the reconstruction period. It is based on the idea of eliminating any waste in the industry, i.e. any activity or task that does not add value and requires resources. It is considered in every level of the industry, e.g. design, manufacturing, distribution, and customer service. The main wastes are: over-production against plan; waiting time of operators and machines; unnecessary transportation; waste in the process itself; excess stock of material and components; non value-adding motion; defects in quality. The diversity of these issues will be covered from algorithms, mathematical models, and software engineering by design methodologies and technical or practical solutions. This book intends to provide the reader with a comprehensive overview of the current state, cases studies, hardware and software solutions, analytics, and data science in dependability engineering.

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