UNIVERSITÀ DEGLI STUDI DI PADOVA

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Lean assessment tools: a literature review

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Abstract

Lean assessment is an important approach for understanding the lean performance of an organization. Indeed, any improvement and implementation of lean should be based on an assessment of the current state and measurement of the distance to the desired level. In this thesis, the scientific literature about lean assessment is reviewed and a comprehensive framework of lean assessment qualitative, quantitative, and hybrid tools proposed to date is presented. A content analysis of significant literature is conducted to summarize the main characteristics and structure of lean assessment tools, and finally a new matrix of classification for lean assessment tools which are developed based on the adoption of lean practices (LP) is proposed.

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Introduction

The Lean thinking was originated from Toyota Motor Corporation, and many innovative methodologies and tools also constructed the basis for the creation of Toyota Production System (TPS) which is developed in Toyota under the leadership of Taiichi Ohno (Hines. P et al.,2004). As defined by Stone (Kyle B. Stone, 2012), after the Lean concepts were disseminated in the period 1991-1996, Lean thinking as a philosophy of management started to get a lot of interests from scholars as well as practitioners. At the same time the benefits of applying the Lean thinking principles in the organisations were well noted and some important industry such as automotive started to adopt the Lean thinking principles internally and tried to get the new benefits discovered through the new approach. However, in 2006 Bhasin and Burcher (Bhasin. S et al., 2006) stated that the success rate of implementing lean initiatives in the companies was extremely low. This observation reminded scholars and practitioners that it was not enough to just implement tools and techniques in companies for becoming leaner, it was also very important to understand the critical factors which contributed to lean implementation success (Gopalakrishnan Narayanamurthy Anand Gurumurthy, 2016).

Lean assessment gives complete analysis of current level of leanness of the organization with process accuracy, stability and improvement and the degree of employee commitment towards these activities (Baviskar. P, 2015). Before deciding to conduct a lean assessment, practitioners need to have a full understanding of the characteristics and structure of the lean assessment tool to accurately decide which type of lean assessment tool should be used in the specific context.

In this thesis a total of 59 papers which proposed lean assessment tools are reviewed and a comprehensive framework of lean assessment qualitative, quantitative, and hybrid tools is presented. The main characteristics of lean assessment tools are reviewed through the general descriptive analysis and categorical analysis. Finally, a new matrix of classification for lean assessment tools which are developed based on the adoption of lean practices (LP) is proposed. The remaining chapter of this thesis is structed as follows: Chapter 1 describes the general review and fundamental concepts of lean production. Chapter 2 details the methodology of the systematic literature review and shows the complete framework of 59 lean assessment tools collected through the literature review. Chapter 3 explains the importance of lean assessment, planning of assessment, and the definition of qualitative/quantitative/hybrid tools. Chapter 4 illustrates the results of descriptive and categorical analysis of collected tools and presents the new classification matrix for lean assessment tools which are developed based on adoption of lean practices (LP).

Chapter 1

1. A general review of Lean production

1.1. The mass production

In craft production, one-of-a-kind parts are individually made to fit together for each product. Mass production, however, could not exist without the invention of interchangeable parts. The manufacture of interchangeable parts was an idea that originated in the early 1700s, in the making of clock gears. By the end of that century, it had become a military necessity for the manufacture and maintenance of firearms. Soldiers needed to be able to replace parts on their weapons to stay in the fight. The first demonstration of the interchangeability ideal came at the Harpers Ferry Arsenal in 1827 when muskets (long guns) were assembled from pieces selected at random from boxes of parts. It took almost 100 years for that idea to propagate to the manufacturing of consumer products and to make the mass production paradigm possible. Under the craft production paradigm, flawed or irregular parts were discarded (or improved) by craftsmen as they assembled one-of-a-kind products on an assembly stage. Only when large quantities of identical, truly interchangeable parts were available, could Henry Ford's mass production scheme be successful. As product progressed from station to station, assemblers had to have parts that would fit and could be added without alteration. Interchangeable parts made it possible for the system to move and maintain the desired output. The availability of interchangeable parts is a key enabler of mass production. The opening of the moving automobile assembly line in Dearborn by the Ford Motor Co. in 1913 is regarded as the starting point of the mass production era. The car that Ford produced on this line was the famous Ford Model T.

The contribution the moving assembly line made can be seen in the data below. From 1911 to 1914 the number of cars produced increased from 40,000 to 260,000 units annually. And, in the next 10 years Ford's annual production increased eightfold, to 2 million units. But it is also worth noting that an earlier sevenfold increase, from 1908 to 1911, resulted from simply organizing the assembly work sequentially—the assembled cars were stationary, and the workers moved from one car to the next, with each group doing just a limited set of operations on each car.

Ford Model T

1908 -	**6000**
1911 -	**40,000**
Moving Assembly Line	
1914 -	**260,000**
1916 -	**580,000**
1924 -	**2,000,000**

Fig.1.1 Quantity of Model T produced (Koren, Y. ,2010)

Ford's assembly scheme essentially converted a parallel process, where small teams of workers performed multiple tasks on a single unit, into a sequential (serial) process, where workers perform only a small set of tasks, and then transfer the working-progress to the next worker team who performed another set (approximately the same amount of work effort in each step). Henry Ford did this conversion from parallel to sequential assembly before introducing the moving assembly line and cut the time that a worker spent on a car, from 9 hours to 2.3 minutes per car (i.e., the worker did the same task, taking about 2.3 minutes, and therefore became more efficient). With the moving assembly line, which brought the car to a stationary worker, the time per car was cut again, from 2.3 to 1.2 minutes. This was a direct saving of almost another 50% on labour, achieved just by implementing the moving assembly line.

The cars that Ford produced were identical. His statement “You can have any colour you want, as long as it’s black” symbolizes the limited variety of cars offered. However, at that time, consumers were not as picky as today, needing a car just for transportation (not as a status symbol), and they were happy just to be able to buy a car. In 1909, wages were low-just $2 per day, and this money was needed for food, clothes, and lodging. Only a small percentage of the U.S. population could afford a car (like the situation in China in 2000).

The introduction of the sequential process, and later the moving assembly line, was complementary to Ford’s mass production business strategy: Increased production at low cost enabled a consequent reduction in the product price; by lowering the product price, more people could afford to buy cars, which, in turn, expanded the market for Ford’s cars.

Henry Ford expanded the market by reducing the price of the car from $825 to $440. This allowed more people to afford to buy one. Instead of selling some 12,000 cars per year at $825 per car (in 1909)—revenues of $10 million—he reduced the selling price by about 50% and sold 260,000 vehicles in 1914—a revenue of $115 million, which is 11 times larger. This huge price decrease was enabled by increased production capacity.

The capacity (i.e., maximum possible production volume) of the moving assembly line was enormous compared with that of the parallel assembly method. The cost benefits were also huge even though the innovation required new and expensive hardware because those costs were distributed over the whole production run. The main principle of the mass production paradigm is, therefore, as follows: Producing a limited variety of standardized products at low cost as a strategy that increases customer demand and allows market expansion.

But the reduction in the car price alone was not enough to create the big market expansion that Ford envisioned. He was also concerned about the small number of people who were currently in the car buying market. Earning a common salary of just $2 per day, Ford's workers were not able to buy new cars. Paying his workers more than the prevailing wage, about $5 a day, was the second part of Ford's strategy. He needed to expand the market for all the cars he could make, and so he increased his customers' purchasing power. By increasing his workers' salary to more than twice what they were accustomed to earning, they saw that they could own one of the cars they were building. Because of equity across industries, an increase in salaries at Ford eventually caused an overall increase in all U.S. salaries, and Ford's car market doubled again (from 260,000 units annually to 580,000 units) in just more 2 years. It is ironic that Henry Ford, an icon of American capitalism, contributed to his workers' wealth more than anybody else ever did.

The mass production era continued from 1913 until the mid-1980s. Its peak in the USA was around 1955, the year in which product variety was the lowest and the volume per product was at its maximum (compared to the U.S. population at that time).

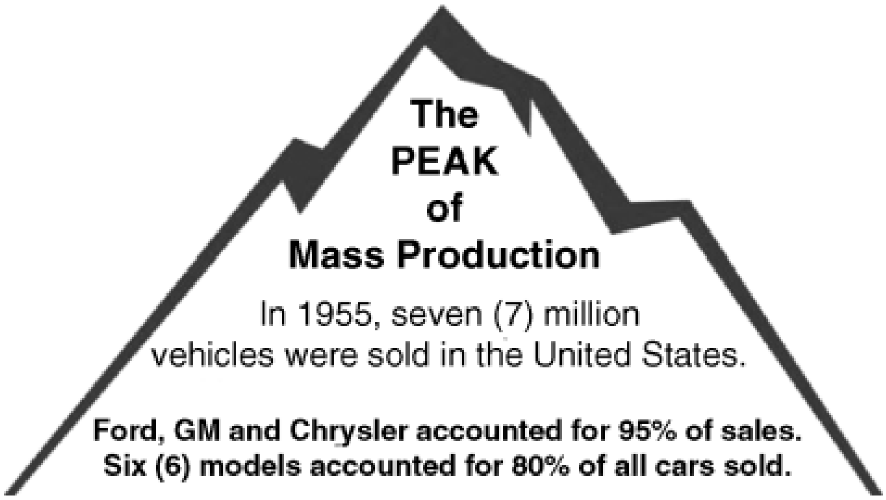

Fig.1.2 Historical trend of development of mass production (Koren, Y. ,2010)

The mass production business model may be summarized as follows: Production of standardized products in very high volume reduces production cost, which, in turn, allows price reduction to the benefit of the customers. Reduced product price increases demand and sales.

Production of standardized products in very high volume reduces production cost, which, in turn, allows price reduction to the benefit of the customers. Reduced product price increases demand and sales.

In the mass production paradigm both product and process changes come very slowly at a snail's pace. But mass production manufacturers do not care where the customers come from. They just assume they will always be there to buy their products. The product is designed with limited variety and the manufacturing system is designed to produce a limited product variety (see Figure 1.3).

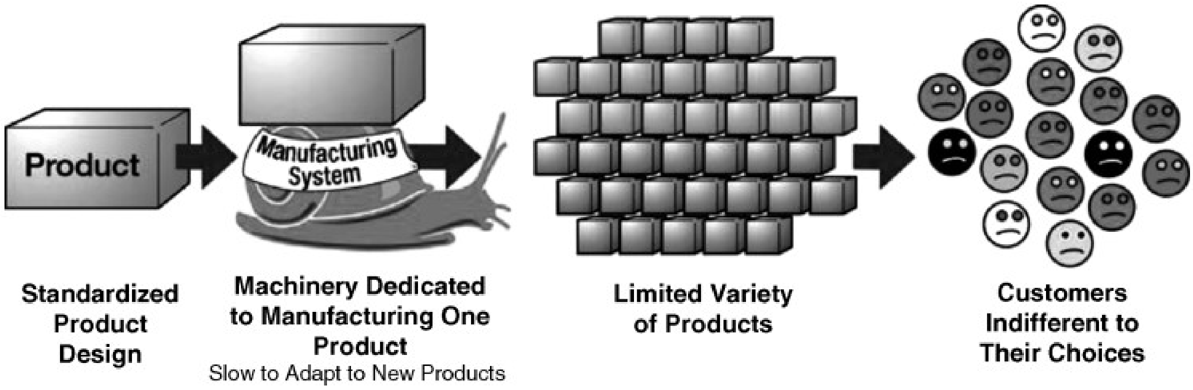

Fig.1.3 Limited products variety to customers (Koren, Y. ,2010)

To summarize, the goal of mass production is low-cost manufacturing. Three enablers contribute to the achievement of this goal:

(1) interchangeable parts

(2) the moving assembly lines

(3) dedicated machinery and manufacturing systems.

However, the mass production has the following disadvantages (www.lacconveyors.co.uk):

- Inflexible to consumer demand

As mass production focuses on the creation of one product in mass quantity, it is difficult to adjust to ever-changing customer demands if that product’s demand suddenly declines.

- Disengaged workforce

The monotony that is the nature of mass production work, in turn, could lead to disengaged and unmotivated staff, which if not addressed can lead to high staff turnover. If the staff are not rotated frequently and work on the same product each day, this could lead to inefficiency in certain aspects of the manufacturing process, such as quality control.

- Difficult to restructure production

Because mass production is a system of machines working together in unison, changing the aspect of the production line could have large financial and logistical consequences; especially in the height of the modern trend to create more eco-friendly processes.

By 1948, Toyota Motor Company engineers, Taiichi Ohno and and Sakichi Toyoda, were utilizing the assembly line but were eager to find and eliminate more waste (www.global.toyota/en).They realized inventory accounted for a lot of waste and there was no system in place to manage it. This observation led Ohno and Toyoda to design the Toyota Production System (TPS) or Just-in-Time production, eliminating waste by making only what is needed, when it is needed, and in the needed amount.

1.2. TPS -Toyota production system

"We strive to produce better products by making improvement every day''

This is the quote expressed by Kiichiro Toyoda who spearheaded the creation of the first Toyota automobile and the founding of Toyota Motor Corporation in 1937.

The designation "Toyota Production System" is used because the system was developed by a vice president of Toyota Motor Company, Mr Taiichi Ohno. Toyota implemented the Toyota production system under Mr. Ohno's guidance and direction over a period of 15 years. The system has now been in operation up to now and has been widely adopted by other Japanese manufacturers and extended also to the other continents manufacturers.

The Toyota production system pervades all aspects of the production and inventory flow process. It covers such areas as process design, job design, and job standardisation, economic lot sizes and accelerated setup times, just-in-time production, autonomation, Kanban, Judoka, Andon, and Yo-i-do.

After the second world War, Toyota and Ohno of Toyota Motor company inspected the car factory of Ford Motor Company. At that time, the factory produced 7000 cars a day, more than Toyota's annual output. However, Toyota did not want a simply copy from Ford's production mode. He believed that "there is still some possibility of improving the production system there". After returning to Japan, Toyota and Taiichi Ohno carried out a series of explorations and experiments. According to Japan's national conditions (social and cultural background, rigorous hierarchical relationship, teamwork spirit), they established a set of new production management system, and adopted Lean production mode to organize production and management, so that Toyota's quality, output and efficiency jumped to a new level and became the king of the world's automobiles.

Unlike the mass production, lean production is "simplified": compared with mass production, it requires only half of the labour intensity, half of the manufacturing space, half of the tool investment, half of the product development time, a large reduction in inventory, a large reduction in scraps and a large increase in variety. The biggest difference between the two concept is in their final goal: the mass production emphasizes "enough" good quality, so there are always defects; Lean production pursues perfection (continuous reduction of price, zero defects, zero inventory and unlimited varieties).

- Appearance of lean production

The lean production technique created by Toyota and Ohno can be illustrated by an example.: In the mass production mode, the replacement of stamping die for automobile cover parts was a big problem. Due to high precision requirements, mold replacement is expensive and time-consuming, requiring high skilled workers to complete. To solve this problem, the manufacturers used a set of presses to produce the same part, so they could go for months or even years without changing the die. For Toyota in the 1950s, this didn't work. They didn't have enough money to buy hundreds of presses to make car covers. They had to make all the stamping parts for their cars on a few lines. So, Ohno invented a new rapid change mold technology (SMED method –Single Minute of Dies), this technology makes the change of a pair of mold time reduced from 1 day to 3 minutes, also do not need special mold change workers. Then Ohno got a surprising discovery -- it was cheaper to produce in small batches than in large ones. There are two reasons for this fact. The first reason is that small batch production does not require the same amount of inventory (including equipment and personnel, of course) as mass production. The second reason is that only a small number of parts are produced before assembly, and errors found can be corrected immediately. However, in mass production, parts are always manufactured in large quantities in a lot of time in advance, and the errors of parts will only be found in the final assembly, resulting in many scraps or reworks. Based on the last reason, Ohno concluded that products should be kept in stock for less than two hours. And to achieve this goal, there must be working groups of highly skilled and highly responsible workers. But if workers can't find problems and fix them at any time, the operation of the whole factory can become a mess.

- Labour relations changed and working together

In the late 1940s, due to the overall economic situation, Toyota was facing great difficulties. The owner of the company proposed to fire a quarter of the workers but received strong opposition from the workers and labour union. finally, the company made a deal with the union: a quarter of the workers were fired, and Toyota, the company's boss, resigned as punishment for the company's failure. The rest of the workers were given a double guarantee of lifetime employment and a salary rise in line with their years in the company without the consideration of the job type. In other words, the worker becomes a member of the company and enjoys all the benefits of the company. For workers, forty years of service pays more than twenty. But if he were to move to another company, he would get much less than a 20-year worker (since other Japanese companies started this rule at the same time). In this case, workers associate their own interests with those of the company and feel a sense of ownership, forcing them to work hard for the company. They accept any work assigned by the company, solve problems in production at any time, and take the initiative to put forward reasonable suggestions. All of them actively safeguard the interests of the company. And companies see workers as their own capital, and more important capital than machinery. To make full use of this capital, the company continuously trains workers to improve their skills and make full use of them to obtain greater benefits from their employees.

- Correct problems when found

In the mass production enterprises, the workers on the assembly line only perform some simple actions repeatedly. The team leader does not participate the assembly work, but only ensures that the workers on the assembly line work according to the regulations. Others, such as maintenance workers, cleaners, and inspection workers, all just do their own duties. They have no right to deal with problems found on the spot and must be left to the rework factory at the end of the assembly line for correction. There is also a category of "versatile workers" who are used to replace workers who are temporarily absent from work. In a mass production plant, the assembly line should generally not stop to ensure the output, otherwise the output cannot be guaranteed, and the defective product is allowed to continue the assembly line until the assembly is completed for repair. According to Ohno, there are 2 kind of waste: first ,a waste of manpower, Ohno believes that assembly line workers can do most of the work of other professionals, or even better, because they know everything about the assembly line best, there are too much workers out of assembly line who do not add any value to the cars Second, allowing a faulty product to continue assembly in order to ensure that the assembly line does not stop will multiply the errors.

Ohno's approach was the opposite. First, he divided the workers into groups, and the leader not only coordinated the work of the whole group, but also dose the assembly work himself. His working group was responsible for a set of assembly processes and required everyone to work together to do their job well. Second, the cleaning of the work site, tool repair and quality inspection tasks are also given to the team. He also asked the group to meet regularly for improving the process. This type of group work is the origin of teamwork and QC group work, and it is one of the main working methods in the future manufacturing industry. Ohno told the workers that if they found a problem, as long as they could not solve it at that time, they should immediately stop the entire assembly line, and everyone (the whole group) would come and solve the problem together. This was a revolutionary measure compared with mass production where only senior managers in charge of the assembly line had the authority to stop the line. In addition, in mass production plants, there is a tendency to treat problems as random events and the idea is to simply fix them. Ohno is taking other measures, he developed a system to solve the problem, called "five whys", each worker told how to trace each system errors to find the root cause and finally find out the improvement measures, make this problem not happen again. This is one of the ideas of total quality management. As you can imagine, when Ohno first put his idea into practice, the assembly workshop was chaotic, the assembly lines kept stopping and the workers were mostly frustrated. But as all the working groups gain experience in identifying problems and finding their root causes, the number of errors decreases dramatically. At a Toyota assembly plant today, every worker has the right to stop the line, but it almost never does.

What is more amazing is that at the end of the production line, with the progress of Ohno's experiment, the quantity of rework is constantly reduced, making the quality of the cars delivered constantly raised. The reason is simple, because a full-time quality inspector, no matter how hard he tries, cannot find all the errors (especially after assembly) in a complex product like a car (more than 10,000 parts).

In today's Toyota assembly plant, there are virtually no repair sites and almost no repair operations. In contrast, in many of today's mass production plants, 20% of floor space and 25% of man-hours are devoted to repair.

- Supply chain

Car manufacturing involves more than 10,000 parts and assembling them into more than 100 major components that are finally assembled into a product. It is a complex supply system to make the required parts having high quality, low price and arrive at the assembly station at the right time. In the mass production plant, the earliest attempt was to establish a centralized ordering system, with all orders coming from the top decision maker and even some advanced system could not solve this problem completely and today “make or buy” is still a problem which is not solved from theoretical point of view. But Ohno and his colleagues are considering other solutions. They believe that when it comes to the sourcing of vehicles for final assembly, regardless of the legal relationship between the assembly plant and the cooperative plant, the essence of the problem is that both parties work together to reduce costs, improve quality and benefit from each other.

In American car companies, more than 10,000 parts and assemblies on the car are designed by technicians at the company headquarters, and then the company sends the drawings to the partner factories, which are then selected by bidding. Among all the bidders, the bidder with the lowest quotation, quality meeting the requirements and short delivery time wins the bid. The relationship between the car plant and the partner plant is temporary in nature because the car plant often changes the order between the partner plant without prior notice. When there was a market goes down in the auto industry, each company acted for itself and dealt with the business relationship in a short-term manner.

Toyota, however, took a different approach, separating the self-built supporting parts of the factory into independent first-level cooperative units, with Toyota retaining some shares. Toyota's relationship with them is the same as with any of its factories. Over a period, Toyota and the first tier of cooperative plants have shares in each other. In addition, Toyota, and its partner plant (group) exchanges personnel. When the load is too heavy in the short term, they lend their own personnel to the cooperative plant, and sometimes, they transfer senior Toyota executives to the cooperative plant to take senior positions. At the same time, each cooperative unit should be closely involved in Toyota's new product development and hold shares in Toyota and other members of the Toyota Group. In this way, the cooperative factories and Toyota depend on each other. As a result, some management systems implemented within Toyota, such as JIT, can also be implemented to its cooperative units, forming an organic whole. In this environment, Toyota's real-time supply system based on days can be implemented smoothly. Only when the next process needs to make a supply request to the next process, the last process can produce the required parts in a very short time and deliver them to the next process exactly when needed. This is known as the "pull system’’. It is fundamentally different from the "push" type in mass production. However, the implementation of such a system is both difficult and risky, because it eliminates almost all inventory, and when a small part fails, the entire production system can be shut down. But for Ohno, this is where the JIT system is superior. By removing all security measures, it requires everyone to keep in mind for looking every possible problem and resolve them immediately when found. In short, after 20 years of hard work, Toyota finally successfully implemented the real-time supply system, and achieved remarkable achievements in productivity, product quality and adaptability to the market.

- Variety

The demand for cars is changing, and people are now demanding cars that are more reliable and fit their needs better. Toyota's flexible system is particularly suited to this situation. Toyota has been able to reduce production costs and thus diversify its product offerings so that buyers can get what they want at a modest additional cost.

- Relationship with customers

All the advantages of lean manufacturing mentioned above will be useless if customers are not satisfied. As a result, in earliest time Toyota has already considered the relationship between its production system and its customers.

The Toyota system adopted a completely different supply system, which was like the "supply chain" mentioned earlier, and greatly improved their relationship with customers. Toyota is phasing out mass production of cars before it knows who the customers are, in favour of organising production to order. They build long-term, stable relationships with retailers and customers by integrating them into production systems and customers into product development processes. As the first step in a "JIT" system, retailers send orders to factory and deliver them to customers within one to three weeks. It is possible to schedule production to order, first, Toyota's production methods can meet this demand; Second, instead of waiting for customers, the sale’s staff visit them and make direct contact with them. The company keeps a database of any family who is interested in Toyota products so that they can be contacted frequently about the company's new products. With such an information resource, the sale's staff can also focus on finding the most likely customers.

1.3. The 5 basic lean principles of lean

In the project management book "The machine that changed the world", Womack and Jones described the five principles of lean as the ultimate recipe to improve the efficiency of a workplace, these five principles are outlined in more detail below:

Fig.1.4 The 5 principles of lean (www.planettogether.com)

1.3.1. Define value

The first lean principle is all about identifying the needs and requirements of the customers. It important for managers to evaluate the actual needs of their customers by conducting detailed interviews and analysis. It is possible that consumers are unable to properly articulate exactly what they want. This is especially common where new products are being developed or with technology. The definition is the responsibility of the customer, but the creation is the responsibility of the manufacturer.

1.3.2. Mapping the value stream

In this step, the overall goal is to utilize the customer's value as a reference point and locate areas that correlate with their values. Any activities and processes that do not add value to the end customer are considered wasteful. The waste can be broken into two categories: (www.theleanway.net)

- non-value added but necessary
- non-value and it is unnecessary

The last one is pure waste and should be eliminated while the former should be reduced as much as possible.

1.3.3. Creating flow

After removing the waste from the value stream, the following action is to ensure that the flow of the remaining steps will run smoothly without interruption or delays， Lean production management requires that "all people must fight against the idea of departmentalization and batch production", and use continuous improvement, one-piece flow and other methods to create continuous flow of value under any batch production conditions. Of course, the necessary conditions must be in place to make the value stream flow. These conditions include: (www.theleanway.net)

Eliminate defects. Both the waste and rework caused by defects cause the value stream to be interrupted or even backflow. Achieving continuous flow requires that every process and every product is correct.

The integrity of the environment and equipment is the guarantee of flow. 5S, namely the sort (Seiri), set in order (Seiton), shine (Seiso), standardize (Seiketsu) and sustain (Shitsuke), total productive maintenance (Total Productive Maintenance, TPM) is one of the preconditions of value flow. Systematically carry out process design and capacity planning to avoid the blockage caused by bottlenecks.

1.3.4. Establish pull

Inventory is one of the biggest wastes within a production facility. The overall goal of a pull-based system is to limit inventory and work in process

(WIP) items while ensuring that the requisite materials and information are available for a smooth workflow. A pull-based system allows for Just-In-Time delivery and manufacturing where products are created at a time they are needed and, in the quantities, needed. Through following the value stream and working backward through the production system, you can ensure that the products produced will be able to satisfy the needs of customers.

1.3.5. Pursue perfection

Waste is prevented through the achievement of the first four steps which include identifying value, mapping the value stream, creating flow, and adopting a pull system. The fifth step, pursuing perfection makes lean thinking and continuous process improvement a part of the organizational culture. All employees should attempt to strive toward perfection while delivering products based on the customer's needs.

1.4. Waste in lean manufacturing

Optimizing processes to not have waste is very important for the success of your company. Having wasteful activities can lower profitability, increase customer costs, decrease quality, and even employee satisfaction. For this reason, you need to identify the non-value adding activities and try to improve the process where they appear or ultimately eliminate them. (www.kanbanize.com) But we should remember that not all wasteful activities can be eliminated from your work process, some of them are a necessity, Based on Taiichi Ohno's observations, he categorized the 7 types of waste (7 Mudas), which later became a popular practice for cost reduction and optimizing resources.

1.4.1. Overproduction

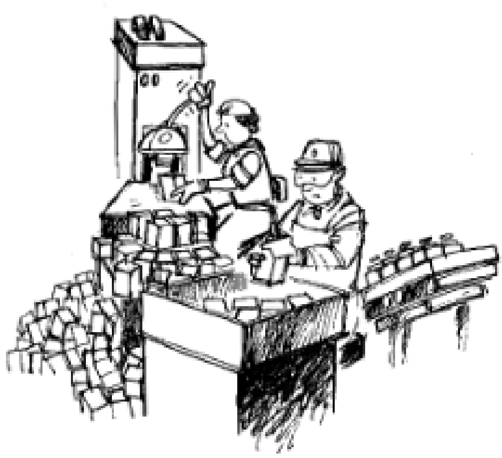

Fig 1.5 Overproduction (www.alfraconsulting.eu)

Overproduction is producing unnecessary quantities of unnecessary things when they are not necessary. There are two aspects of over-production and production anticipated. Managers often believe that excessive production or production anticipated can improve efficiency or reduce capacity loss and balance the productivity of the workshop, but this will cause difficulties in working capital turnover, business difficulties, but also lead to inventory increase and increase more management and maintenance costs. In addition, the production of too many products will lead to the product update cannot keep up with the market demand, so overproduction is one of the easily identifiable wastes.

1.4.2. Inventory

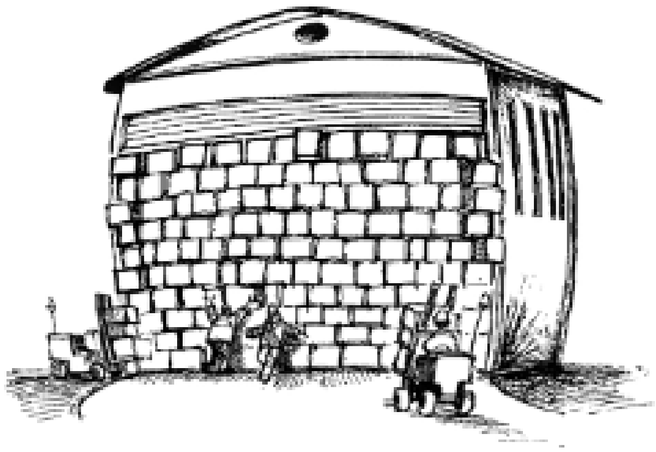

Fig 1.6 Inventory (www.alfraconsulting.eu)

The excessive inventory will lead to the increase of handling volume and the increase of places for placing, and the daily management will add extra time and colleagues will increase the time of inventory, all of which are a waste. In addition, the increase in inventory will make it difficult for the warehouse to meet the FIFO (First in and first out) principle. When the inventory increases, the product will cause backlog, and the backlog for a long time will form dead stock causing the operating difficulty of the company.

1.4.3. Waiting

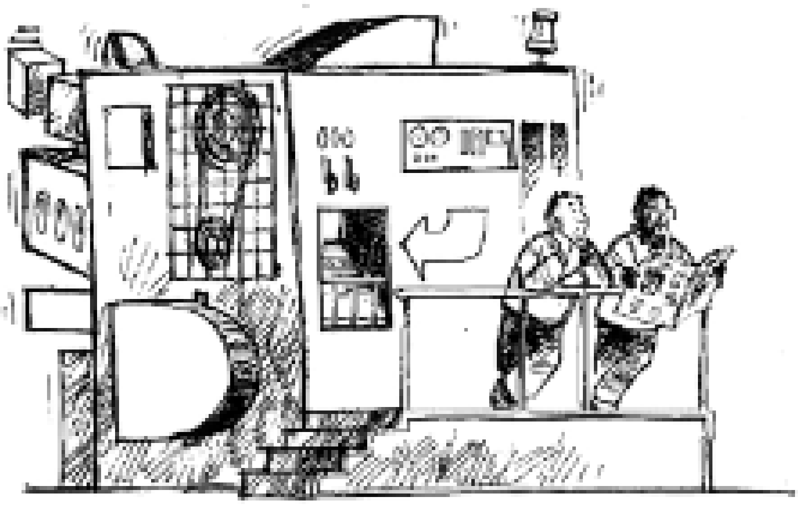

Fig 1.7 Waiting (www.alfraconsulting.eu)

The most easily identifiable waste is “waiting” because lost time is the most obvious thing you can detect. (www.kanbanize.com)

The common reasons for waiting (www.alfraconsulting.eu):

- Poor material flow, large batch production & capacity blockages.
- Machine downtime & material shortages.
- Long production change times & no production plan.

1.4.4. Defects

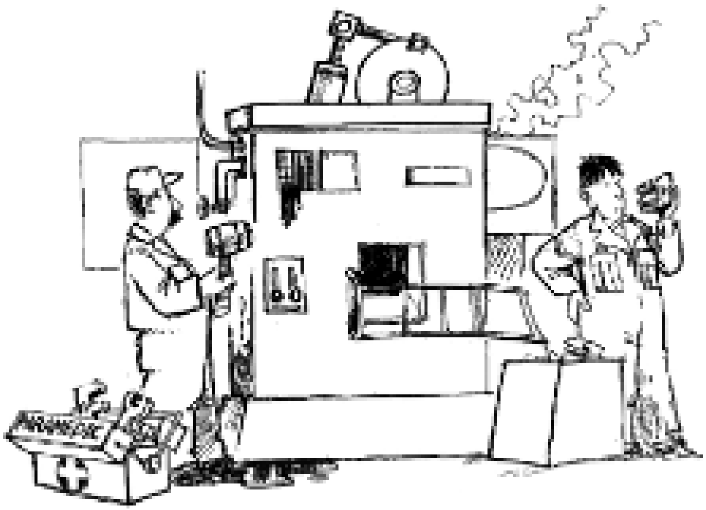

Fig 1.8 Defects (www.alfraconsulting.eu)

Defects can cause rework, or even worse, they can lead to scrap. Usually, defective work should go back to production again, which costs valuable time. Moreover, in some cases, an extra reworking area is required, which comes with additional exploitation of labour and tools. (www.kanbanize.com)

1.4.5. Motion

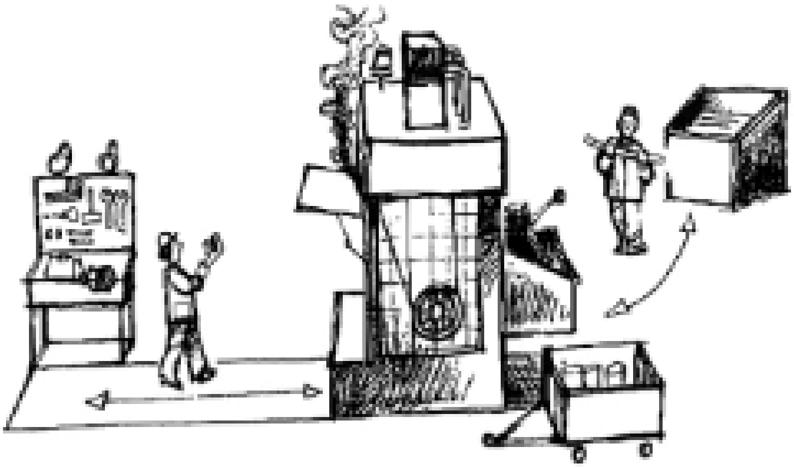

Fig 1.9 Motion (www.alfraconsulting.eu)

The excessive motions will increase the intensity of the work and reduce the efficiency of production. In other words, do whatever is necessary to arrange a process where workers need to do as little as possible to finish their job. (www.kanbanize.com)

1.4.6. Overprocessing

Fig 1.10 Overprocessing (www.alfraconsulting.eu)

This type of waste means doing some steps which are not able to add any value or bring the value which are not required by customer and creating some extra features which are not used, but the price of the products will be increased and usually the customer is not willing to pay for it.

1.4.7. Transport

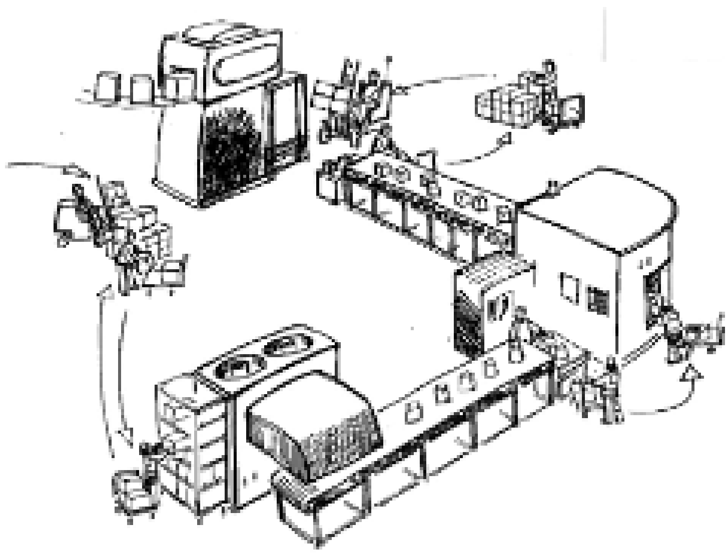

Fig 1.11 transport (www.alfraconsulting.eu)

Most people will agree that transportation is a kind of ineffective action, some people will think that transportation is a necessary action, because how to move to next step if there doesn't exist the transportation? At the end a lot of people accepted the existence of transportation without trying to eliminate it. In effect the unreasonable plant layout leads to unreasonable logistic pathway causing more costs in operation activities. The waste of transportation reflects the fragmentation of logistic and information flow.

1.5. Continuous improvement

Continuous improvement (CI) is like a religion consisting of "Improvement initiatives that increase successes and reduce failures" (Juergensen, T, 2000). CI aims to eliminate the wastes in all systems and processes of an organisation and involves all relative people to work together in the company but not necessarily using an important capital investment. (Bhuiyan, N et al.,2005) Explained shortly, it is a never-ending strive for perfection in everything you do. (www.kanbanize.com)

The thing that we should keep in mind is that the major improvement could not be realized instantly, and it is composed by a lot of small progressive improvements.

The CI is known as Kaizen (Kai-do,change,Zen-well) in Japan which is considered not only a philosophy in the management study but also happens in the normal life. The Kaizen is originated around the Second

World War and gained the popularity in Japan manufacturing industry and became the key factor for success of Toyota automobile manufacturer to be the one of most important carmakers in the world.

In the context of lean, CI focus on the constant reduction of wastes in every process in the company trying to eliminate all the activities which cannot add the value to the products. (Singh, J et al.,2015)

There are three types of waste in Lean (www.kanbanize.com):

- Muda – The seven wastes
- Mura – The waste of unevenness
- Muri – The waste of overburden

Muda consists of 7 major process wastes: transport, inventory, motion, waiting, overproduction, over-processing, defects. It's impossible to remove all these wastes completely but our aim is trying to have minimum impact on the CI implementing.

Mura means unevenness, non-uniformity, irregularity, and variability. Mura causes Muda and that's why exist the seven wastes of Muda.

Muri means overburden, beyond one's power, excessiveness, impossible or unreasonableness. In other words, Muri means unreasonableness, like the use of oversized or excessive means relative to the need or the desired result. Muri is also about the physical overload, the hardship, exposure to mental stress, which lead to wasting energy, health, and ultimately human capital. Muri is usually a result of Mura. (www.thinkinsights.net)

If the company want to implement the CI successfully, needs to focus on reduction of those wastes trying to understand how to eliminate them as much as possible and keep in mind that the CI takes time and it's a long-term activity which has never ending.

1.5.1. Plan-Do-Check-Act (PDCA)

The model Plan-Do-Check-Act is the most popular approach for achieving continuous improvement. Also known as the Deming circle (named after its founder, the American engineer William Edwards Deming), it is a never-ending cycle that aims to help you improve further based on achieved results. (www.kanbanize.com)

Phase P: The phase "PLAN" is to establish the necessary goals and processes for driving results according to customer requirements and organizational policies.

Phase D: The phase “DO” is to do the specific operations according to the predetermined plan, standard, and the known internal and external information, design specific action methods, programs, layout to achieve the goals established.

Phase C: The phase “CHECK” is to confirm whether the implementation plan has achieved its goals. Whether the program is effective, and the goal is completed, we need to check the effect before we can draw a conclusion. After confirming the countermeasures taken, the collected evidence is summarized and analysed, and the completion situation is compared with the target value to see whether the predetermined target has been reached. If we could not obtain the expected results, it’s necessary to check if the plan is executed in the right way, if it is, means the plan fails and the new plan should be determined again.

Phase A: The phase “ACT” is the key step in the process PDCA because this step is to solve the existing problems, summarize the experience and draw lessons from the stage. Without this step, it is impossible to turn the PDCA cycle forward.

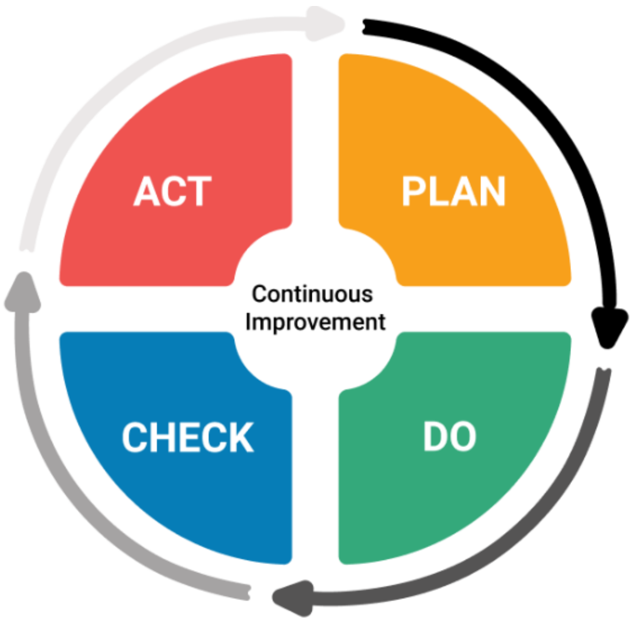

Fig. 1.12 PDCA cycle (www.kanbanize.com)

1.5.2. Root cause analysis

Root Cause Analysis (RCA) is a technique which helps to identify "what","how", "why" an event happened. Only after the people can find "why" an event or failure occurred, they could take the countermeasures to prevent the future events of the type observed (Rooney, J. J et al.,2004)

To apply RCA for continuous improvement, you need to perform a thorough analysis of the problem.

Here's an example Toyota offers of a potential 5 Whys that might be used at one of their plants.

1. **"Why did the robot stop?"**
   The circuit has overloaded, causing a fuse to blow.
2. **"Why is the circuit overloaded?"**
   There was insufficient lubrication on the bearings, so they locked up.
3. **"Why was there insufficient lubrication on the bearings?"**
   The oil pump on the robot is not circulating sufficient oil.
4. **"Why is the pump not circulating sufficient oil?"**
   The pump intake is clogged with metal shavings.
5. **"Why is the intake clogged with metal shavings?"**
   Because there is no filter on the pump.

Fig. 1.13 Example of 5 why in Toyota plant (www.buffer.com)

1.5.3. Applying Lean Kanban

Lean production is an advanced management method in today's world. Just-in-time production is one of the three theoretical pillars of lean production, and to achieve just-in-time production, it needs a matching information means, which is commonly referred to as Kanban management.

Lean Kanban was originally created by Toyota Motor Corporation in the 1950s as a delivery tool for production and delivery instructions, inspired by the operation mechanism of supermarkets. Kanban management is a tool used to effectively manage the job site. Its aim is to quickly delivery production information and share information among production units.

Kanban management in lean production is an information system that coordinates the production of the whole company, making the necessary products, when necessary, in the necessary quantities. This management style is known as "just-in-time production". In Toyota, Kanban management is regarded as a subsystem in the whole production mode of Toyota.

The Kanban method relies on five core principles (Ahmad, M. O et al.,2013):

- Visualise the workflow
- Limit Work in Progress
- Measure and manage flow
- Make process policies explicit
- Improve collaboratively (using models and the scientific method)

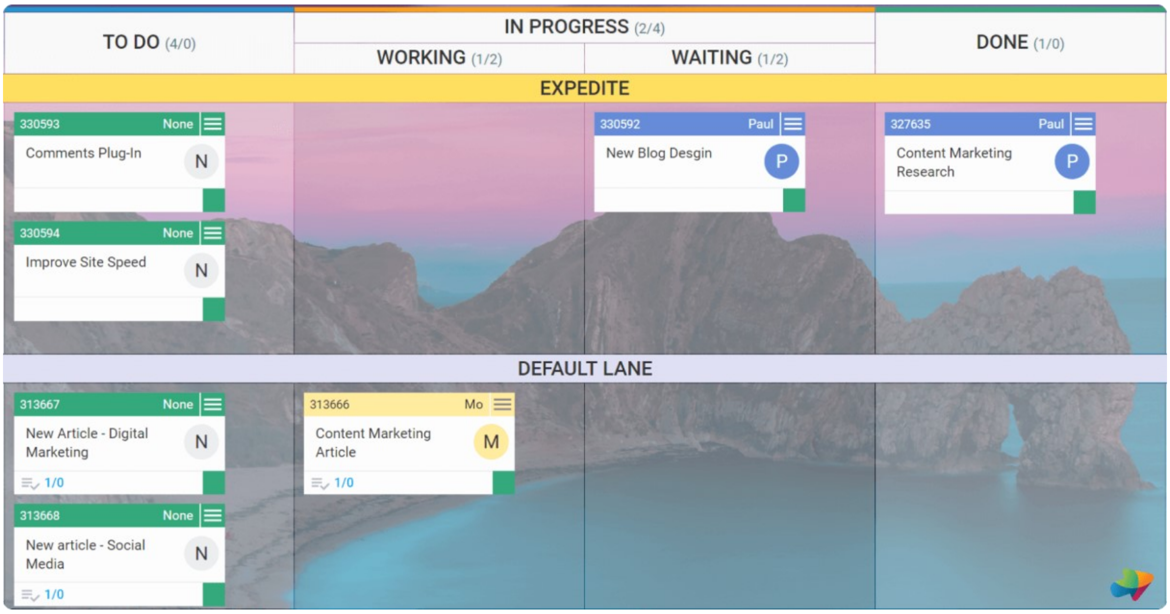

Fig. 1.14 example of Kanban board (www.kanbanize.com)

1.6. Benefits of lean manufacturing

Lean manufacturing maximizes productivity while minimizing waste. By implementing lean practices, manufacturers will see quality improvements, improved productivity, resource savings, better lead times, improved customer service and satisfaction, improved employee satisfaction, and better sustainability.

Through efficiency improvements, lean will improve the success of the company, both in terms of productivity and by increasing the bottom line. While there are risks in every process improvement, the benefits greatly outweigh the risks of lean manufacturing. A few of benefits include (www.gomingo.io):

- Quality improvements
- Improved productivity
- Saves resources
- Better lead times
- Improved customer service and satisfaction
- Improved employee satisfaction
- Better sustainability

1.7. Lean transformation

Lean transformation is the process of introducing changes in an organization to maximize the flow of value produced for the customer. As a result of this process, wasteful activities are identified, removed, or optimized. This comes contrary to the popular belief that Lean is all about eliminating waste.

Lean is all about producing more customer value, and the removal of waste is just a consequence. This might sound like a nuance to some, but making a distinction is important.

If we think about Lean only from the perspective of reducing waste, then it's easy to confuse a Lean initiative with cost-cutting or budget reduction. It's a shame, but many companies mean exactly this when they claim to be going Lean. This is plain wrong and far from what the real intentions should be.

Before starting to transform your organization into a lean system, we should know what you can get yourself and your team, there are 5 elements being in focus during the lean transformation (www.kanbanize.com)

- Situational Approach
- Process Improvement
- Capability Development
- Responsible Leadership
- Basic Thinking, Mindset, Assumptions

It must be very clear for all staffs in company that you are starting the lean transformation and got full solid support at all levels of your organization otherwise you will risk reverting to the "old ways" quickly. We should keep in mind that a lot of methods and techniques initially seem illogical to most people in your company, that's why it's important have a clear communication about what is expected to happen during and after the lean transformation to avoid mass resistance.

Chapter 2

2. Description of the systematic literature review (SLR)

The main objective of this thesis is to give a scientific literature review about lean assessment, also presents a comprehensive framework of lean assessment qualitative and quantitative tools which proposed to date. At the end, a content analysis of significant literature reviewed will be conducted.

2.1. Definition of the Systematic Literature Review (SLR)

As presented by (Okoli C et all., 2010), a rigorous literature review must be systematic in following a methodological approach, explicit in explaining the procedures by which it was conducted, comprehensive in its scope of including all relevant material, and hence reproducible by others who would follow the same approach in reviewing the topic.

2.2. Methodology

In the past years, many guides have been developed on how to conduct a SLR. In the part of content analysis we selected a procedure suggested by (Mayring P, 2003) , which is successfully used in the paper regarding the literature review of supply chain management wrote by (Seuring S et all., 2008). The same procedure was applied also in a literature review in the lean assessment field by (Gopalakrishnan Narayanamurthy Anand Gurumurthy, 2016). This procedure has 4 steps:

1. Material collections
2. Descriptive analysis
3. Category selection
4. Material evaluation

In this thesis, the same 4 steps have been used to conduct the content analysis. Before going to review the lean assessment, we should emphasize that the research area will be “lean management” and the topic is “lean assessment”. Therefore, it is necessary to define the search content correctly as well as to reflect the core topic. The following questions have been formulated:

What is the lean assessment?

What are the characteristics of lean assessment?

What is the structure of lean assessment?

How the lean assessment supports the lean management?

How to conduct a lean assessment?

Where is considered essential to make a lean assessment?

2.2.1. Material collections

The collection of materials related to the "lean assessment" has the following steps:

Firstly, the search is based on the platform Google Scholar which is a search engine easily accessible and freely available. With this search engine we can find all kind of publications and give the direct indications. The paper (Gopalakrishnan Narayanamurthy Anand Gurumurthy, 2016) indicated the use of multiple keywords, such as: lean assessment, lean evaluation, lean performance measurement, lean quantification, degree of leanness, lean appraisal, and leanness. Usage of multiple keywords resulted in studies that addressed assessment topic in specific and thereby added studies of high relevance to the material collected. We established the search period from 1996 to 2022, because the earliest model was presented by (Karlsson C et all.,1996) which had an important effect on transforming in lean manufacturing.

Secondly, a lot of papers related to the lean assessment have been found through the search on platform, but not all these papers compared are coherent with our literature review on lean assessment tools. Based on our study case, we defined several criteria for making exclusion of papers. The detail of inclusion and exclusion criteria are illustrated in table 2.1 and we will follow these criteria to filter the papers.

	CRITERIA	DESCRIPTION
INCLUSION	Consideration of abstract	The papers with abstract useful to the theme focused on the lean assessment and lean management
	Analysis of full papers	The papers with context related to the lean assessment tool proposed are included after reading and analysing the full paper
	Theme area	Engineering, lean management, lean assessment
EXCLUSIO N	Language	The search includes only the papers in English
	Origin	The papers published in journals, conference paper, chapter of book, thesis, academic paper (university journal or dissertations). Citations are not included.
	Duplicate	The duplicate are excluded
	Accessibility	The papers which require the log in by the account will be excluded

Table 2.1 Criteria of inclusion and exclusion

With the above inclusion and exclusion criteria, the number of papers is reduced dramatically from the countless papers to the countable quantity. Once all the papers are filtered by the criteria mentioned we can start to make the descriptive analysis. The papers selected are illustrated in table 2.2 with other important items extracted from the papers.

No.	Sources	Title	Authors	Year of pubblication	Journal	Objects in analysis	Nature of tool	Type of scale	Approach	Case Study	Industrial sector	geografic location
1	Journal	Assessing changes towards lean production	Christer Karlsson, Pär Åhlström	1996	International Journal of Operations & Production Management	KPIs	L	-	Survey	Yes	Office equipment	Sweden
2	Journal	Lean indicators and manufacturing strategies	Angel Martínez Sánchez,Manuela Pérez Pérez	2001	International Journal of Operations & Production Management	KPIs	L	likert	Survey	Yes	automotive/machinary	Spain
3	Journal	A model for evaluating the degree of leanness of manufacturing firms	Horacio Soriano-Meier, Paul L. Forrester	2002	Integrated Manufacturing Systems	LP	L	likert	Survey	Yes	Ceramic	UK
4	Journal	Development of a lean enterprise transformation maturity model	Nightingale D and Mize JH	2002	Information Knowledge Systems Management	LP	L	Maturity	Survey	Yes	Not specified	USA
5	Academic paper	Read a plant fast	Goodson ER	2002	Harvard Business Review	LP	L	Multi-scales	Survey	NO	-	-
6	Journal	The use of a lean production index in explaining the transition to global competitiveness: the auto components sector in South Africa	Kojima S and Kaplinsky R	2004	Technovation	LP	L	likert	Survey	Yes	Automotive	South African
7	Journal	A review of lean assessment in organizations: an exploratory study of lean practices by electronics manufacturers	Doolen TL and Hacker ME	2005	Journal of Manufacturing Systems	LP	L	likert	Survey	Yes	Elettronic	USA
8	Journal	Applying lean assessment tools in Chinese hi-tech industries	Shahram Taj	2005	Management Decision	KPIs	L	likert	Survey	Yes	Not specified	China

9	Journal	The lean index: operational "lean" metrics for the wood products industry	Ray CD, Zuo X, Michael JH	2006	Wood and Fiber Science	KPIs	T	-	FA	Yes	Wood products	USA
10	Journal	Application of mahalanobis distance as a lean assessment metric	Srinivasaraghavan J and Allada V	2006	International Journal of Advanced Manufacturing Technology	KPIs	T	-	Mahalanobis Distance	Yes	Not specified	USA
11	Journal	Measuring lean initiatives in health care services: issues and findings	Kollberg, B., Dahlgaard, J.J. and Brehmer, P.-O.	2006	International Journal of Productivity and Performance Management	KPIs	T	-	FM	Yes	Healthy care	Sweden
12	Journal	Defining and developing measures of lean production	Rachna Shah and Peter TWard	2007	Journal of Operations Management	LP	L	likert	Survey	Yes	Not specified	USA
13	Journal	A leanness measure of manufacturing systems for quantifying impacts of lean initiatives	Wan HD and Chen F	2008	International Journal of Production Research	KPIs	T	-	DEA-SBM	NO	-	-
14	Journal	Measuring the leanness of manufacturing systems—A case study of Ford Motor Company and General Motors	Bayou ME and de Korvin A	2008	Journal of Engineering and Technology Management	KPIs	T	other scales	FL	Yes	Automotive	USA
15	Journal	Lean and performance measurement	Bhasin S	2008	Journal of Manufacturing Technology Management	KPIs	T	-	DMP	NO	-	-
16	Journal	Application of benchmarking for assessing the lean manufacturing implementation	Gurumurthy A and Kodali R	2009	Benchmarking: An International Journal	LP/KPIs	LT	-	BM	Yes	Air conditioners	India
17	Journal	Decision support for lean practitioners: A web-based adaptive assessment approach	Wan HD and Chen F	2009	Computers in Industry	LP/KPIs	T	-	Adaptive assessment	NO	-	-

18	Journal	Development of index for measuring leanness: study of an Indian auto component industry	Singh B, Garg SK and Sharma SK	2010	Measuring Business Excellence	LP/KPIs	LT	other scales	FL	Yes	Automotive	India
19	Conference paper	Measuring Organizational Leanness Using Fuzzy Approach	Zanjirchi SM, Tooranloo H and Nejad LZ	2010	International Conference on Industrial Engineering and Operations Management	LP	LT	other scales	FL	Yes	Ceramic	No country specified
20	Journal	A framework for assessing the use of lean production practices in manufacturing cells	Saurin, T.A., Marodin, G.A. and Ribeiro, J.L.D.	2011	International Journal of Production Research	LP	L	binary	Survey	Yes	Elettronic components	No country specified
21	Journal	Measuring the Leanness of an organisation	Bhasin S	2011	International Journal of Lean Six Sigma	LP	L	Maturity	Survey	Yes	Not specified	UK
22	Journal	Leanness assessment using multi-grade fuzzy approach	Vinodh S and Chintha SK	2011	International Journal of Production Research	LP	LT	other scales	FL	Yes	Elettronic components	India
23	Conference paper	Lean performance evaluation of manufacturing systems: A dynamic and innovative approach	Behrouzi F and Wong KY	2011	Procedia Computer Science	KPIs	T	-	FL	Yes	Not specified	No country specified
24	Journal	Measuring parameters of lean manufacturing realization	Chauhan G and Singh TP	2012	Measuring Business Excellence	LP	L	likert	Survey	Yes	Automotive/Machinary	India
25	Journal	Thirty criteria based leanness assessment using fuzzy logic approach	Vinodh S and Vimal KEK	2012	International Journal of Advanced Manufacturing Technology	LP	LT	other scales	FL	Yes	Transformers	India
26	Journal	An integrated model to assess the leanness and agility of the automotive industry	Azevedo SG, Govindan K, Carvalho H	2012	Resources, Conservation and Recycling	LP	L	likert	Survey	Yes	Automotive	No country specified
27	Journal	An ANP-based assessment model for lean enterprise transformation	Ibrahim Cil and Yusuf S. Turkan	2012	International Journal of Advanced Manufacturing Technology	LP	L	likert	ANP	Yes	Lock	Turkey

28	Journal	What is the leanness level of your organisation in lean transformation implementation? An integrated lean index using ANP approach	Wong, P., Ignatius, J., and Soh, K.	2012	Production Planning & Control	LP/KPIs	T	-	ANP	Yes	Semiconductor	Malaysia
29	Journal	An integrated stochastic-fuzzy modeling approach for supply chain leanness evaluation	Behrouzi F and Wong KY	2013	International Journal of Advanced Manufacturing Technology	KPIs	LT	Multi-scales	Stochastic-FL	Yes	Automotive	Iran
30	Journal	Application of artificial neural network for fuzzy logic based leanness assessment	Vinodh S and Vimal KEK	2013	Journal of Manufacturing Technology Management	LP	LT	other scales	NN-FL	Yes	Transformers	India
31	Journal	A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations	Karim A and Arif Uz-Zaman K	2013	Business Process Management Journal	KPIs	T	-	CPM	Yes	Voltage switchgear	Australia
32	Journal	A strategic and operational approach to assess the lean performance in radial tyre manufacturing in India	Gupta V, Acharya P and Patwardhan M	2013	International Journal of Productivity and Performance Management	LP/KPIs	L	likert	Survey	Yes	Tyres	India
33	Journal	Measuring the leanness of manufacturing systems by using fuzzy TOPSIS: a case study of the "Parizan Sanat" company.	Alemi MA and Akram R	2013	South African Journal of Industrial Engineering	LP	LT	other scales	TOPSIS-FL	Yes	Garage equipment	Iran
34	Journal	Performance evaluation of lean manufacturing implementation in Brazil	Lucato WC, Calarge FA, Junior ML	2014	International Journal of Productivity and Performance Management	LP	L	Maturity	Survey	Yes	Not specified	Brazil
35	Journal	Status of lean manufacturing practices in Indian industries and government initiatives: A pilot study	Thanki, S.J. and Thakkar, J.	2014	Journal of Manufacturing Technology Management	LP	L	likert	Survey	Yes	Not specified	India

36	Conference paper	A Conceptual Model for Evaluating Product-Service Systems Leanness in UK Manufacturing Companies	Elnadi M and Shehab E	2014	International Conference on Through-life Engineering Services	LP/KPIs	L	-	-	NO	-	-
37	Journal	Criteria for a lean organisation: development of a lean assessment tool	Pakdil F and Leonard KM	2014	International Journal of Production Research	LP/KPIs	LT	likert	Survey-FL	Yes	Not specified	No country specified
38	Academic paper	A lean logistics assessment tool for SMES in the manufacturing sector	Ramirez S and Lorena D	2014	Purdue University	LP	L	Maturity	Survey	NO	-	-
39	Journal	Group fuzzy ANP procedure development for leanness assessment in auto part manufacturing companies	Hosseini MS and Ebrahimi TA	2015	Journal for Global Business Advancement	KPIs	T	other scales	ANP-FL	Yes	Automotive	Iran
40	Conference paper	The Lean Management Maturity Self-Assessment Tool Based on Organizational Culture Diagnosis	Urban W	2015	Procedia—Social and Behavioral Sciences	LP	L	Maturity	Survey	NO	-	-
41	Journal	An intergrated lean assessment framework for tyre distribution industry	Mahfouz A and Arisha A	2015	Winter Simulation Conference (WSC)	KPIs	T	-	VSM-DEA	Yes	Tyres	No country specified
42	Journal	Development of a lean maturity model for operational level planning	Maasouman MA and Demirli K	2015	International Journal of Advanced Manufacturing Technology	KPIs	LT	Maturity	FL	Yes	Not specified	No country specified
43	Journal	Application of fuzzy logic for leanness assessment in SMEs: a case study	Vidyadhar R, Kumar RS, Vinodh S	2016	Journal of Engineering, Design and Technology	LP/KPIs	LT	other scales	FL	Yes	Transformers	India
44	Journal	Assessing leanness level with demand dynamics in a multi-stage production system	Ali, R. and Deif, A.	2016	Journal of Manufacturing Technology Management	KPIs	T	-	SDM	Yes	Kitchen equipments	Egypt
45	Conference paper	A lean assessment tool based on systems dynamics	Omogbai O and Salonitis K	2016	CIRP Design	KPIs	T	-	SDM	Yes	Packaging	No country specified

46	Journal	A fuzzy logic model to evaluate the lean level of an organization	Abreu A and Calado JMF	2017	International Journal of Artificial Intelligence & Applications	LP	LT	other scales	FL	Yes	Aeronatical	No country specified
47	Conference paper	Lean assessment tool for workstation design of assembly lines	Goncxalves and Salonitis	2017	CIRP Design	LP	L	likert	Survey	Yes	Automotive	UK
48	Journal	Development of an integrated performance measurement framework for lean organizations	Sangwa NR and Sangwan KS	2018	Journal of Manufacturing Technology Management	KPIs	T	-	-	NO	-	-
49	Conference paper	Development of a Lean Assessment Tool for Small and Medium Sized-Enterprises	Belhadi A, Touriki FE and El fezazi S	2018	Closing the Gap Between Practice and Research in Industrial Engineering	KPIs	L	likert	Survey	Yes	Not specified	No country specified
50	Journal	Leanness assessment of an organization using fuzzy logic approach	V. A. Wankhede, A Chaurasia, and N. Khatekar	2019	Journal of engineering practice and futuristic technologies	LP	LT	other scales	FL	Yes	Not specified	India
51	Journal	A neuro-fuzzy hybrid model for assessing leanness of manufacturing systems	P. G. Saleeshya, and M. Binu.	2019	International Journal of Lean Six Sigma	LP/KPIs	LT	other scales	NN-FL	Yes	Telecome equipment	Australia
52	Journal	Assessing Leanness of Fast-Moving Consumer Goods (FMCG) Industry with Fuzzy Logic	N. Kumar, S. K. Jarial, and M. S. Narwal	2019	International Journal of Engineering and Advanced Technology	LP	LT	Multi-scales	FL	Yes	Food	India
53	Journal	Maturity of lean practices in Brazilian manufacturing companies	dos Santos Bento, G. and Tontini, G.	2019	Total Quality Management and Business Excellence	LP	L	Maturity	Survey	Yes	Not specified	Brazil
54	Journal	A continuous improvement assessment tool, considering lean, safety and ergonomics	Brito, M.F., Ramos, A.L., Carneiro, P. and Gonçalves, M.A.	2020	International Journal of Lean Six Sigma	LP	L	binary	Survey	Yes	Not specified	No country specified
55	Journal	A fuzzy-based leanness evaluation model for manufacturing organisations	M. A. Amin, M. R. Alam, H. Alirdisi & M. A. Karim	2020	Production Planning & Control	KPIs	T	other scales	FL	Yes	Voltage switchgear	No country specified

56	Conference paper	Measuring leanness index using fuzzy logic approach	Dahda, S.S. Andesta, D. and Wicaksono, A.S.	2020	Journal of Physics: Conf. Series	LP/KPIs	LT	other scales	FL	Yes	Steel processing	Indonesia
57	Journal	A leanness assessment methodology based on neutrosophic DEMATEL	Huseyin Selcuk Kilic, Pinar Yurdaer, Canan Aglan	2021	Journal of Manufacturing Systems	LP/KPIs	T	-	Survey -Neutrosophic DEMATEL	Yes	Not specified	No country specified
58	Journal	Lean Maturity Assessment in ETO Scenario	Mariastella Chiera , Francesco Lupi , Andrea Rossi and Michele Lanzetta	2021	Applied Sciences	LP/KPIs	T	Maturity	Survey-PFM	Yes	Wood working machines	Italy
59	Journal	Product-service system leanness assessment model: study of a UK manufacturing company	Moustafa Elnadi, Essam Shehab	2021	International Journal of Lean Six Sigma	LP/KPIs	LT	other scales	FL	Yes	Automotive	UK

Table 2.2 Results of literature collections

2.2.2. Descriptive analysis

Some general information extract from the paper selected will be taken in analysis. For example, the publication of journal/conference/academic papers, the timeline distribution, authorship, and geographic location of the case study. These descriptive analyses help us to understand the trend evolving over years in the research topic (Gopalakrishnan Narayanamurthy Anand Gurumurthy, 2016).

2.2.3. Category selection

All the information collected are shown in figure or table which contains the related analytic categories (Seuring S et all., 2008). The related categories are as follows:

Objects in analysis: The literature will be classified if the tool considers the lean practices (LP), KPIs or LP as well as KPIs.

Nature of tool: The literature will be classified if the tool is a quantitative method-based tool (T), qualitative method-based tool (L) or a hybrid tool (LT).

Type of scale: The literature will be classified if the scale is used for assessment. For example, Likert scale, binary scale, and maturity scale.

Approach: The literature will be classified based on the approach incorporated in the model for evaluation of leanness. For example, Survey, Fuzzy logic, Analytic network process, VSM (value stream mapping), etc.

Case study: The literature will be classified if the model has been empirically validated through a case study or just a conceptual model, the results will be shown in binary scale (Yes/No).

Industrial sector: The literature will be classified in industrial sector if manufacturing field have been mentioned.

2.2.4. Material evaluation

After the step of ccategory selection, the literature information will be further evaluated and analysed (Gopalakrishnan Narayanamurthy Anand Gurumurthy, 2016). The details of evaluation results will be presented in chapter 4.

Chapter 3

3. Lean assessment

3.1. The importance of lean assessment

As Peter Drucker said, “what get measured, gets done”. In the last two decades the lean manufacturing and the related tools became more popular because of its impressive improvements which in all aspects of manufacturing system (Behrouzi F et al., 2010). Therefore, many managers implemented the lean techniques like just-in-time (JIT) and Kaizen, expecting that these tools or techniques could help to manufacture products with lower cost and higher quality. But many companies got into trouble with the implementation of lean due to the ignorant of critical factors which contribute to lean implementation success. As defined by (Baviskar P, 2015), Lean assessment gives complete analysis of current level of leanness of the organization with process accuracy, stability and improvement and the degree of employee commitment towards these activities. Knowing the current state and distance to desired level of lean is extremely important in the lean implementation.

Lean assessment metric should have some basic properties such as (Baviskar P, 2015; Srinivasaraghavan J et al., 2005):

- Measurable
- Aligned with the company's strategic goals
- Capable to control and evaluate the performance.
- Useful to understand the current scenario and helpful to identify the possible improvements.
- Realistic and updated

3.2. Lean assessment planning

Evaluating the complex of an enterprise is the first phase for any lean project. It consists in studying all hierarchical levels in all fields, starting from the lowest level (suppliers, employees) to the highest level (top management, managers). By this way, we could understand which category should be considered and included in the assessment project which existing tool is able to contribute to realize the lean process.

Therefore, it is very important to understand the company's structure, history, and current situation. Once you understand the way in which the company operates, its relationship with customers, employees and people involved in the lean project, you could start the improvement intervention.

Before starting to conduct a lean assessment, you need to decide which type of lean assessment tool should be used in the specific context. In the phase of collection, we found that the tools could be classified in qualitative method-based tool, quantitative method-based tool, and hybrid tool (Gopalakrishnan Narayanamurthy Anand Gurumurthy, 2016) for leanness assessment.

After the evaluation of all the data collected, you can obtain the map of the "state of excellence" of each category, and from the results derived from the assessment, it is possible to start to consider how to proceed with the action plan.

In addition, the results should be archived to understand the evolution of performance over time through another round of assessment after several month or year.

In summary the process of lean assessment has 3 phases:

- Data collection: Based on the method applied in assessment in this phase, collecting the scores given by different questions from questionnaire or collect the measures of key performance indicators.
- Evaluation: Use different techniques and approaches like Fuzzy logic, MCDM (multi criteria decision making) or simple calculations like additions, average to analyse the collected information to understand the level of lean. The evaluation depends on the model proposed.
- Planning and executing to find the resources to construct an improvement plan.

3.3. Lean assessment tools

Lean assessment has been fully researched and developed in the last 30 years and the various tools were detailly developed. The earliest model found in the literature was presented by (Karlsson C et all.,1996). In this paper authors developed a tool capable of defining the progress of a lean manufacturing firm in attempt to adopt lean fundamentals from the book ‘‘The Machine that Changed the World. (Silvério L et al.,2019) Based on the existing lean assessment tools overviewed, each tool focused on the different sides of lean operations with different weight (Pakdil F et al., 2014). Before a practitioner starts planning a lean assessment in the company, it is important to have a deep understanding of the different types of lean assessment tools.

3.3.1. Qualitative/Quantitative/hybrid method-based tool

The qualitative method is usually formed by the self-rated assessment (Oleghe O et al.,2016; Oleghe O et al., 2018; Taggart P et al., 2013), each lean characteristic is measured by broad perception, measured through the accumulation, average of scores awarded for individual questions or subcategories. This kind of tools could be quickly distributed in the organization and the process is not time-consuming, the collected data could be analysed quickly. The characteristic of this kind of tool is more subjective in nature which are not based on the 'hard' measures and suitable give a rough lean estimate (Berlec T et al., 2014; Goodson R.E, 2002). The personal justification is considered as the drawback of this method (Oleghe O et al., 2018; Ray C.D et al., 2006; Pakdil F et al., 2014). Likert scale or others should be considered as the qualitative method-based tool.

The quantitative method-based tool aims to avoid the nature of subjectivity (Wan H.D et al., 2008). The quantitative method-based tool uses data which are tracked directly with numbers to measure the overall leanness level (Oleghe O et al.,2016).

There are some advantages to using quantitative method-based tool. The statistical approaches could be used to identify the leanness of a company by describing the patterns of relationships among quantifiable predictor variables (Ray C.D et al., 2006), a lot of variables can be combined into a unit-invariant score which is easily comprehensible to quantify the leanness level of manufacturing system (Wan H.D et al., 2008). The relationship between the different components which should be evaluated in the measuring the degree of leanness possessed by the manufacturing company can be quantifiable (Soriano-Meier H et al., 2002).

The quantitative method-based tool has also some disadvantages. Some important lean aspects are not quantifiable like prevalence of continuous improvement culture, employee involvement, employee spirit and cooperation (Oleghe O et al., 2015).

As discussion, above tools have its advantages and disadvantages. To solve the problem, a new tool was introduced in (Pakdil F et al., 2014) which integrated the qualitative measures and the quantitative measures to give an overall view of the organisation's leanness level. In this thesis this kind of tool is called "hybrid tool".

The lean assessment tools have been well researched and advanced of which tool should be adopted depends on the specific situation in terms of the complexity, robustness, data requirements and how the management of the company wants to estimate the lean performance (Oleghe O et al., 2018).

The lean assessment tools could be categorized in the following types:

- **Measurement of degrees of lean based on lean practices adoption:**
    - ➢ **Absolute model**

A complete list of questions in different sectors interested are created in the questionnaire. The company get the “state of lean excellence” only if company get fully implemented all the activities at the maximum level. The absolute model could be qualitative or quantitative.

- ➢ **Contingent model**

Not all practices are suitable for the company's situation. Sometimes practices applied in assessment don’t make any sense, it could also give the wrong indications in the phase of evaluation as well as time-consuming. Primarily, the contingent model includes in checking if the practices make sense in the context and only for the important practice verify the degree of implementation. The contingent model could be qualitative or quantitative. In this thesis, we will concentrate on the contingent model.

- **Measurement based on analysis of Key Performance Indicators (KPIs):**

There are also tools which take in consideration the KPIs for the evaluation of leanness. The KPIs could be distinguished in physical parameters and financial parameters. The physical parameters include "Overall Equipment Effectiveness (OEE)", "Work-In-process (WIP)", "Average lead time", etc. The financial parameters include Gross profit margin, Operating profit margin (EBIT), Return on assets (ROA), Return on equity (ROE), etc.

3.3.2. Types of scales in data collection phase

Usually, in the phase of data collection, there are 3 types of scales for the practices listed in the questionnaire, shown as follows:

- **Binary scale:**

A binary scale gives only 2 choices. In the figure 3.1 shows an example of scoring with Yes/No.

RPA Questionnaire

The total number of yeses on this questionnaire is an indicator of a plant's leanness: the more yeses, the leaner the plant. Each question should be answered yes only if the plant obviously adheres to the principle implied by the question. In case of doubt, answer no.

		yes	no
1	Are visitors welcomed and given information about plant layout, workforce, customers, and products?	○	○
2	Are ratings for customer satisfaction and product quality displayed?	○	○
3	Is the facility safe, clean, orderly, and well lit? Is the air quality good, and are noise levels low?	○	○
4	Does a visual labeling system identify and locate inventory, tools, processes, and flow?	○	○
5	Does everything have its own place, and is everything stored in its place?	○	○
6	Are up-to-date operational goals and performance measures for those goals prominently posted?	○	○
7	Are production materials brought to and stored at line side rather than in separate inventory storage areas?	○	○

Fig. 3.1 Example of scoring with Yes/No (Goodson R.E, 2002)

- **Likert scale:**

A Likert scale is a close-ended, forced-choice scale used in a questionnaire that provides a series of answers that go from one extreme to another. For example, a scale might have five choices that start at one and end with "strongly agree" to the other which with less extreme choices in the middle three points. In the figure 3.2 shows an example of one section in a questionnaire of lean assessment which give 7 choices.

SECTION : II

Please tick (√) the appropriate box on a scale of 1 (strongly disagree) to 7 (strongly agree) and middle point of 4 (neither agree nor disagree).

Extent of Lean Manufacturing Implication

(i) Elimination of waste (EOW):

1. The rate at which correction, repairs or rework done is very low.
   1 2 3 4 5 6 7
2. The rate of scrap generation is very low.
   1 2 3 4 5 6 7
3. Motion - any wasted motion to pick up parts or stack parts is not a regular feature.
   1 2 3 4 5 6 7
4. Over production - producing more than needed is not a regular feature.
   1 2 3 4 5 6 7
5. Over production - before it is needed is not a regular feature.
   1 2 3 4 5 6 7
6. Extent of wasted effort to transport raw material is very low.
   1 2 3 4 5 6 7
7. Extent of wasted effort to transport finished goods into or out of storage is very low.
   1 2 3 4 5 6 7
8. Extent of wasted effort to transport WIP between processes is very low.
   1 2 3 4 5 6 7
9. Maintaining inventory (raw material) level not more than lead time consumption.
   1 2 3 4 5 6 7
10. Inventory (WIP) is very small.
    1 2 3 4 5 6 7

Fig.3.2 Example of scoring with Likert scale (Chauhan G et al., 2012)

- **Maturity scale:**

A Maturity scale give the choices based on the detailed description of lean implementation. It starts from the “worst situation” to the “best situation", each criterion gives the visible and clear signs of lean adoption. People who complete the survey must match the status with one choice. In the figure 3.3 shows an assessment with maturity scale.

Part I. Lean culture

Organization's vision components (0-5 points for each criterion)

V1. A clear vision of organizational improvement, shared by all employees, exists in our company

V2. We believe that in order to achieve a long-term vision of the company, short-term gains are sacrificed if necessary

V3. In our company we do not accept temporary solutions to problems. We get them right first time, and if it is necessary, we stop the whole process to solve the problem immediately

V4. Our company shows respect for our business partners, and if they want us to, we help them to improve their processes

Leadership (0-5 points for each criterion)

L1. Our company emphasizes the development of leaders who identify with the company's vision and rules

L2. It is obvious that top managers are often found close to the value stream, and they serve there in problem solving

L3. We believe that decisions should be forwarded to an operational level; employees are empowered to make decisions about issues related to their work

L4. In our company we do not accept "pretend projects" that run without a full understanding of their meanings and without the conviction that they will bring good results

Associated with the value stream (0-5 points for each criterion)

S1. It is obvious that the reference point for most of the activities within the company is the value stream. It determines the organization of operations

S2. It is sought to obtain a continuous and smooth flow in the value stream

S3. The company aims to manufacture/serve according to customer orders; a pulling system is being implemented – production is proceeded by external needs

S4. In our company we do not accept impulsive, careless decisions; before any decision there is long thought, but immediately after the decision is made it is implemented into practice

Operational improvement (0-5 points for each criterion)

I1. The norm is that we still carry out improvement projects in various spheres of the company

I2. It is important for our company to improve all operations systematically, and all employees continuously work on discovering and eliminating waste

I3. In our company nobody hides faults; spotted errors are treated as an opportunity to improve

I4. We emphasise communicating in a visual way all the guidance of operations, and other important information, such as errors and performance

People treatment (0-5 points for each criterion)

P1. The employees are treated with respect and healthy partnership; care of people is manifested in attention to their needs and their development

P2. We believe that continuous learning for all employees should be an integral part of the work in our company

P3. We always remember to challenge people; challenges are taken on by managers and employees

P4. We pay attention to facilitate conditions for individual initiative and creativity in every position in our company

The sum of five groups (V+L+S+I+P) is ...... out of 100.

Fig. 3.3 Example of maturity scale (Urban W, 2015)

Chapter 4

4. Results and discussions

4.1. Results of descriptive analysis

The descriptive analysis was carried out on the papers collected through the material collection step as discussed in the previous chapter.

4.1.1. Publication of papers

The 59 papers are selected through the material collection step. The 49 papers came from journals, 8 papers came from conferences and 2 papers came from academic papers (dissertation/academic journals). Figure 4.1 provides the complete list of papers collected from journals, conferences, and academic journals. The abbreviation of the journal title is shown in Table 4.1.

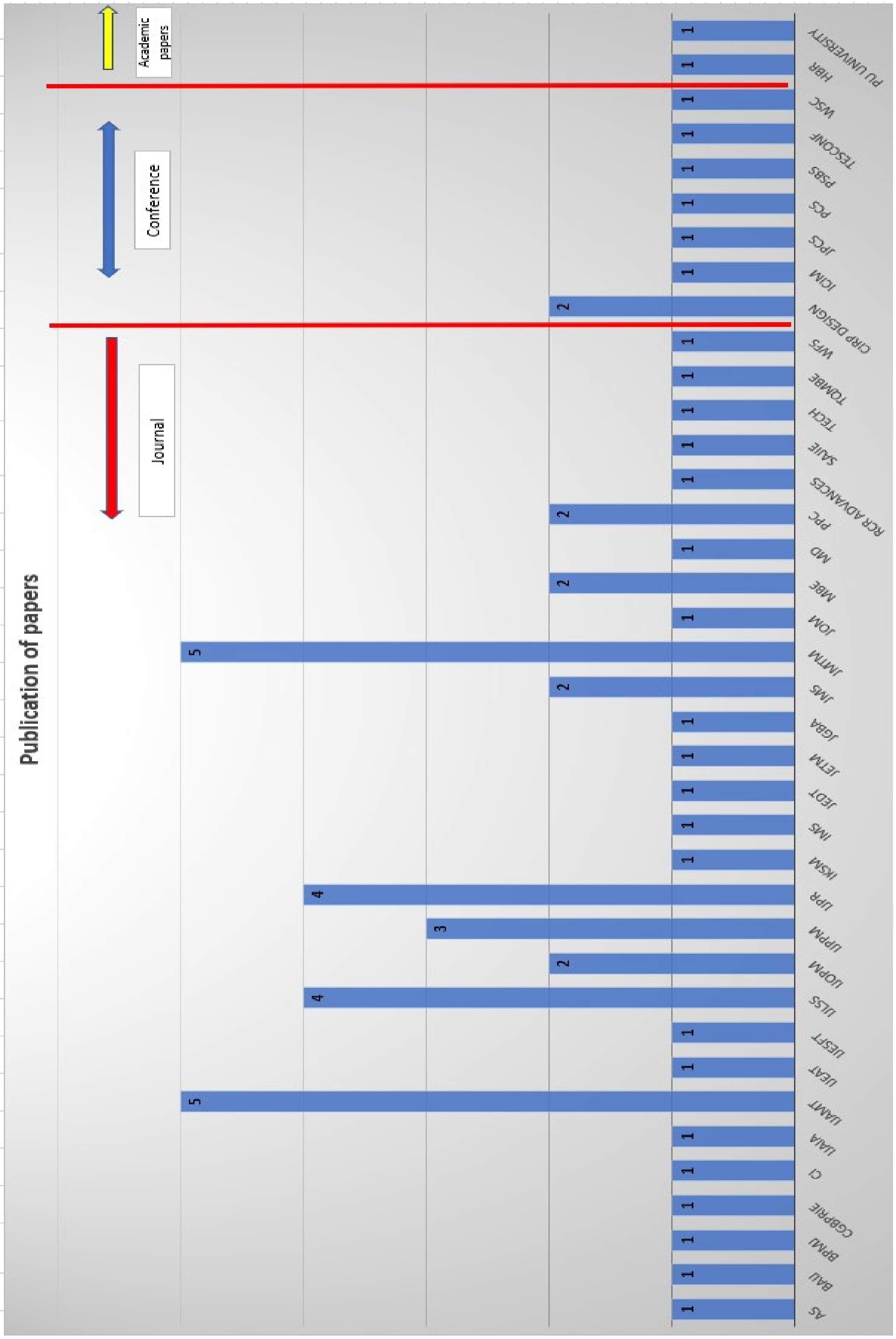

Fig. 4.1 Classification of papers by journals/conferences/academic papers

Description	Abbreviation	Description2	Abbreviation2
Applied Sciences	AS	Journal of Engineering and Technology Management	JETM
Benchmarking: An International Journal	BAIJ	Journal for Global Business Advancement	JGBA
Business Process Management Journal	BPMJ	Journal of Manufacturing Systems	JMS
Closing the Gap Between Practice and Research in Industrial Engineering	CGBPRIE	Journal of Manufacturing Technology Management	JMTM
Computers in Industry	CI	Journal of Operations Management	JOM
CIRP Design	CIRP Design	Journal of Physics: Conf. Series	JPCS
Harvard Business Review	HBR	Measuring Business Excellence	MBE
International Conference on Industrial Engineering and Operations Management	ICIM	Management Decision	MD
International Journal of Artificial Intelligence & Applications	IJAIA	Procedia Computer Science	PCS
International Journal of Advanced Manufacturing Technology	IJAMT	Production Planning & Control	PPC
International Journal of Engineering and Advanced Technology	IJEAT	Procedia – Social and Behavioral Sciences	PSBS
Journal of engineering practice and futuristic technologies	IJESFT	Purdue University	PU University
International Journal of Lean Six Sigma	IJLSS	Resources, Conservation and Recycling	RCR Advances
International Journal of Operations & Production Management	IJOPM	South African Journal of Industrial Engineering	SAJIE
International Journal of Productivity and Performance Management	IJPPM	Technovation	TECH
International Journal of Production Research	IJPR	International Conference on Through-life Engineering Services	TESConf
Information Knowledge Systems Management	IKSM	Total Quality Management and Business Excellence	TQMBE
Integrated Manufacturing Systems	IMS	Wood and Fiber Science	WFS
Journal of Engineering, Design and Technology	JEDT	Winter Simulation Conference (WSC)	WSC

Table 4.1 Abbreviations of journal title

The top four journals that published papers related to the lean assessment are:

- International Journal of Advanced Manufacturing Technology (IJAMT)
- Journal of Manufacturing Technology Management (JMTM)
- International Journal of Lean Six Sigma (IJLSS)
- International Journal of Production Research (IJPR)

From Fig.4.1, most of paper in lean assessment have been published in the main operation management journals. This goes to evidence the importance and significance of lean assessment as a research topic in the operation management field. We could also see that the papers related to lean assessment are not just limited to the field of manufacturing but also applied in other area such as healthy service, civil construction, public sector, etc. This demonstrated that lean as a philosophy is universally applicable. Papers on lean assessment have been also published in the computer science filed (Hung-da wan et al., 2009; Farzad Behrouzi et al., 2011). The reason for this could be many tools need high support of simulations and programming.

4.1.2. Timeline distribution

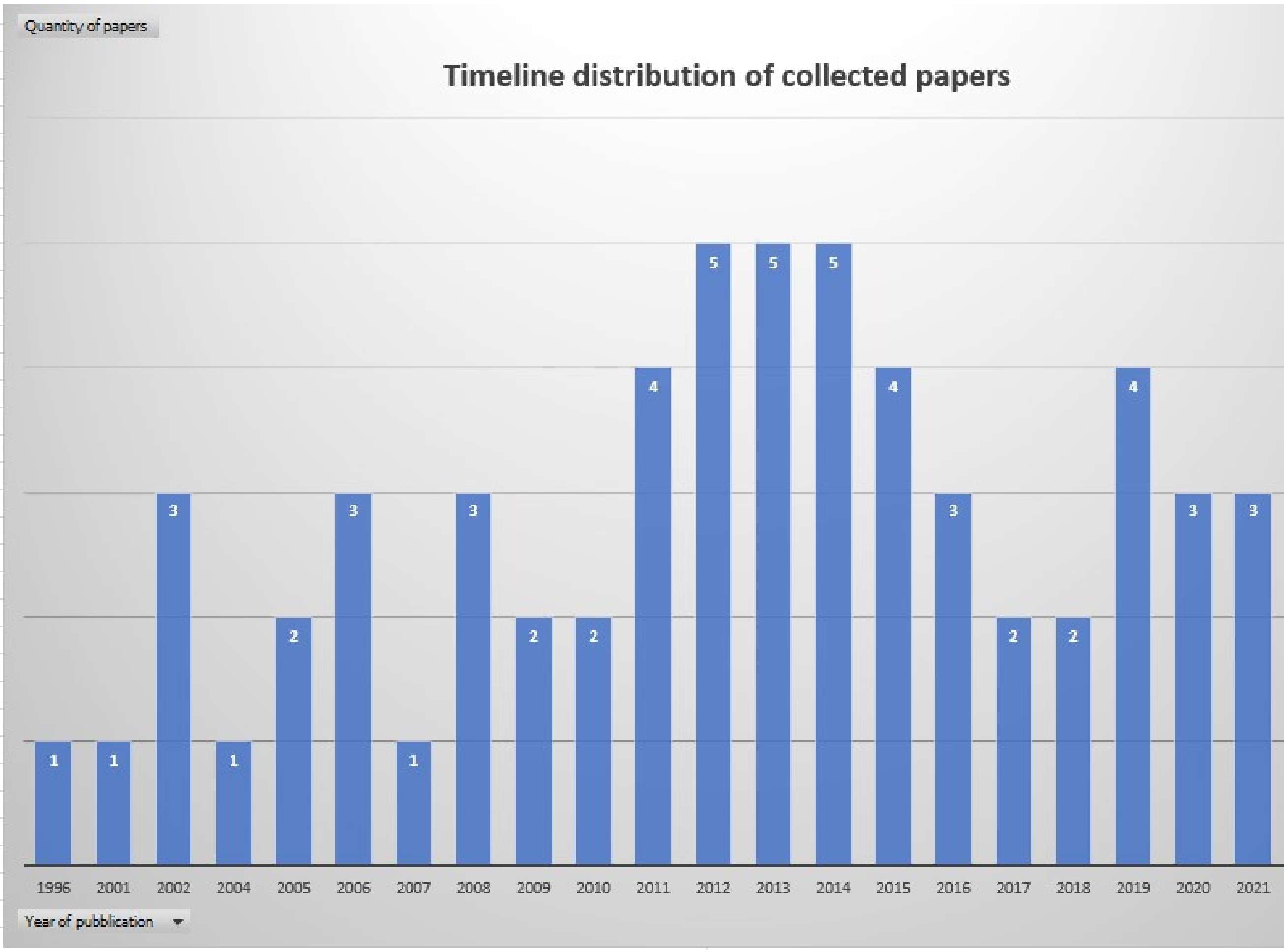

Fig.4.2 Timeline distribution of collected papers

The figure 4.2 shows the timeline distribution of collected papers. It is very clear that the research on lean assessment has never been stopped since 2004. Thirty-six of 59 papers have been published in the recent ten years. The first model proposed by Karlsson, and Ahlstrom was published in 1996 and the next paper was published after 5 years. The reason for this vacancy could be that lean assessment was at the initial development phase and the practitioners of lean implementation didn't give importance on this topic. The focus was on implementation of lean thinking and lean principles in the organisations. In 2012, Stone (Kyle B. Stone, 2012) defined development phases of lean:

- Discovery phase: 1970 -1990

In this period the Japanese methods started to get interests from the world after the oil crisis and the term of "lean production" was used by Womack in 1990 (James P. Womack et al., 1990) to describe the manufacturing techniques developed by Toyota Motor Company.

- Dissemination phase: 1991-1996

In this period the lean concepts started to be disseminated around scholars and the various techniques such as Kanban, JIT were deeply explained by researchers. At the same time the benefits of applying the lean principles in the organizations were well noted and some important industry such as automotive started to adopt the lean principles internally and tried to get the new benefits discovered through the new approach. Therefore, after the dissemination phase arrived quickly the intense implementation phase. Some companies wanted to understand “how to become lean”, what kind of actions should be taken in the direction of lean production and how to measure the progress of lean implementation. This explained why some researchers start to pay attention on the lean assessment, as Karlsson and Ahlstrom proposed the first tool of lean assessment in 1996.

- Implementation phase:1997-2000

In the late 1990s, managers of firms were struggling to implement lean techniques into a coherent system (James P. Womack et al., 1996a) and Lean thinking as a philosophy of management was well explained in many articles and helped organizations to understand the strategic approach of planned change throughout the organization and enterprise (James P. Womack et al., 1996b). During this phase, even though there are a lot of articles on the topic of lean thinking and lean principles, the empirical research remained little.

After 2000, with the continuous progress of research of Lean thinking philosophy, many companies in different sectors and different sizes all over the world started to adopt Lean thinking practices. In 2006, Bhasin and Burcher (Sanjay Bhasin et al., 2006) stated that the success rate of implementing lean initiatives in the companies was extremely low. Repenning and Sterman (Nelson P. Repenning et al., 2001) also observed that companies use lean initiatives almost as a fad, number of tools, techniques, and technologies available to improve operational performance is growing rapidly. On the other hand, despite dramatic successes in a few companies, most company efforts to use them fail to produce significant results. These observations reminded scholars and practitioners that it was not enough to just implement tools and techniques in companies for becoming leaner, it was also very important to understand the critical factors which contributed to lean implementation success (Gopalakrishnan Narayanamurthy Anand Gurumurthy, 2016). Lean assessment tools help practitioners to understand why the company could not reach the predefined level of lean and which are the key problems to resolve for improving their performance. The above information explained why the quantity of papers on lean assessment have been increased continuously from 2000.

4.1.3. Authorships

The collected papers are also classified based on the quantity of original authors as shown in Fig.4.3.

Q.ty of authors	Q.ty of papers
One	6
Two	34
Three	16
Four or more	3
TOT	59

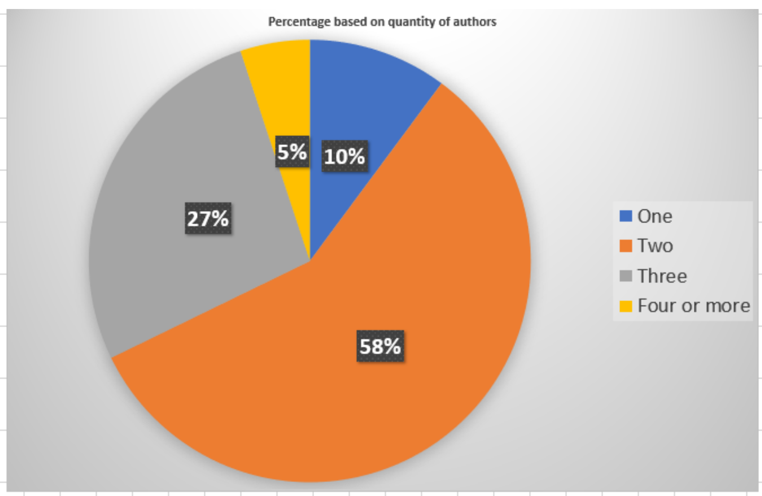

Fig. 4.3 Papers counted by quantity of authors

The papers wrote by two authors occupied for 58% and if we added the papers with three authors the percentage covers more than 80%. This indicator evidence that the major projects and research of lean assessment require the strong cooperation between scholars or between scholars and practitioners. Any model of lean assessment proposed needs to be validated through some cases study, and the combination between the academic research and industrial application is always required.

4.1.4. Geographic locations

In figure 4.4 papers are classified based on the geographic location of case studies.

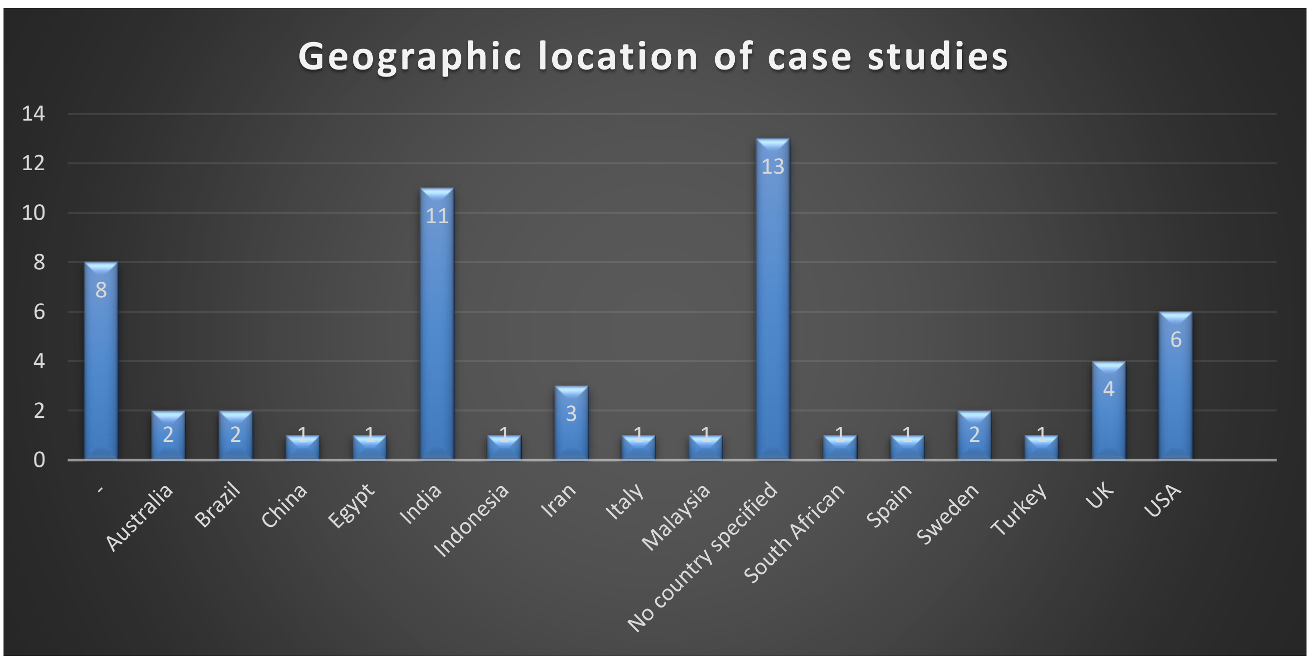

Fig 4.4. Geographic distribution of case studies

The data collected for case studies of lean assessment tools distributed across 15 countries. 13 papers didn't specify the country, the reason may be that the information is required to be confidential. 8 papers didn't carry out case study and the author only proposed the tool of lean assessment.

4.2. Results of analysis of categories selected

After having a general overview and trend of lean assessment topic in review by descriptive analysis, the analysis of categories selected was conducted detailly in the following.

4.2.1. Industrial sector

Figure 4.5 shows the classification of industrial sectors to which the organizations in case study belong.

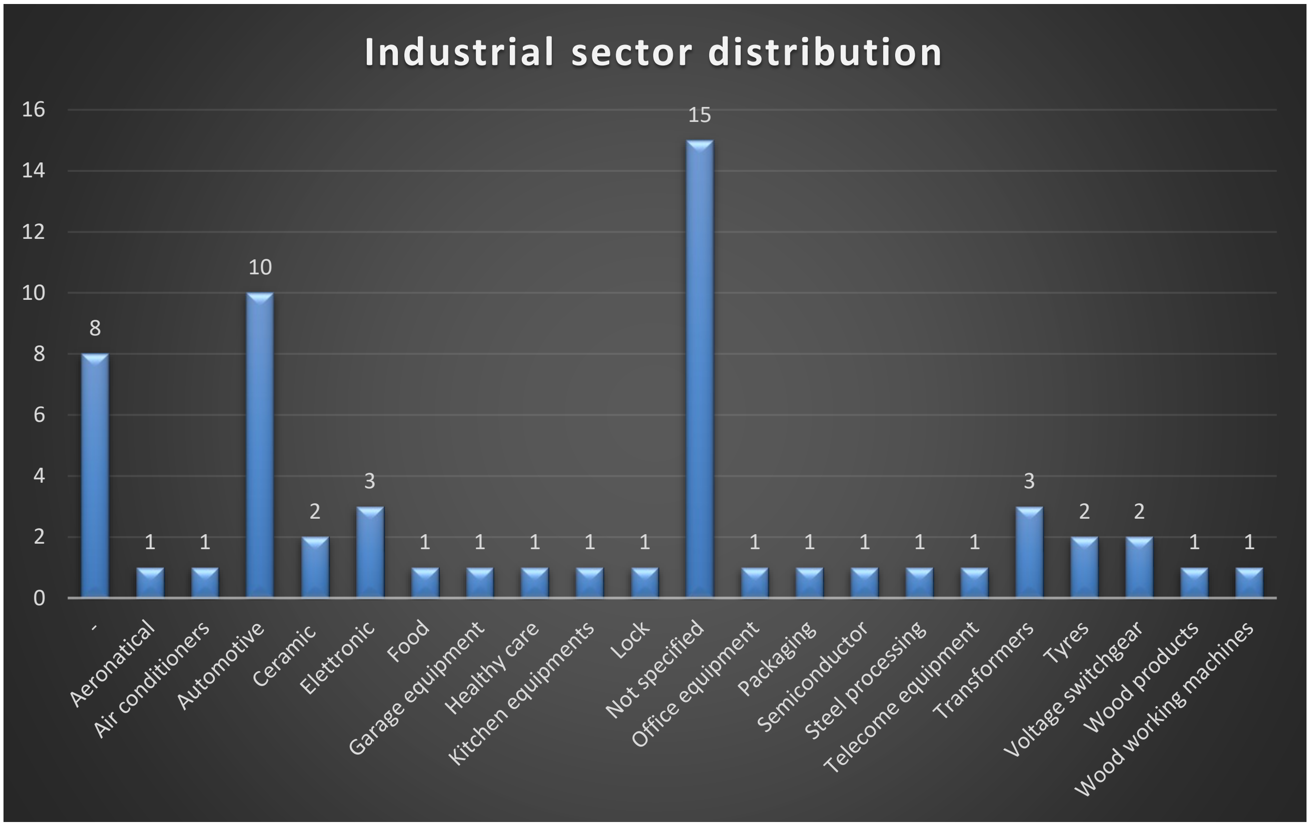

Fig.4.5 Distribution of industrial sectors to which organisations belong

Eight papers didn’t conduct the case study. 15 papers conducted case study without indicating the sector to which organization belong. Some proposed tools (Bhasin S, 2011; Shah R et al., 2007; Thanki S et al., 2014) used survey approach, and sometimes it was not representative to specify the industrial sector because of too many sectors involved. One paper (Belhadi A et al., 2018) proposed a lean assessment tool which is specifically designed for the small and medium size enterprises (SMEs). This kind of tools could be suitable for most sectors to which companies of SME belong. As what we expected, Automotive sector was on the top of list of industrial sectors, followed by the electronic and transformer sectors. The reason could be that in the heavy industry such as automotive, if a critical obstacle identified through a suitable lean assessment tool and then the company overcame the obstacle, the benefit in economic term could be very significant.

4.2.2. Objects in analysis

Figure 4.6 a/b/c shows the objects used in lean assessment tools. Based on the previous explanation, the tools could be developed on the degree of adoption of LP or KPIs. The percentage and quantity of every object is shown in figure 4.7.

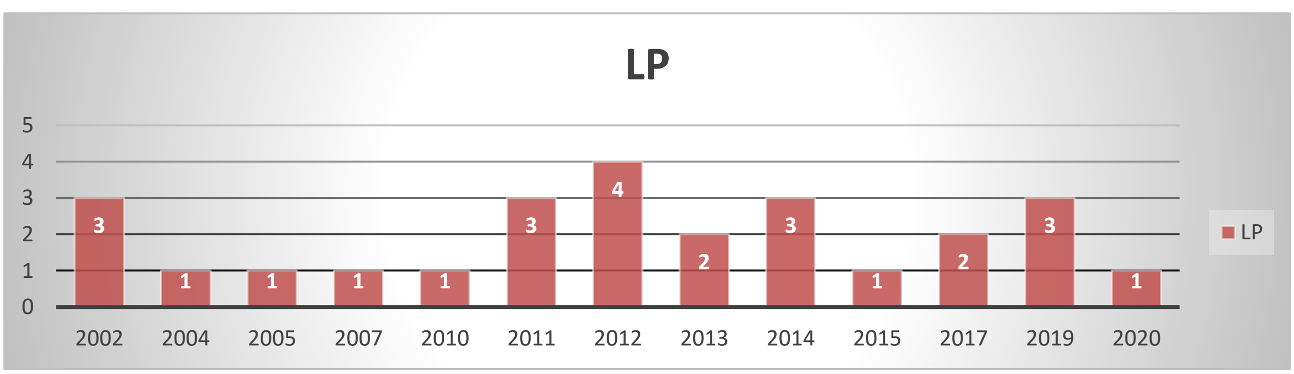

Fig.4.6a Classification of lean assessment tools based on adoption of lean practices

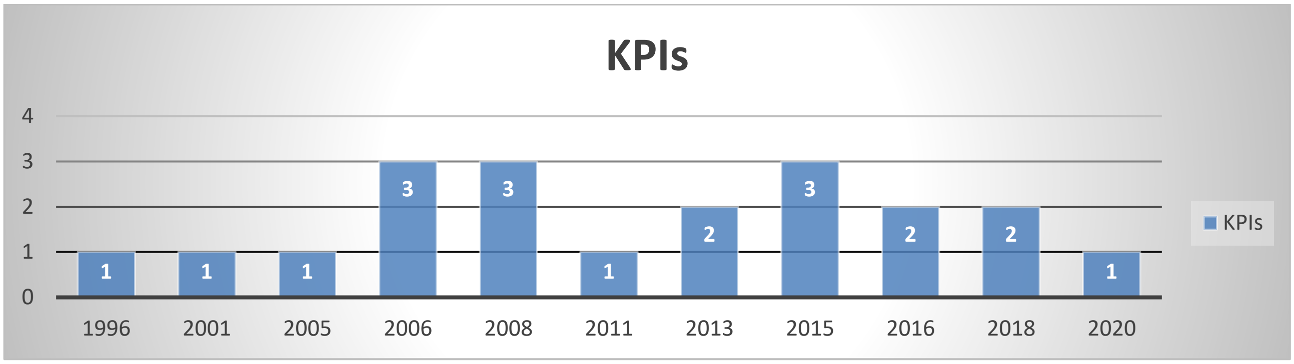

Fig.4.6b Classification of lean assessment tools based on KPIs

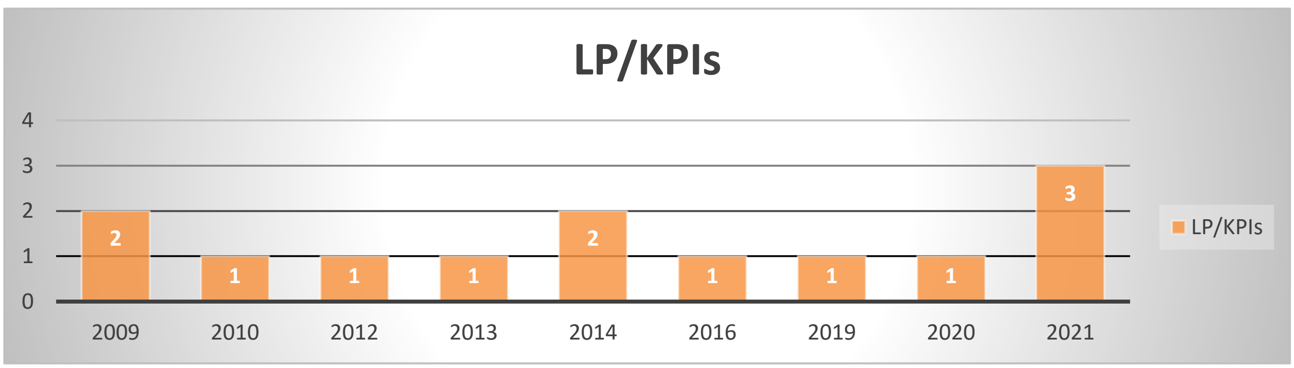

Fig.4.6c Classification of lean assessment tools based on LP/KPIs

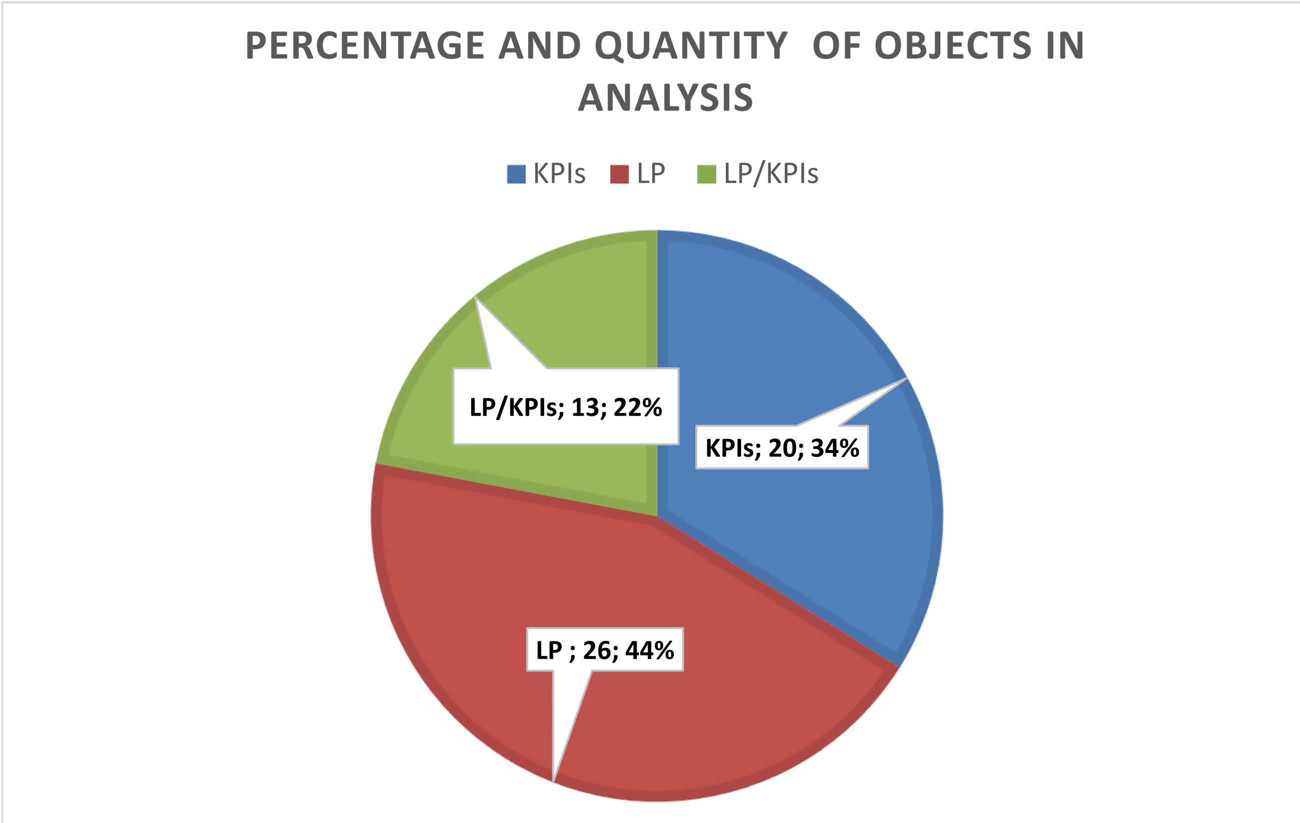

Fig.4.7 Percentage and quantity of objects in analysis

In 59 papers, we found 26 tools which were developed based on adoption of LP, 20 tools which were developed based on KPIs, 13 tools which were developed based on LP as well as KPIs. As indicated from the figure 4.6c, the tools developed based on LP and KPIs started trending from 2009 and the research remained low on this kind of tool. This kind of tools include more leanness attributes, not just limited on lean practices.

The study in the future can develop tools based on LP as well as KPIs and using KPIs can overcome the problem associated with the perception of perceptual judgment.

4.2.3. Nature of tool

Figure 4.8 a/b/c show the nature of tool used in lean assessment tools. Based on the previous explanation, the tools could be classified in qualitative, quantitative and hybrid tool. The percentage and total quantity are shown in the figure 4.9.

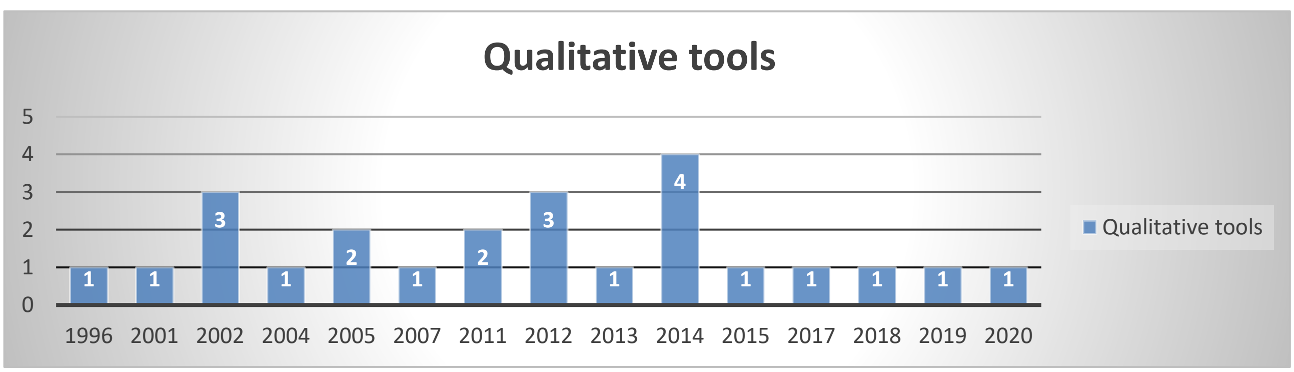

Fig.4.8a Qualitative tools (L)

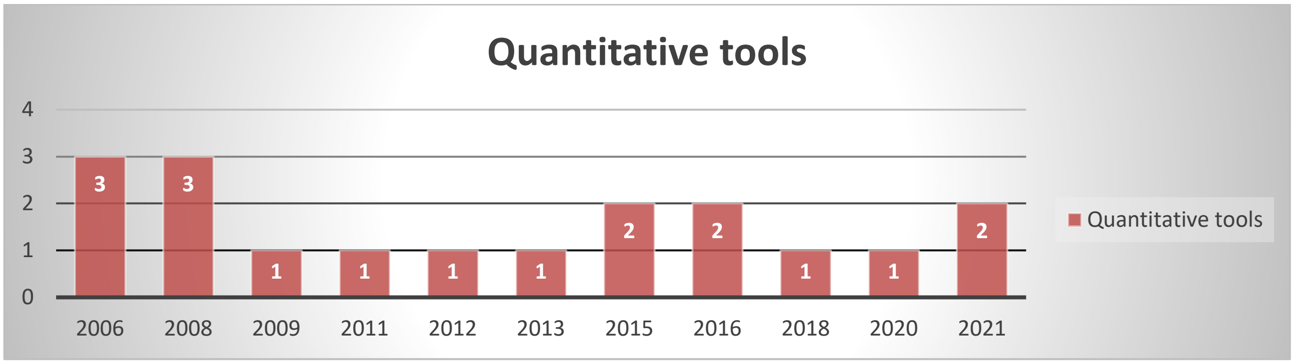

Fig.4.8b Quantitative tools (T)

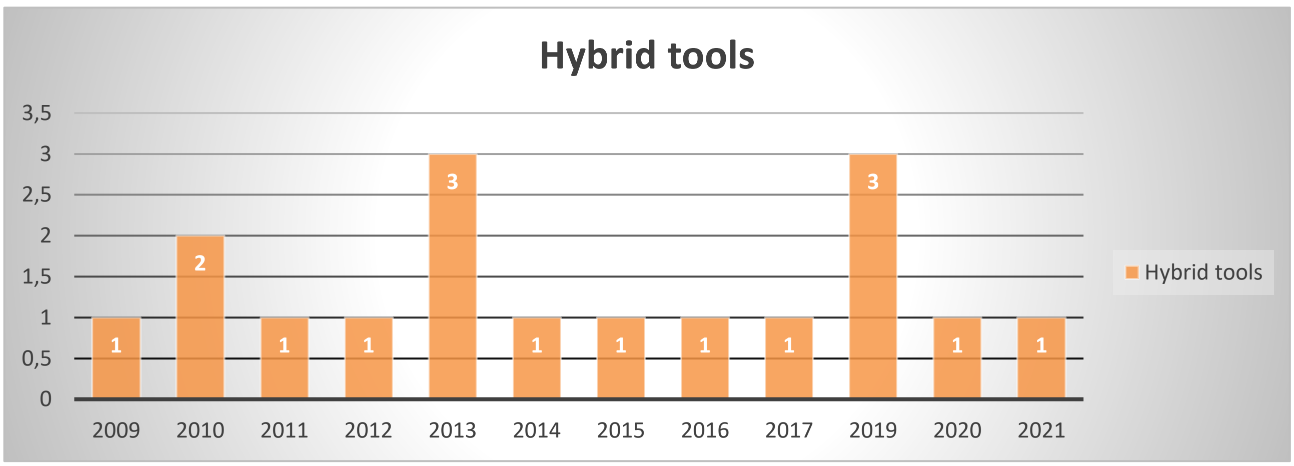

Fig.4.8c Hybrid tools (LT)

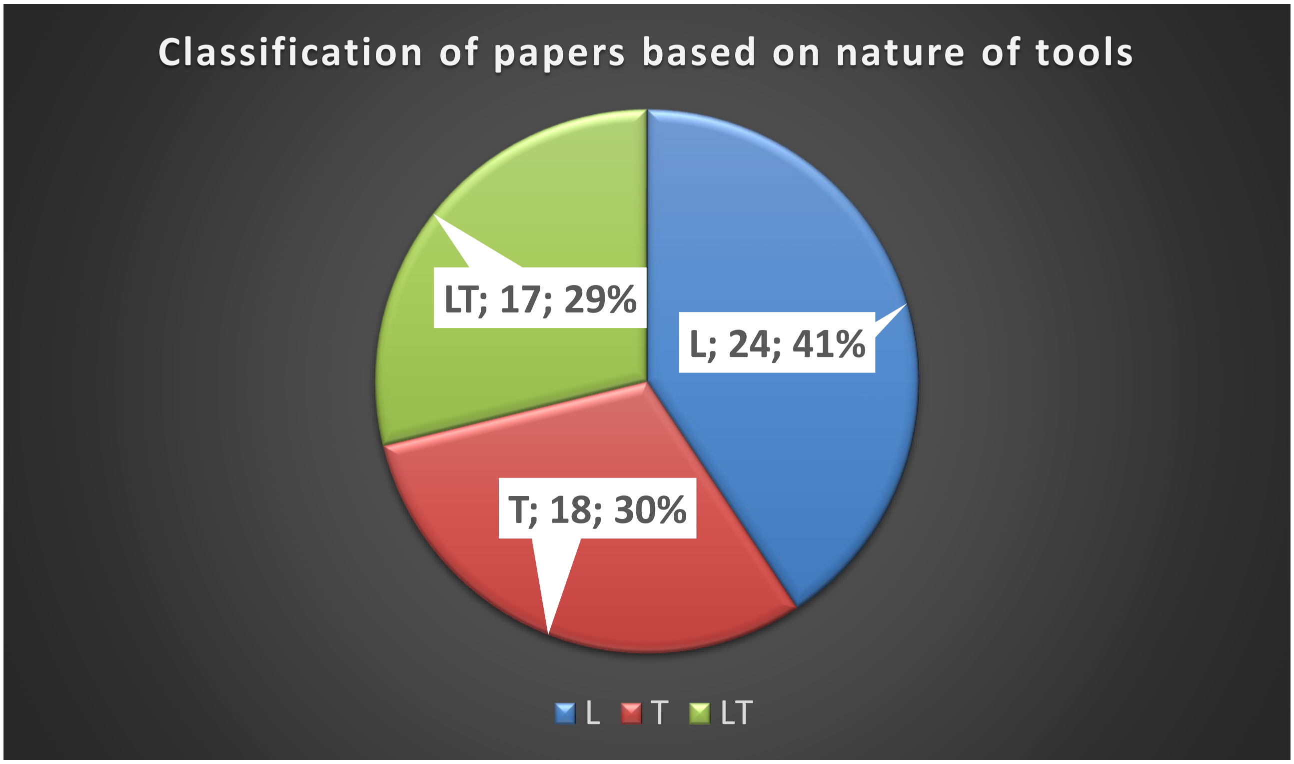

Fig.4.9 Percentage and total quantity of papers based on nature of tools

As indicated from above charts, the development of qualitative tool was earlier than quantitative tool and hybrid tool. The first tool developed by Karlsson and Ahlstrom in 1996 (Karlsson C et all.,1996) is a qualitative tool, authors developed an operationalized tool which can be used to assess the changes taking place to introduce lean production. This model indicated the principles to implement and the actions which should be taken to achieve the desired performance. The mathematical calculations with indicators measurable for level of lean were not found.

In 2006 three papers were found which proposed the quantitative tool. (Ray C.D et all.,2006) developed a tool with Factor analysis technique which allowed measure the leanness of a company. The tool with Factor analysis approach was as a quantitative tool (Oleghe O et al., 2018). (Srinivasaraghavan J et al.,2006) proposed a quantitative tool with Mahalanobis Taguchi Gram Schmidt System (MTGS) approach which could measure the overall leanness of an organization. (Kollberg B et al.,2006) proposed a tool with “flow model” which contained 8 measures for representing the critical success factors for assessing the changes towards lean thinking in health care services.

We noticed that the hybrid tool has been getting more popular from 2009. As indicated from (Pakdil F et al.,2014), using just one approach may create a bias and a tool which could combine both quantitative and qualitative measures was able to overcome the disadvantages of each nature, and it also allowed to obtain complete view of the organisation's leanness efforts.

Between the hybrid tools, the tools which use fuzzy logic as approach for evaluating the leanness level of company should be highlighted. As defined by (Bayou M.E et al.,2008), the lean is a matter of degree, and the measurement of leanness should use the fuzzy logic approach. Using the fuzzy logic could remove the vagueness effects created during the qualitative evaluation (Vinodh S et al.,2011), the ambiguity and the uncertainty of human evaluation (Abreu A et al.,2017). Some authors defined that the tool with fuzzy logic was quantitative tool (Oleghe O et al., 2018; Bayou M.E et al.,2008). In this thesis the tools with fuzzy logic are defined as a hybrid tool. It is true that using the fuzzy logic allows to integrate the quantitative or qualitative measures into fuzzy numbers, but the performance rating and the related weight are still based on the personal justification, the subjectivity still exists.

4.2.4. Type of scale

The figure 4.10 shows quantity of type of scale used in lean assessment tools.

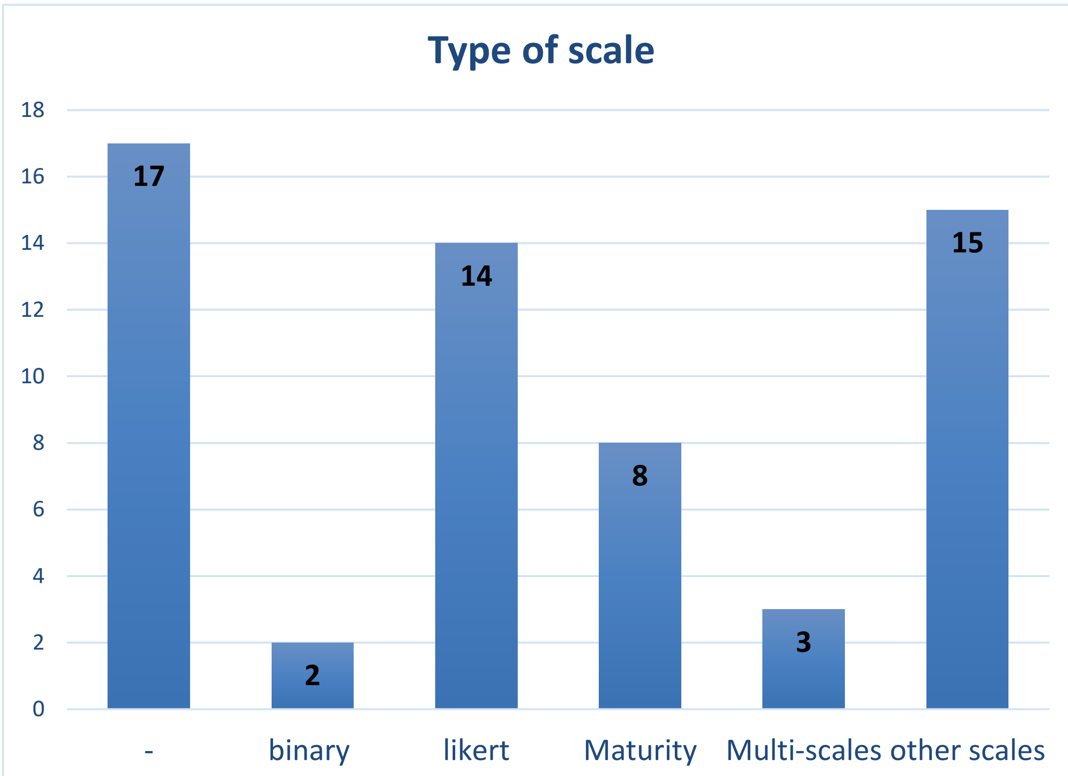

Fig.4.10 Quantity of each type of scale

In the 59 tools the major qualitative tools used the scales such as Likert, Binary, or maturity scales. 15 tools used fuzzy scale with linguistic variables for level of leanness were classified in “other scales”. 3 papers which used multi-scales, (Goodson R.E, 2002) created an RPA questionnaire in which questions should be answered with yes or no, the total number of Yes supported to give scores in Likert scales for every category. The paper (Behrouzi F et al.,2011) firstly used a survey to identify and categorize the most important lean supply chain performance measures in automotive industry in Iran, the answers were responded according to a five-point scale. Based on the mean scores and the relative weight obtained the leanness evaluation was conducted through approach stochastic-fuzzy. The same procedure was appeared also in (Kumar N et al.,2019) which started from a questionnaire with answers on five Likert scale and used fuzzy scale to calculate the level of leanness. We also found 17 tools without scale, and the majority of these 17 tools was quantitative which consisted in quantifying the level of lean through mathematical calculations with numerical measures.

4.2.5. Approach used in tools

The figure 4.11 shows the specific approach used in tools developed by researchers, and the Figure 4.12 shows the abbreviation of some approaches.

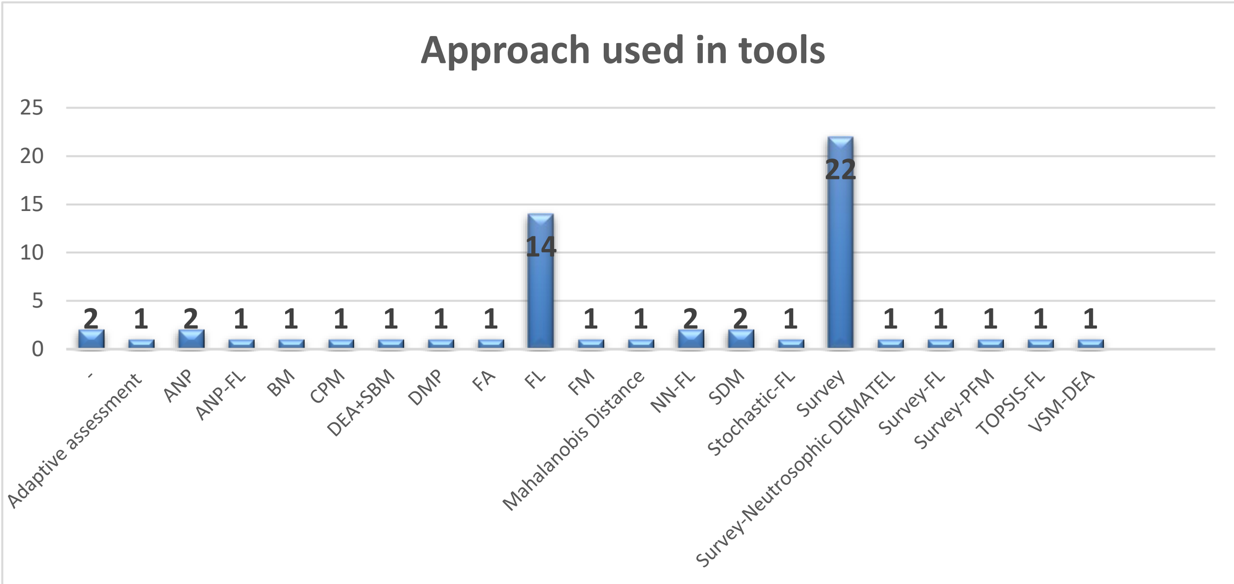

Fig.4.11 Classification of approaches used in tools

Description of Approach	Abbreviatio
The analytic hierarchy process	AHP
The analytic network process	ANP
Benchmarking	BM
Continuous performance measurement	CPM
Data envelopment analysis	DEA
Decision-making Trial and Evaluation Laboratory	DEMATEL
Dynamic multi-dimensional performance	DMP
Factor analysis	FA
Fuzzy logic	FL
Flow model	FM
Neural network	NN
Problem focus matrix	PFM
Slacks based measure	SBM
Systems dynamics modeling	SDM
Technique for Order Preference by Similarity to Ideal Solution	TOPSIS
Value stream mapping	VSM

Fig.4.12 Abbreviation of different approaches

The survey approach tops the list, and this kind of approach is considered as the most popular approach used in lean assessment. A major part of qualitative tools used survey, the reason could be that the survey approach is a self-rated assessment, and the collected data could be analysed quickly.

Another important approach used by 13 tools as indicated from the table is Fuzzy logic (FL). The FL is considered as one useful technique of Multiple Criteria Decision Making (MCDM). As indicated by (Alexander L.M et al.,2022), the AHP, ANP, TOPSIS, VIKOR, FL were the traditional technique in lean assessment. MCDM techniques helps us to break down the complex problems into minor parts. After analysing each single part, it is possible to combine all components to give the comprehensive situation of the same problem.

The paper (Cil I et al.,2012) used ANP approach to the identification of weights of the organization's lean transformation determinants, and the highly qualitative relationship among the lean transformation components are operationalized. (Wong W.P et al.,2012) developed a lean index which was quantified using ANP to assess the leanness level of the organisation in sustaining lean transformation.

There were also some special approaches used in different tools such as adaptive assessment, BM, CPM, DMP, FA, FM, SDM, and Mahalanobis Distance. These approaches were used by less than 2 papers. The reasons could be a lot: the complexity of the approach, compatibility with specific organization, real time collection of data, etc. (Gopalakrishnan Narayanamurthy Anand Gurumurthy,2016).

The paper (Alexander L.M et al.,2022) explained also that the current lean implementation and assessment methods were time-consuming and the delay in the outcomes existed always. Using only one technique could not be able to handle a large volume of information which rendered complex the system. The combined approach could assist humans in overcoming the limitations of their inability to handle the multiple variables.

The paper (Seyedhosseini S.M et al.,2015) combined in a unique approach the group fuzzy logic with ANP to resolve the interdependencies within two determined levels in the proposed tool and found a new way to calculate the leanness score for the overall organisations as well as the leanness score for each level through auditing the companies.

The paper (Vimal K.E.K. et al.,2013) proposed a tool based on fuzzy logic for leanness assessment, the problem associated with manual computation has been overcome by the application of an artificial Neural Network (NN). The paper (Saleeshya P.G. et al.,2019) developed a tool for lean assessment which accounted aspects of inventory management, industrial scheduling, organisational flexibility, ergonomics, products, process, management, workforce, supplier relationship and customer relationship with NN-FL hybrid approach. The accuracy of leanness index and the learning capacity of tool was increased by integrating NN in the approach with fuzzy logic. The paper (Behrouzi F et al.,2013) combined the FL with stochastic approach for evaluating the predicting the total leanness of a supply chain based on the real situation and available data. The paper (Kilic H.S et al.,2021) proposed a tool which considered a wide range of lean indicators with a comprehensively designed survey, and the tool used neutrosophic DEMATEL to evaluate the leanness. The paper (Alemi M.A. et al.,2013) presented a tool by using fuzzy TOPSIS to measure the leanness of manufacturing system, as a paradigm. The Fuzzy TOPSIS aimed to determine the ranking order of all the categories, and this ranking reflects the status of the plant before applying important coefficients for computing the leanness score of company.

Others approaches which combined two techniques such as survey-FL, VSM-DEA, DEA-SBM were also used in lean assessment. In summary, we found few tools which were developed with 2 approaches combined. Using 2 techniques combined as a unique approach could help to make the lean assessment more accurate ((Alexander L.M et al.,2022) and to handle the complexity of the contingent context. Future research can continue to choose a combination of the two appropriate approaches to develop new tools with the goal to maximize the shortcomings of using only one approach.

4.3. A new classification matrix of lean assessment tools based on adoption of lean practices (LP)

4.3.1. Definition of the new classification matrix

After a literature review with content analysis of 59 papers that proposed lean assessment tools, a clear criterion for classification of lean assessment tools totally or at least partially based on adoption of lean practices (LP) has not been found. Biazzo (Biazzo S et al.,2003) stated that the "excellence models" as evaluation framework for organisational self-assessment was not necessarily the proper "choice", particularly for SMEs. Authors have proposed a framework that could differentiate self-assessment methods based on three key dimensions: the assessment logic adopted, nature of the self-assessment tools, and the types of analytical frames employed to guide data gathering (process or non-process based). Finally, the five different approaches in a matrix were identified: paradigmatic, normative, situational, normative-situational, and open.

The same problem was also highlighted by Panizzolo in 2010 (Panizzolo R et al.,2010). In this paper authors pointed out that the major models and tools were not capable of effectively supporting company assessment needs since they do not envisage clear mechanisms for stimulating critical considerations on current management practices and for sustaining improvement planning. In this paper a refined matrix for classification of assessment methods was presented based on two dimensions: logic of assessment adopted (Conformity, Coherence, Causality), nature of tools used with reference to the level of incorporation of diagnostic expertise.

Based on the work of papers (Biazzo S et al.,2003; Panizzolo R et al.,2010), a new classification matrix is proposed in this thesis. The Figure 4.13 shows that the new classification consists in a matrix subdivided in four cells: Scoring approach, adaptive scoring approach, positioning approach, and situational positioning approach.

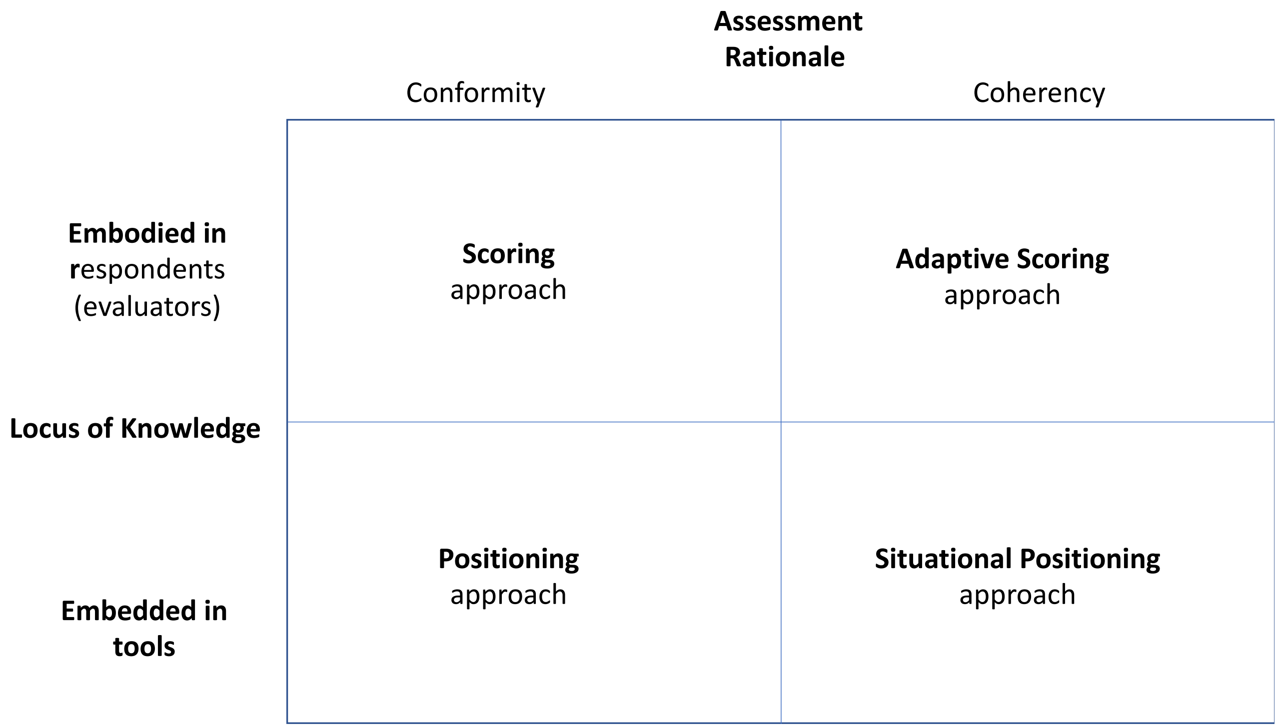

Fig. 4.13 Matrix of classification of lean assessment tools based on adoption of LP

This matrix differentiates the assessment tools based on two fundamental dimensions:

- Locus of Knowledge

This dimension aims to distinguish assessment tools based on how dependent they are on the knowledge/experience of "evaluators". Evaluators could be the internal staff or external experts. If the assessment tool uses binary scales or Likert scales with simple numerical values (for example from 1 to 5 or from 1 to 7) we can affirm that the knowledge is embodied in the respondents. Conversely, if the assessment tool contains a maturity scale in which the knowledge is clearly given for each of practices, then the knowledge is embedded in the tool. In other words, the answers are less related to the sensitivity of the respondents.

- Assessment rationale

This dimension aims to identify two different assessment logics:

-Conformity consists in seeking adherence to a predefined set of Lean "best practices" that are considered universally applicable.

-Coherency is the search for alignment to a reference model of Lean "good practices" that varies in relation to the contextual conditions both internal and external to the organization.

When these 2 dimensions are cross-referenced, the matrix is created, which differentiates 4 lean assessment approaches:

➢ **Scoring**

In case that the dependence on the knowledge of the evaluator is very high and the logic is conformity, the tool belongs to "Scoring". The kind of assessment consists in the evaluation through Likert-Type Scales or Binary-scales of a set of lean practices that in fact represent a universal reference model on which to base the degree of leanness of a company. The choice of the score to be assigned to the individual practices to evaluate the degree of implementation heavily relies on knowledge embodied in evaluators in terms of knowledge of the company organization and its lean expertise.

- **Positioning**

In case that the dependence on the knowledge of the evaluator is strongly reduced as they seek to embed as much knowledge as possible in tools and the logic is conformity, the tool belongs to “Positioning”. The kind of assessment includes an assessment through maturity scales. For each practice, a maturity scale is developed on "n" levels that codify and operationally describe different degrees of implementation of the practice. Respondents are asked which level better describes the current state of implementation of the specified practice and then correctly position the company in the maturity grid.

- **Adaptive scoring**

In case that the knowledge is embodied in respondents and the logic is coherency, the tool belongs to “Adaptive scoring”. There is no universal Lean model of reference with concept of coherence according to the normative-contingent perspective (Biazzo S et al.,2003). The evaluation is in fact based on a Lean tool that is contingent according to the contextual conditions both internal and external to the organization. This variation is reflected in differentiating the importance of the different lean practices, and at the limit excluding certain practices irrelevant / not relevant in a context of implementation. The evaluation is always carried out with Likert-Type Scales or Binary-Scales.

- **Situational positioning**

In case that the knowledge is embedded in the tool and the logic is coherency, the tool belongs to “Situational positioning”. This kind of assessment consists in integrating the normative-contingent perspective with use of maturity grids. This kind of tool would allow managers to identify a consistent reference model with the operational and strategic conditions that characterize the company.

4.3.2. Results of classification in matrix of tools collected

After defining the new classification matrix, 39 tools based on the adoption of LP were selected to classify according to the proposed new matrix. The figure 4.14 shows the results, and the figure 4.15a/b/c shows the reference of papers for Scoring/Adaptive Scoring/Positioning approach.

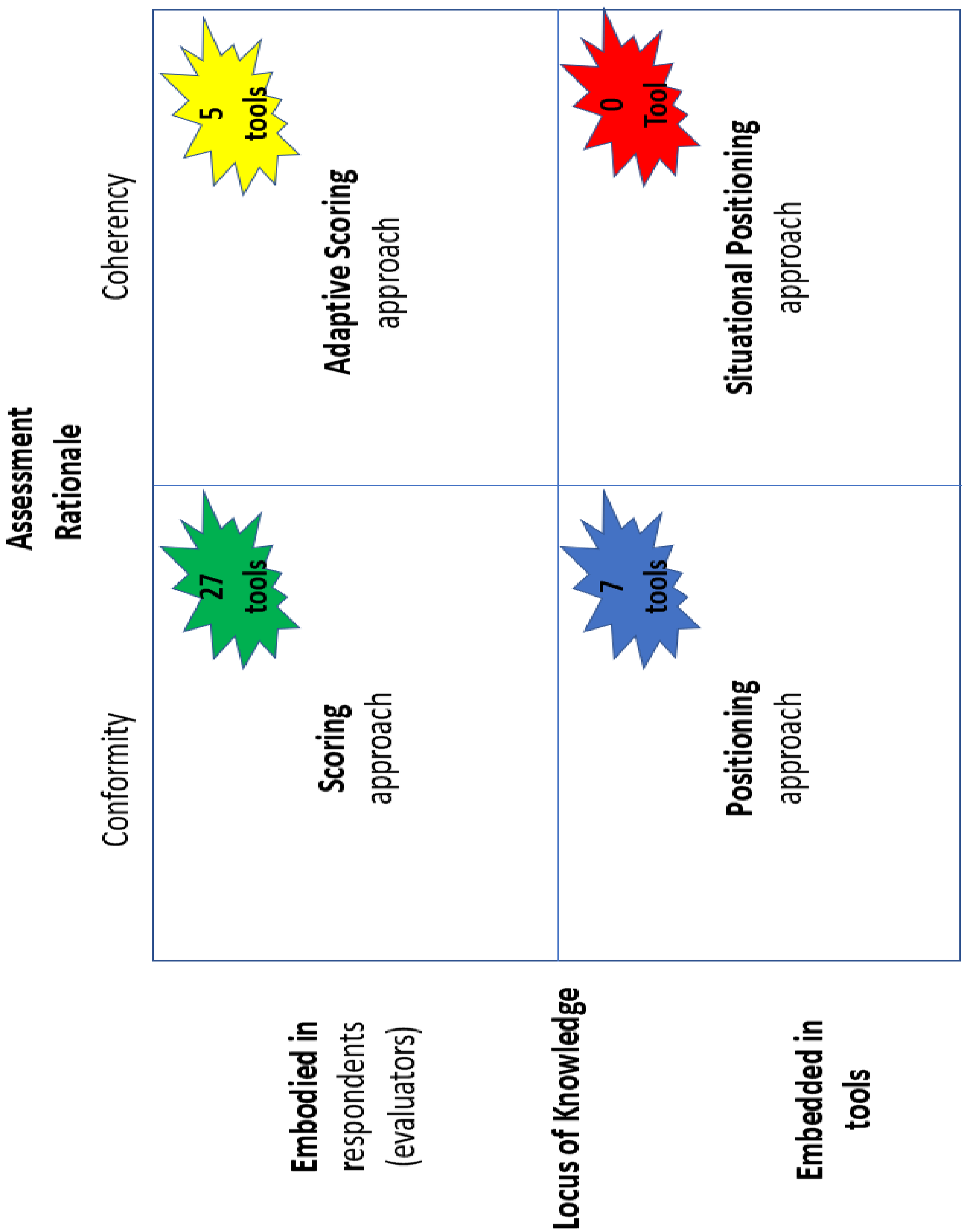

Fig. 4.14 Results of classification in matrix of 39 tools based on adoption of LP

No.	Reference of papers -Scoring approach
1	Horacio Soriano-Meier, Paul L. Forrester, (2002),"A model for evaluating the degree of leanness of manufacturing firms", Integrated Manufacturing Systems, Vol. 13 Iss: 2 pp. 104 - 109
2	Goodson ER (2002), Read a plant fast. Harvard Business Review 80(5): 105–113.
3	Kojima S and Kaplinsky R (2004), The use of a lean produc tion index in explaining the transition to global competi tiveness: the auto components sector in South Africa. Technovation 24(3): 199–206.
4	Doolen TL and Hacker ME (2005), A review of lean assess ment in organizations: an exploratory study of lean prac tices by electronics manufacturers. Journal of Manufacturing Systems 24(1): 55–67.
5	Shah R and Ward PT (2007), Defining and developing mea sures of lean production. Journal of Operations Manage ment 25(4): 785–805.
6	Singh B, Garg SK and Sharma SK (2010), Development of index for measuring leanness: study of an Indian auto com ponent industry. Measuring Business Excellence 14(2): 46
7	Zanjirchi SM, Tooranloo H and Nejad LZ (2010), Measuring organizational leanness using fuzzy approach. In: Proceed ings of the 2010 international conference on industrial engi neering and operations management, Dhaka, Bangladesh, 9–10 January.
8	S. Vinodh & Suresh Kumar Chintha (2011), Leanness assessment using multi-grade fuzzy approach, International Journal of Production Research, 49:2, 431-445
9	Chauhan, G. and Singh, T.P. (2012), Measuring parameters of lean manufacturing realization, Measuring Business Excellence, Vol. 16 No. 3, pp. 57-71.
10	Vinodh, S., Vimal, K.E.K.(2012), Thirty criteria based leanness assessment using fuzzy logic approach. Int J Adv Manuf Technol 60, 1185–1195 .

11	Azevedo SG, Govindan K, Carvalho H, et al. (2012) An inte grated model to assess the leanness and agility of the auto motive industry. Resources, Conservation & Recycling 66: 85–94.
12	Wong, P., Ignatius, J., and Soh, K. (2012) What is the leanness level of your organisation in lean transformation implementation? An integrated lean index using ANP approach. Production Planning & Control: The Management of Operations, 23, 1–15.
13	Vimal, K.E.K. and Vinodh, S. (2013), Application of artificial neural network for fuzzy logic based leanness assessment, Journal of Manufacturing Technology Management, Vol. 24 No. 2, pp. 274-292
14	Gupta, V., Acharya, P. and Patwardhan, M. (2013), A strategic and operational approach to assess the lean performance in radial tyre manufacturing in India: A case based study, International Journal of Productivity and Performance Management, Vol. 62 No. 6, pp. 634-651
15	Alemi MA and Akram R (2013) Measuring the leanness of manufacturing systems by using fuzzy TOPSIS: a case study of the "Parizan Sanat" company. South African Journal of Industrial Engineering 24(3): 166–174.
16	Thanki, S.J. and Thakkar, J. (2014),Status of lean manufacturing practices in Indian industries and government initiatives: a pilot study, Journal of Manufacturing Technology Management, Vol. 25 No. 5, pp. 655-675.
17	Elnadi M and Shehab E (2014), A conceptual model for evalu ating product-service systems leanness in UK manufactur ing companies. Procedia CIRP 22: 281–286
18	Pakdil F and Leonard KM (2014), Criteria for a lean organisa tion: development of a lean assessment tool. International Journal of Production Research 52(15): 4587–4607.
19	Abreu A and Calado JMF (2017), A fuzzy logic model to eval uate the lean level of an organization. International Journal of Artificial Intelligence & Applications 8(5): 59–75.
20	Goncxalves M and Salonitis K (2017), Lean assessment tool for workstation design of assembly lines. Procedia CIRP 60: 386–391.

21	V. A. Wankhede, A Chaurasia, and N. Khatekar (2019), Leanness assessment of an organization using fuzzy logic approach, Journal of engineering practice and futuristic technologies. Vol. 2, no. 1, pp. 1-6.
22	To cite this document: Saleeshya P.G., Binu M., (2019), A neuro-fuzzy hybrid model for assessing leanness of manufacturing systems, International Journal of Lean Six Sigma, Vol. 10 Issue: 1, pp.473-499
23	Bhankhar, Narender & Jarial, S & Narwal, M. (2019), Assessing Leanness of Fast-Moving Consumer Goods (FMCG) Industry with Fuzzy Logic. International Journal of Engineering and Advanced Technology.
24	Brito, M.F., Ramos, A.L., Carneiro, P. and Gonçalves, M.A. (2020), A continuous improvement assessment tool, considering lean, safety and ergonomics, International Journal of Lean Six Sigma, Vol. 11 No. 5, pp. 879-902.
25	Dahda, S.S. Andesta, D. and Wicaksono, A.S. (2020), Measuring leanness index using fuzzy logic approach, Journal of Physics: Conference Series, Vol. 1469 No. 1
26	Huseyin Selcuk Kilic, Pinar Yurdaer, Canan Aglan.(2021),A leanness assessment methodology based on neutrosophic DEMATEL,Journal of Manufacturing Systems,Volume 59,,Pages 320-344.
27	Elnadi, M. and Shehab, E. (2021), Product-service system leanness assessment model: study of a UK manufacturing company, International Journal of Lean Six Sigma, Vol. 12 No. 5, pp. 1046-1072.

Fig.4.15a Reference of papers-Scoring approach

No.	Reference of papers -Adaptive Scoring approach
1	Anand Gurumurthy, Rambabu Kodali, (2009) Application of benchmarking for assessing the lean manufacturing implementation, Benchmarking: An International Journal, Vol. 16 Issue: 2, pp.274-308,
2	Wan, H.-D. and Chen, F.F. (2009), Decision support for lean practitioners: a web-based adaptive assessment approach, Computers in Industry, Vol. 60, pp. 277-83.
3	Tarcisio Abreu Saurin , Giuliano Almeida Marodin & José Luis Duarte Ribeiro (2011), A framework for assessing the use of lean production practices in manufacturing cells, International Journal of Production Research, 49:11, 3211-3230
4	Cil, I., Turkan, Y.S.(2013), An ANP-based assessment model for lean enterprise transformation. Int J Adv Manuf Technol 64, 1113–1130
5	Vidyadhar R, Kumar RS, Vinodh S, et al. (2016), Application of fuzzy logic for leanness assessment in SMEs: a case study. Journal of Engineering, Design and Technology 14(1): 78–103

Fig.4.15b Reference of papers- Adaptive Scoring approach

No.	Reference of papers -Positioning approach
1	Nightingale D and Mize JH (2002), Development of a lean enterprise transformation maturity model. Information Knowledge-Systems Management 3: 15–3
2	Sanjay Bhasin, (2011),Measuring the Leanness of an organisation, International Journal of Lean Six Sigma, Vol. 2 Iss 1 pp. 55 - 74
3	Lucato WC, Calarge FA, Junior ML, et al. (2014), Performance evaluation of lean manufacturing implementation in Brazil. International Journal of Productivity and Perfor mance Management 63(5): 529–549
4	Ramirez S and Lorena D (2014), A lean logistics assessment tool for SMES in the manufacturing sector. Master's thesis, Purdue University, West Lafayette, IN.
5	Urban W (2015), The lean management maturity self assessment tool based on organizational culture diagnosis. Procedia—Social and Behavioral Sciences 213: 728–733.
6	dos Santos Bento, G. and Tontini, G. (2019), Maturity of lean practices in Brazilian manufacturing companies, Total Quality Management and Business Excellence, Vol. 30 No. sup1, pp. S114-S128.
7	Chiera, M.; Lupi, F.; Rossi, A.; Lanzetta, M. Lean Maturity Assessment in ETO Scenario. Appl. Sci. 2021, 11, 3833.

Fig.4.15c Reference of papers- Positioning approach

As indicated in the figure 4.14, a major part of tools belongs to “Scoring”, a few tools belong to “Adaptive Scoring” and “Positioning”. No tools were found which could be classified in “Situational Positioning”.

The possible future research could be to develop “Situational Positioning” tools to fill the gap in the literature and in the practice of lean assessment.

4.4. Research limitations

From all the papers collected to date on the topic of lean assessment, the limitations of research could be made in the following:

- The number of papers which proposed lean assessment tools is countless. Due to time and resources, this thesis cannot include all the lean assessment tools developed in the past. This thesis is limited to represent some mainstream tools and some tools that are frequently cited in other literatures.
- The review is focused on the manufacturing field, but it doesn’t mean that the lean assessment could only be found in this field. Since lean

thinking became a philosophy from the late 1990s expanded into various industries, the different tools proposed in other fields could also be useful in the manufacturing field.

- The reason for choosing a tool considering the different characteristics such as the nature of tool, objects in analysis, approach used is not detected in this thesis.

Conclusions

Any improvement and implementation of lean should be based on an assessment of the current state and measurement of the distance to the desired level of lean. Lean assessment is fundamentally important in the lean transformation roadmap. However, the complex manufacturing system and external operating environment determined that there is no longer a simple "do-then be lean'' relationship and lean assessment tools are evolving to be more flexible and sophisticated.

In this thesis, a comprehensive framework of lean assessment qualitative and quantitative tools proposed to date in the manufacturing field was presented. The 59 papers which proposed lean assessment tools were found through conducting a scientific literature review with the procedure suggested by Phillip Mayring (Phillip Mayring, 2003). The general overview and trend of lean assessment is illustrated through the descriptive analysis on the publication of papers, timeline distribution, authorships, and geographic locations of case study. The main characteristics and the structure of lean assessment tools were reviewed through the categorical analysis which is conducted based on industrial sector of case study, objects in analysis, nature of tools, type of scales, and approach used in tools. The main findings can be summarized as follows:

- The tools which were defined “hybrid tool” could integrate the unquantifiable measures with the numerical measures to calculate the overall leanness level.
- The survey and fuzzy logic (FL) were the most popular approaches used in lean assessment tools, and the combination of two appropriated approaches of Multiple Criteria Decision Making (MCDM) started getting more attention from researchers for the reason of good ability to handle the massive information, and capacity to increase the accuracy of assessment tool.
- A new matrix of classification for lean assessment tools which are developed based on the adoption of lean practices (LP) is proposed

in this thesis. The new matrix of classification differentiates the assessment tools into 4 approaches: “Scoring”, “Adaptive Scoring”, “Positioning”, and “Situational Positioning”. A total of 39 tools selected from 59 tools reviewed was classified in the new matrix.

The future research could focus on detecting the reason for choosing the different type of lean assessment tool and developing “Situational Positioning” tools to fill the gap in the literature and in the practice of lean assessment.

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