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Six sigma versus lean manufacturing – An overview

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ABSTRACT

This study investigates recent research outputs in six sigma and lean production as management techniques in manufacturing systems. To achieve this, this work consists of a detailed explanation of six sigma and lean production methodologies, where they are used in manufacturing, how they work, their benefits and the advancements that have been made thus far. In addition, the different types of lean six sigma were explained with brief examples to help one have a better and deep understanding of the concept.

Selection and peer-review under responsibility of the scientific committee of the 10th International Conference of Materials Processing and Characterization.

1. Introduction

In industries, the production rate is a vital key as it determines how long the industry will run and how fast it will grow. It is for this reason that company owners always look for better ways to produce their goods, minimize scrap and hence make the company more productive. Two typical methods that can make a company more productive are the six-sigma method and lean manufacturing method. These methods, therefore, aim at helping the company processes focus mainly on the technique which improves the productivity of a company by eliminating the processes which usually take time but yield very little productivity [1]. The combination of these methods produces the best and most effective tools a company can possess to increase its overall productivity. The six-sigma method includes techniques and tools which help in using statistics to improve processes [2]. While the lean manufacturing method is a method that eliminates waste in manufacturing systems to improve productivity [1]. A brief explanation of these methods has been developed in the subsequent sections.

1.1. Six sigma

Six sigma is a profit-maximizing technique achieved by meeting consumer satisfaction. It was first successfully implemented by the cellular company, 'Motorola' in 1986 and since then, other companies have also adopted it [3]. This technique follows a statistical approach and it is attained by minimizing variations and providing quality services or defect-free products. By reducing deficiencies, fewer materials are wasted and hence an optimal amount of raw materials is completely utilized. As six Sigma seeks to enhance the organization's capacities and satisfy the ever-changing consumer demands, it uses data in order to provide better solutions and statistically speaking, reaching the sixth sigma means that the achieved products or outputs have almost no defects. These are the kind of results that any organization would like to achieve [4]

1.2. Six sigma methodology

There are different approaches to six-sigma methodologies as indicated in Fig. 1 [5]. The six-sigma methodology does not require one to have a deep understanding of statistics. As indicated earlier on, it is explained by means of a statistical measure, determining the efficiency or the quality of a product or service. Six-sigma is normally denoted by "6σ", where "σ" is a Greek letter indicating sigma. This letter denotes the standard deviation. In statistics, the standard deviation gives an indication of how far the data parameters are away from the mean. A low standard deviation implies that the data values are closer to the mean and a higher standard deviation means that the data values tend to be away from the mean. This gives an idea of the variation that exists among the data parameters.

Another important statistical tool to add insight into the understanding of the six sigma is the bell-shaped distribution. It describes the distribution of a set of data. The bell-shaped curve is centralized around the mean, i.e. the mean is always at the centre. The peak represents the mode and a data set with multiple

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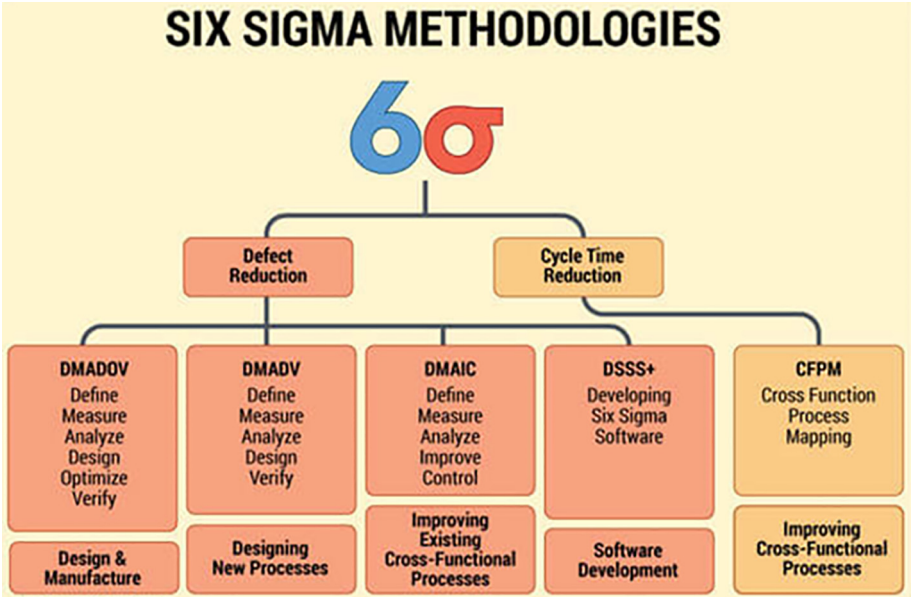

Fig. 1. Six Sigma Methodologies.

modes would produce a bell-shaped curve with multiple peaks that are as many as the number of modes. Approximately 68.2% of the data parameters lie within one standard deviation from the mean, about 95.4% data sets occurring within two standard deviations and about 99.7% lying within three standard deviations [5]. The percentage distribution of the data parameters on the bell-shaped curve is represented in Fig. 2.

This is how the six-sigma methodology operates. We will look at a pizza delivery business as an example. Suppose that pizzas are to be delivered to local offices. The objective is to deliver freshly prepared pizzas before lunchtime, that is, between 11:45p.m. and 12:15p.m. This enables clients to pick up their orders just before lunchtime. Suppose also that any client to receive his delivery before 11:45p.m. or after 12:15p.m. would receive 30% discount. Note that, a client receiving his pizza between 11:45p.m. and 12:15p.m. is the "requirement" and a customer receiving his pizza outside the stipulated time range is a "defect". Because the business is keen to meet customer satisfaction and avoid having to sell pizzas at discounted prices, it would ensure that it delivers pizzas within the stipulated time range.

This is how the six-sigma method applies to this scenario. By referring to Fig. 1, if only 68.2% of the pizzas are delivered on time, this would put the process at a two-sigma range. Again, if 95.4% pizzas are delivered on time, the process would be at a three-sigma range. And lastly, if 99.7% pizzas are delivered on time, the business would be operating at a six-sigma range, and that would be nearly perfect. If we look at this scenario on a larger scale, where a million are pizzas produced, the business would end up with three or four pizzas delivered outside the time range if it was operating on a 6-sigma level. The narrowing down of the delivery time from 30 min to 10 min would worsen the sigma levels. With more pizza delivery variation, where many pizzas are delivered outside the time range, the bell-shaped curve will produce larger dark shaded areas, as can be seen in Fig. 3a. On the other hand, with less pizza delivery variation, where fewer pizzas are delivered outside the time range, the bell-shaped curve will produce smaller dark shaded areas, as can be seen in Fig. 3b.

Just like in the pizza example, the six sigma techniques follow the same methodology for any other scenario. The first requirement in getting an understanding of the significance of the sigma levels is to know for certain what the customer wants. An arbitrary question to ask would be that "is it possible to get a 100% efficiency in any production under the six-sigma approach?" The answer to that question would be "it is not possible". Under the six-sigma technique, the concept of zero defects is not feasible. The six-sigma approach considers that there are always going to be possible defects in any production.

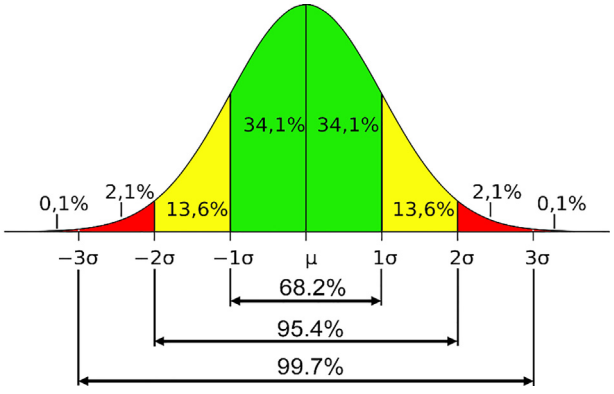

Fig. 2. The percentage distribution of the data parameters on the bell-shaped curve [5].

1.3. The role of six sigma in manufacturing

The main aim of the six-sigma approach is to achieve customer satisfaction by producing products of less variation. This is very crucial in the manufacturing process because the product that does not meet customers' requirements are eliminated and taken back for re-manufacturing, only those that are defective free can be sold. A study has revealed that when customers experience the negative results of faulty products or poor service, they do not just keep it to themselves, they are more likely to influence other customers to boycott that product or service [5].

1.4. Design for six sigma

There are many institutions that believe that the design for six sigma is a process used for the design of product meanwhile it is

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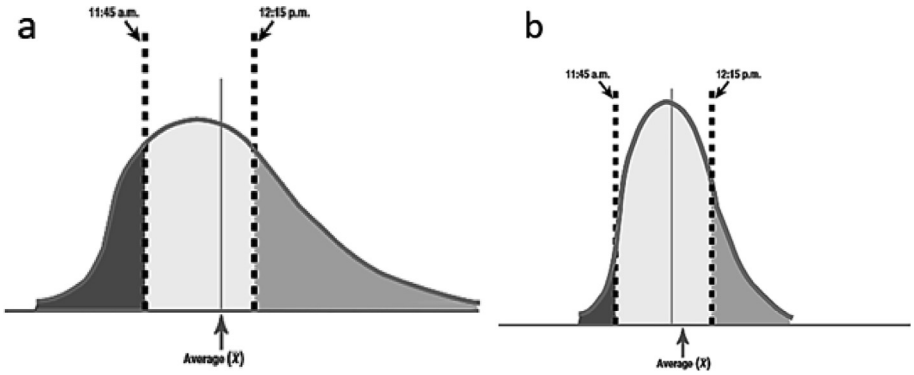

Fig. 3. Bell-shaped distribution of (a) a high variation pizza delivery (b) a low variation pizza delivery.

not. Design for six sigma is a method of enhancing already existing products and services in a way that allows for better control of resources [6]. The method derives a large amount of its process from the successful tools and techniques used in the six sigma approach [7]. The design for six sigma method has been used in several industries such as the marketing, process industries as well as electronics. This method focuses on using statistical methods as well as more traditional empirical research [8].The design for the six sigma method is also used by manufacturing companies for them to design products, processes, and services which are safer and more reliable.

Similar to the six-sigma approach, the design for the six-sigma method is focused on producing the highest quality process and products with the least number of defects. The method derives a large amount of its process from the successful tools and techniques used in the six sigma approach [7]. Design for six sigma (DFSS) allows for the optimization of the cost, time to market and quality of new product development processes (NPD). In general, the NPD process has several high-level phases of development [6].

1.5. Steps in designing for six sigma

The fundamental procedures to be followed in DFSS include, defining and researching the needs of the customer, analysing the needs of the customer and classifying them accordingly, changing the request from the customer into engineering data, develop a design that could solve the problem, validate the implementation of processes that are required in order to achieve the goals set up. The team in charge of DFSS must be cross-functional in order to make sure that all the aspects that need to be considered for the product are taken into account, from the research on the target market up until the design phase of the product, manufacturing of the product and the launch of the product [9]. DFSS that is used on a micro-level has 4 main steps which are known as IDOV, identify, design, optimize and validate [10].

The Identification stage involves making sure that there is a clear understanding of the customer requirements for design activities on a micro-level. The definition of customers, in this case, can include external, internal customers as well as any other stakeholders. The financial goals of the business are also considered in this stage of IDOV. The requirements are collectively dubbed the term CTXs [6]. The CTXs have then adapted into specification, performance criteria or any other unbiased measures. In the second step of IDOV that is design, development, testing and the validation of the design concepts occurs. Concept selection methods, as well as failure effects and failure modes analysis matrices, are then used to organize data that pertains to the concept selection process. Once the measurement system has been developed for performance of the designs, then the system will be used to identify the risk involved with regards to the CTXs, a decision can then be made on whether to proceed or to relook the design concepts [10].

At the Optimization stage, the designers are required to ensure the concepts have been optimized with regards to the business and customer specifications. The most important part of this step is to see how well the systems meet the requirements of the customer. If it is possible to demonstrate that the design satisfies the requirements of the customer, the next step is then to check if the design has a high enough quality level for a given price point. Validation, the last step in the IDOV, focusses on the testing of the optimized design to ascertain its performance. This performance test involves checking if the customer requirements, reliability of the product, process or service. Once the design has been objectively validated then the designer should establish control plans as well as action plans. The final objective of the designer is to make an overall assessment of the risks and how the CTXs will be impacted [6].

1.6. The power of DFSS

Most of the tools used in DFSS are not new tools they have been employed for several numbers of years in other strategies of manufacturing. The main functionality of DFSS is in finding the best way to organize the tools in a coherent way that is in line with the NPD process, not necessarily in the tools themselves [6]. One of the main problems that NPD improvement was faced with in the past was that people focused on the use of individual tools and not the use of these tools in tandem in order to meet the overall objective of the NPD process. The use of DFSS in manufacturing means that the production of a firm can be increased while keeping the total risk low and ensuring that there is as little waste as possible. Since DFSS also considers the cost involved in manufacturing, it is clear that it also keeps the cost of production relatively low [11].

2. Lean manufacturing system

Lean manufacturing can best be defined as waste disposal in a production system, waste is anything that does not add value to the end-product. Lean manufacturing aims to create a product that is precisely what the client wants while minimizing all non-value-added production operations [12]. The value is described merely as what the client is prepared to pay for. Quality assurance is the best illustration of non-value-added activity since inspections of quality do not add any value to a product rather, they simply identify flaws before reaching the consumer [12].

Toyota has illustrated non-value adding waste types in business or production lines [13]. They are as follows:

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- Waiting – People waiting for equipment, tools, servicing, raw materials, etc. and equipment waiting for maintenance, individuals, equipment, tools, etc.
- Overproduction – Producing more than inner or outer clients require and producing more quickly than the inner or outer client required,
- Inappropriate processing – Unnecessary or ineffective processing (non-value added),
- Transport – Move products or individuals over large distances,
- Excess Motions – Any movement of persons or equipment that does not contribute value to the service or product,
- Work-In-Process – Inventory process creates additional handling, additional space, and additional price;
- Defective products – Scrap, returns from clients, rework, the dissatisfaction of clients.
- Manufacturing companies use a range of Lean Manufacturing instruments and techniques to accomplish their objectives. Which include: 5S, SMED (Single Minute Die Exchange), Poka-Yoke, TPM (Total Productive Maintenance), etc [14].

2.1. 5S method

The 5S technique is another technique used to improve manufacturing procedures. 5S is the foundation for Lean Manufacturing to be implemented. The name of the technique is obtained from the Japanese words ' first letters: Seiri (1st phase), Seiton (2nd phase), Seiso (3rd phase), Seiketsu (4th phase), Shitsuke (5th phase) [14].

2.2. SMED (Single Minute Die Exchange)

The technique to shorten the changeover time to one minute is SMED. Developer techniques Shingeo Singo has recognized four phases of process enhancement equipment changeover: analysis of the present state workstation, separation activities, change inner and external activities, the transformation of inner activities into external activities [14].

2.3. VSM – value stream mapping

An instrument commonly used in businesses. VSM is a visual way information flow and material is presented in the manufacturing system. The map indicates all the duties performed in the process, from the acquisition of raw materials to the end of the shipment to the client of finished products [14].

2.4. TPM – total productive maintenance

TPM is an instrument used to remove the company's technology machine-related waste. TPM is a leadership approach that integrates all staff in order to preserve the continuity of production. The primary goal of this technique is to improve machinery and equipment's effectiveness and productivity by: A marked reduction in the amount of mistakes, a reduction in time for retrofitting and adjusting machines and brief downtimes and idleness (often triggered by missing employees or waiting for instruments, materials, data, etc.), a reduction in the quality of the item, a reduction in the moment spent on starting manufacturing [14]. The summary of lean manufacturing method used to solve different types of wastes is depicted in Table 1.

Table 1
Summary of the lean manufacturing method used to solve different types of wastes [14].

Waste	Method of lean manufacturing
Over-production	Kanban, Heijunka, VSM
Excessive stocks	Kanban, Heijunka, VSM
Mistakes and defects in the quality of products	Poka-Yoke, Jidoka, Kamishibai
Unnecessary movements	5S, Standardized work
Waiting	TPM, SMED
Excessive processing	Standardized work, Kanban
Untapped potential employee	Kaizen
Unnecessary transport	Kanban

3. Lean six sigma

Lean Six Sigma is a systematic approach that combines Lean and Six Sigma methodologies as indicated in Fig. 4, this means the principles, philosophies, and tools of both methodologies are also combined into one approach. Lean production focuses on eliminating unneeded steps and thus focusing on the steps that add value to the production of which in turn optimizes the process and reduces time taken for the whole process. Six Sigma uses statistical tools to reduce process variety which in turn lowers the production cost without affecting quality [15]. Lean and Six Sigma methodologies enhance and strengthen each other. Therefore, it is best to use both approaches at once.

Lean Six Sigma is a technique that improves productivity and increases value for shareholders by attaining the highest level of improvements in client satisfaction, price, procedure speed, quality and invested capital [2]. Lean Six Sigma begins with clients, its objective is to remove anything that does not satisfy client requirements. It's also essential to check the consistency of your goods, services, and procedures in Lean Six Sigma. How likely is it that the client gets something that they are pleased with consistently? They may give their business and services provided if you produce what they want one day, but not the next day [16].

3.1. Benefits of using Lean Six Sigma technique

By streamlining procedures, this technique improves the production thus improving the income of the company. Lean Six Sigma procedures are more efficient thus allowing for faster production of the product with fewer resources used. Lean Six Sigma allows you to fix procedures that cost valuable resources to your company and allows you to develop effective procedures for your company to produce more goods or services with more satisfied clients than they have ever been. Lean Six Sigma provides your staff with a sense of ownership and accountability. This improves their efficiency in providing outcomes for any project they are engaged in improving [17].

3.2. How Lean Six Sigma work

It allows the company to determine the facts of an ongoing problem and come up with a fact-based solution instead of a solution based on assumptions. This generates enhanced results [18]. An illustration of how lean six sigma works can be found in Fig. 5 while the strengths of lean and six sigma are presented in Table 2 and the weakness of lean and six sigma are also presented summarily in Table 3.

4. Development of lean production and six sigma used in manufacturing

The method of reducing and eliminating waste in a production line is highly recommended that is why the Lean and six sigma principles are being utilized to meet targets, optimize while ensuring clients and customer satisfaction about the produce. Both

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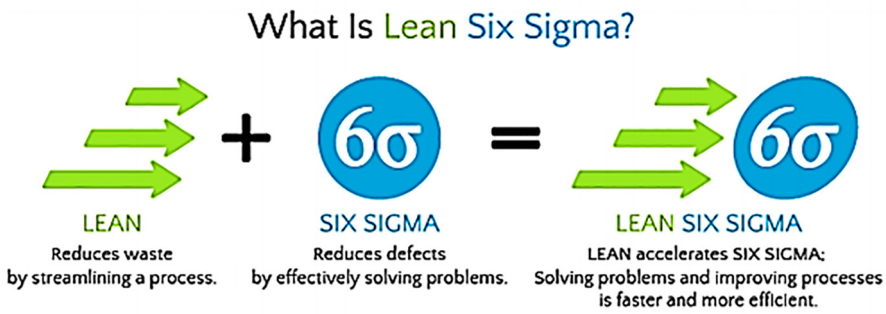

Fig. 4. Lean six sigma systematic approach.

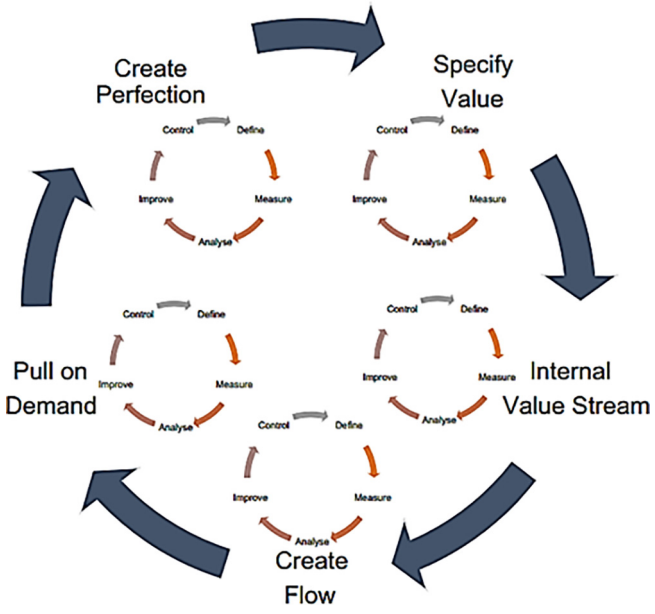

Fig. 5. Lean six sigma procedure [17].

Table 2
Strengths of lean and six sigma [19].

Lean six sigma	Six sigma
Eliminate waste	No defects
Decrease lead time	Money-saving
Reduction of cycle time and work in progress	Uniform process outfit
Short delivery time	Customer satisfaction
Space-saving	Detailed statistical analysis to improve
Needs less equipment	Reduce variation and improve processes
Improves flow in procedures.	Structured problem-solving methodology

methods are being practiced simultaneously in order to come up with new ideas to implement since the variation occurs more frequently [20]. The six-sigma technique is initiated and proven to be capable of reducing the cost manufacturing, minimizing the number of defects, improving cycle life, making customers satisfied and making the business profitable. To achieve lean production, ten steps which subsequently follow each other are implemented and are taken from hundreds of successful functional manufacturing system. The steps are Re-engineering the Manufacturing System, Setup reduction and elimination, Integrate Quality Control into Manufacturing, Integrate Preventive Maintenance into Manufacturing, Level, Balance, Sequence and Synchronize, Integrate Production Control into Manufacturing, Reduce Work-In-Process (WIP), integrate Suppliers, Automation and Computer-Integrated Manufacturing [21].

Table 3
Weakness of lean and six sigma [19].

Lean six sigma	Six sigma
Statistical tools not used.	The process is not improved thought the streamline.
Process incapacity and instability.	Lack of specific speed instruments.
There is no systematic approach to issue resolution.	Six Sigma does not challenge current operating techniques and if it adds value so far it does not change.
No focus on decreasing variability and keeping process output consistent.	It does not consider the capital invested in the stock.

4.1. Types of waste in the manufacturing process

For a company to have effective profitability the company needs to identify wastage that does not add any value to the product or service being rendered during production to meet the target that the customer will be willing to pay for. Seven waste types that had been identified by Toyota are; defects, overproduction of items, unnecessary movements made by employees when they are looking for or reaching for parts and tools, excess inventory, over-processing or incorrect processing, unnecessary transport or conveying and waiting for either stock being delayed [21].

4.2. Steps used to eliminate waste in the manufacturing process

Process improvement is one of the most used ideas implemented to improve a company to operate smoothly. The workflow of the company must be examined from station to station in order to see how it affects the manufacturing process. For a company or an individual to begin the journey to lean, they should create a continuous flow chart of all the applications in the manufacturing core and service processes [22]. The Flow process is mainly used to minimize unnecessary procedures from raw material to finished products by doing so, this leads to lowering cost, producing the best quality and making short delivery time for costumers to have easy access to the items.

A company in the production process must take note of the value stream of the manufacturing process. The value stream is known to be the process of going through the entire manufacturing process and spotting things that add value to the finished product and things that do not add any value. Once all the stages have been identified, all the waste can be minimized by concentrating on

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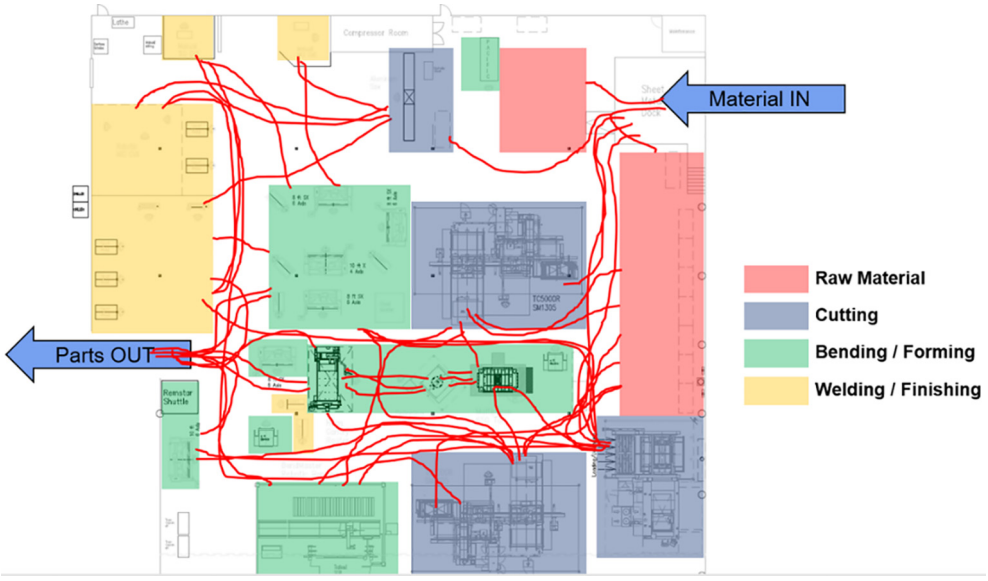

Fig. 6. An illustration of spaghetti diagram in fabricating and metalworking Industry.

them only to utilize them. A recommended way to structure the value stream is by mapping the process throughout the manufacturing process and keeping track [22].

A spaghetti diagram really helps to give out the true path of how the material in the manufacturing industry flows throughout the process of productions as illustrated in Fig. 6. For a better understanding, the tool of mapping the process on paper helps to have a better visual understanding as how the material flows through the production line and how much the material has to travel in order to reach a final destination and it also wastes time in the process [23].

5. Conclusions

In modern manufacturing, production companies are more concerned about customer satisfaction, while ensuring great profits which is most certainly a good business model. There are two main techniques that have been discussed which aim at achieving a winning on the producer as well as the customer perspective, which are 'the six sigma' and the 'Lean production' methods. The primary idea is to have the best possible manner for the organization of tools in a coherent way to have company success and low risk with little material waste hence ensuring low production costs possible.

Lean and six sigma production combined, produces best results a company can ever think of. The two combined eliminate the less important steps in manufacturing, and mainly concentrates on steps that would add value to the respective product or service rendered. While the six sigma aims to lower the process variety without affecting the quality of the outcome. The production becomes strictly what the client/ customer requires and is prepared to pay for, excluding all process activities that do not necessarily add value to a product (Quality Assurance and accidents during operations excluded in the pricing). If the customers are certainly satisfied with the product, then the company runs a better potential of strengthening its reputation in the market and running fewer risks to be boycotted. There are certainly no doubts about increased company profits while guarding against operational speed and quality of the products.

With this understanding, it helps individuals and even companies to start developing towards a more efficient flow of material and minimizing unnecessary travel distance costs. The information that was gathered can be used to make and manage decisions and form future mapping that will assist in implementing and identifying solutions on solving the effectiveness of the production line.

Conflict of interest

The authors have declared no conflict of interest.

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