INSTITUTO UNIVERSITÁRIO DE LISBOA

Prioritizing Lean Techniques by Employing Multi-Criteria Decision-Making (MCDM): The Case of MCoutinho

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Resumo

O ciclo de negócios na indústria automotiva segue de perto o ciclo econômico geral e, portanto, sofre flutuações cíclicas ao longo do tempo. As empresas do setor enfrentam desafios e precisam lidar com as demandas do mercado de forma eficiente e rápida para se manterem competitivas. A abordagem enxuta é uma das estratégias que pode ajudar as empresas a melhorar sua competitividade, minimizando o desperdício (Pullan et al., 2013). Para se beneficiar de uma abordagem enxuta, o primeiro passo é selecionar uma ferramenta adequada com base nos recursos disponíveis e requisitos da empresa.

Devido ao fato de que várias ferramentas enxutas foram introduzidas ao longo do tempo, os tomadores de decisão na empresa podem encontrar desafios ao selecionar a ferramenta adequada com relação às suas demandas. Para lidar com essa questão, a Tomada de Decisão Multi-Critérios (MCDM) pode ajudar muito os tomadores de decisão a comparar as alternativas disponíveis e, conseqüentemente, selecionar a melhor solução possível entre elas. Este estudo tem como objetivo melhorar o processo operacional do Grupo MCoutinho, empresa portuguesa de renome no setor automóvel, auxiliando a administração na seleção da ferramenta enxuta em função das preferências da empresa.

Neste estudo, a aplicabilidade (e resultados) da aplicação de algumas técnicas MCDM (SAW, TOPSIS e VIKOR) é examinada para comparar dez ferramentas enxutas, determinadas com base na literatura. Os resultados revelam algumas lacunas entre os requisitos da empresa e as demandas consideradas em pesquisas anteriores. O processo aplicado pode economizar os custos de tentativa e erro de implementação de diferentes ferramentas enxutas. E, por fim, a adoção de uma ferramenta tão enxuta que foi selecionada totalmente com base nos requisitos exclusivos da empresa pode melhorar a eficiência da empresa.

Palavras-chave: Decision-making, lean management**,** Multi-Criteria Decision-Making (MCDM), SAW, TOPSIS, and VIKOR

Abstract

The business cycle in the automotive industry follows the general economic cycle closely and therefore, undergoes cyclical fluctuations over time. Companies in the sector are faced with challenges and need to deal with market demands efficiently and quickly to stay competitive. Lean approach is one of the strategies that can aid firms to improve their competitiveness by minimizing waste (Pullan et al., 2013). In order to benefit from a lean approach, the first step is to select a proper tool based on the available resources and requirements of the company.

Due to the fact that numerous lean tools have been introduced over time, decision makers in company may encounter challenges in selecting the proper one with regard to their demands. To deal with such an issue, Multi-Criteria Decision-Making (MCDM) can greatly assist decision makers to compare available alternatives and consequently select the best possible solution among them. This study aims at improving the operational process in *MCoutinho Group*, a Portuguese well-known company in the automotive sector, by helping the management board in selecting lean tool due to the company preferences.

In this study, the applicability (and results) of the application of some MCDM techniques (SAW, TOPSIS, and VIKOR) is examined to compare ten lean tools, determined based on the literature. The results reveal some gaps between company requirements and the demands which have been considered in previous surveys. The process applied can save the costs of trial and error of implementing different lean tools. And finally, adopting such a lean tool that has been selected totally based on the exclusive requirements of the company can improve efficiency in the company.

Keywords: Decision-making, lean management**,** Multi-Criteria Decision-Making (MCDM), SAW, TOPSIS, and VIKOR

Executive Summary

The changinging nature of business environment requires adopting effective strategies to deal with these challenges and to better meet the market demand. Lean approach can can aid firms to address such concers. Considering the inevitable and critical role of lean tools in the success or failure of a lean system, this study aimed at contribution to improve the operational process in *MCoutinho Group* which is one of the top spare-parts distributers in Portuguese automotive sector. It was intended to increase the company's chance of gaining competitive advantage, by selecting (an) effective lean tool/s respecting the company's requirements.

The existence of numerous lean tools, each with its own advantages, makes the process of selecting the most adequate tool difficult for decision makers in a company. To cope with such an issue, Multi-Criteria Decision-Making (MCDM) can assisst decision makers to make suitable decision.s MCDM provides a systematic procedure which can help decision makers evaluate and compare available alternatives – in this case, lean tools – in terms of criteria defined based on the company's requirements, to select an appropriate option.

In order to provide an effective evaluation process in MCDM, the first crucial step is to determine the company's needs and preferences, in close collaboration with its decision makers. In this case, four interviews were held with managers and staff of Porto branch of the group. The first meeting was with the general manager of the branch. The purpose of this meeting was to identify the main concerns and challenges of the company in addressing the market and customers' needs, as well as the role of waste reduction in achieving the desired results.

Two other interviews were conducted with the company product manager – who had a comprehensive knowledge on production process and customers' demand – and team leader. In the last interview with two other members of the team together with the product manager, provided details and main attributes were reviewed and finalized. Finally, a list consist of four main requirements of the company which needed to be covered by a proper lean tool was made. These four main criteria were: user-friendliness, long-term impact, payback period, and risk mitigation.

To upgrade the results obtained from interviews and in order to cover the most critical attributes which have been considered in the previous studies in lean management, 26 articles were reviewed.

The result of this survey uncovered five key criteria, which were the most often repeated in the literature, namely, cost, quality, lead time, productivity, and inventory.

After defining the nine main criteria (i.e. user-friendliness, long-term impact, payback period, risk mitigation, cost, lead time, quality, productivity, and inventory) and selecting lean tools from the investigation carried out by Alves et al. (2011), which studied 20 well-known lean tools over a decade in 41 projects in companies based in Portugal, these lean tools (i.e. 5S, Kanban, Cellular Manufacturing, Single Minute Exchange of Die (SMED), Value Stream Mapping (VSM), Visual Controls, Production Leveling (*Heijunka*), Standardized Work, *Poka-Yoke* (Mistake Proofing), and Line Balancing) needed to be assessed and compared based on the defined criteria, using MCDM techniques.

Due to MCDM process, first criteria need to be weighted by experts based on their importance, then alternatives are compared and ranked in terms of the weighted criteria. Hence, with the intention of gathering different perspectives from experts in the field of lean management to help decision makers in selecting (a) suitable lean tool/s, a closed-ended type of questionnaire was designed. Questions were gathered in nine multiple-choice tables, and the experts were asked to rate the impact of each lean tool under analysis on each attribute, on a seven point scale.

After receiving the responses from questionnaire, and before analysing the responses using MCDM techniques, the criteria needed to get weight based on their importance for selecting a lean tool. The process of weighting criteria was done by applying Shannon Entropy which is one of the most commonly used techniques.

Simple Additive Weighting (SAW) method was the first method utilized to assess and compare the alternatives based on weighted criteria. Based on this method, 5S achieved the highest rank. Visual Controls, Poka-Yoke (Mistake Proofing) and Single Minute Exchange of Die (SMED) were respectively placed in the second, third and the fourth places.

The second technique that was applied to evaluate and rank the alternatives was a distance-based method called Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The outcomes of TOPSIS showed the same results as SAW method, for the first three best tools, but in contrast with SAW wherein SMED was the fourth ranked tool, Value Stream Mapping (VSM) placed in the fourth position.

And for the last try, alternatives were evaluated using VIšekriterijumsko KOmpromisno Rangiranje (VIKOR). Although the results of this method represented the same as two other methods for the two best alternatives, in contrast with the last two methods Single Minute Exchange of Die (SMED) was ranked third, and Poka-Yoke (Mistake Proofing) was placed as the fourth option.

In order to unify the obtained results, three aggregate methods, so called Borda, Copeland, and Average method were utilized. Therefore, the final ranking indicated that 5S can be considered as the first option, and Visual Controls, *Poka-Yoke* (Mistake Proofing) and Single Minute Exchange of Die (SMED) were ranked from number 2 to number 4 respectively.

The outcomes highlighted certain points. First, user-friendliness received the highest weighting overall. This suggests that in order to fully benefit from a lean tool, the tool should be user-friendly, i.e. easily understood and performed by different level employees in the team.

Second, tansparency which is the core point behind the top three ranked tools (Moser and Dos Santos, 2003), is a critical aspect for selecting an appropriate tool in the study. As it has been mentioned by Moser and Dos Santos (2003), improving transparency and visualization will encourage progressive and continuous improvement in the system.

Third, 5S which is a fundamental lean tool, was ranked as the first option. 5S is easy to be implemented and can provide a systematic-organized work environment to reduce waste (Spath, 2011). With the purpose of increasing its advantages, the application of Visual Controls, which was ranked second, is often recommended in the literature (Becker, 2001; Lixia and Bo, 2008). It is a good complimentary tool for 5S which increases efficiency and orderliness of the process in the company (Lixia and Bo, 2008). Moreover, in integration with the best ranked tools (i.e. 5S and Visual Controls), and in order to improve quality and reduce lead time, *Poka-Yoke* (Mistake Proofing) as a visual guarantee tool is recommended.

Finally, coupled with the aforementioned tools, in order to diminish cost and leading time and increase flexibility and productivity, SMED is highly recommended to be utilized by the company. As it has been stated by Dave and Sohani (2012), the efficiency and effectiveness of SMED will be improved when it is combined with 5S and Visual Controls. Therefore, this combination can bring considerable advantages to the company.

Based on these results and taking into consideration that the implementation of 5S incurs low expenses and typically requies minimum additional resources, it is recommended that it be adopted by *MCoutinho Group* as the first tool. By employing of 5S which is a fundamental lean tool composed of 5 steps known as 5pillars of the 5S, it is supposed to have cleaner, well-organized work place which provides safer environment for team. Work space can be utilized more efficiently. It removes or reduces the non-value added activities, thus smoother workflow is expected. It is supposed to reach reduction in time of searching tools and materials. It may extend machine and equipment's lifespan because of routine maintenance and clean-up process. Errors and defects are minimized and quality and productivity will be increased. It also may strengthen morality in the team.

To achieve above mentioned aims, 5 Pillars of the tool (i.e. sort-out, set in order, shine, standardized, and sustain) must be implemented properly. This necessitates the contribution of each member of the team, and providing training sessions to prepare them and define their crucial role in the success of the system.

For the first step, everything in work place need to be sorted well. Necessary and unnecessary items must be distinguished easily with using some tags and signs. This step not only decrease the searching time, but it brings down the inventory costs (Ennin et al., 2012). In the second step, everything must be placed in the right place so that they can be used easily. It provides a safer environment and reduces the errors. For the next step, everything should be cleaned up to shine. Providing such a pleasant environment makes avoiding accidents and it prolongs machines life span (Ennin et al., 2012). For the fourth step, all the mentioned steps need to be standardized to make sure that the procedure is followed accurately. This improves transparency, and efficiency in the process. Providing a discipline to increase the level of commitment in team is the last step. Management support and providing rewards will encourage team member to comply the rules and procedure (Ennin et al., 2012).

In order to avoid complexity in implementation different lean tools at the same time, according to the results of the study, it is suggested to only concentrate on adoption of 5S appropriately in the first try. However, to achieve better results in 5S implementation, Visual Controls will facilitate the system by increasing the visibility. Also, considering the current challenges, raised because of the pandemic disease, the result of the study can totally meet the imposed requirements, since one of the main purpose of applying 5S is to provide an extremely neat, hygienic, and safe work place through regular and careful cleaning.

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List of Abbreviations and Acronyms

JIT	Just-in-time
LM	Lean Manufacturing
MADM	Multi-Attribute Decision-Making
MAUT	Multi-Attribute Utility Theory
MAVT	Multi-Attribute Value Theory
MCDM	Multi-Criteria Decision-Making
MODM	Multi-Objective Decision-Making
NIS	Negative Ideal Solution
PIS	Positive Ideal Solution
PROMETHEE	Preference ranking organization method for enrichment evaluation
SAW	Simple Additive Weight
SMED	Single Minute Exchange of Dies
SOPs	Standard Operating Procedures
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TPS	Toyota Production System
VSM	Value Stream Mapping
VIKOR	VIšekriterijumsko KOmpromisno Rangiranje
WM	Waste Management

1. Introduction

In an ever more volatile and competitive environment, quality, cost and lead time become important organizational concerns, and lean management can help address these issues. Lean management intends to provide a systematic approach to increasing efficiency in the organization, through the reduction of waste, which can potentially lead to a sustainable competitive advantage. Quality, productivity and efficiency improvement as well as cost, defect, lead time, and inventory reduction are some of considerable achievements that can be made possible by implementing lean techniques (Pavnaskar et al., 2003).

Different studies on lean management reveal that although lean techniques have considerable benefits in general, each technique has its own positive impact on one or several specific attributes. For instance, research by Marodin et al. (2019) on the impact of eleven lean tools on five operational attributes – lead time, inventory, quality, on-time delivery and turnover – in Brazilian automotive supply chain companies indicated, that lean tools such as pull system and setup reduction have a positive influence on inventory reduction; while other lean tools, like leveling, showed considerable increase in efficiency and employee involvement as well as decrease in lead time. The study also highlighted the beneficial effects of visual management and standardized work on enhancing quality and reducing turnover. Moreover, the authors highlighted the role of country and regional culture on the results achieved through the implemented lean tools (Marodin et al., 2019). The critical importance of country and company culture in the success of lean process implementation has been also emphasized by Taj and Morosan (2011) and Ghosh (2012). Accordingly, paying attention to the company's requirements and regional culture, along with considering the general attributes which have been recommended by experts in the field, is of great importance for the success of the lean implementation.

Taking country culture as a starting point, an investigation into benefits of lean management to industrial companies investigated forty-one projects over a ten-year period (Alves et al., 2011). The most frequently used lean tools as well as their advantages to the entities implementing them were determined. The study found seven lean techniques that were employed in 70% of the companies, of which Kanban, cellular manufacturing and pull systems were the most frequently used, and 5s, Single Minute Exchange of Dies (SMED) or change over, Value Stream Mapping (VSM), and Kaizen were set at the next levels. The results demonstrated that for instance, the

SMED and 5s techniques have a beneficial impact on time and inventory, while cellular manufacturing has the benefits of increasing flexibility and turnover reduction; and Kanban provides more transparency, in addition to reducing temporary stocks.

There are many lean tools to choose from; choosing the right one is absolutely crucial as they are an inseparable part of lean system, and the success and failure of the lean approach is highly depended on them. However, this is often an extremely difficult and complexdecision, where there are multiple alternatives that need to be evaluated and selected in terms of the defined criteria. This was precisely the challenge *MCoutinho Group* was facing.

MCoutinho Group is a Portuguese company in automotive market which sells cars, car parts and accessories, as well as providing insurance and financing. Considering the fast, ever-changing environment in which it operates, the company intended to improve its competitiveness potential and develop the operational processes through the adoption of a lean system, in order to meet market conditions and customer demands. This dissertation is precisely the result of wanting to address this issue. Although the issue was defined before pandemic disease, the issue and the result are still totally relevant (maybe even more relevant).

In order to succeed in any discipline, particularly when there is a broad knowledge and data, decision making plays a major role. Despite the major role it plays, decision is often complicated due to nature of uncertainty it has. Complicated situations can often benefit from the adoption of mechanisms such as Multi-Criteria Decision-Making (MCDM) to assist decision makers to deal with the complexities of their decisions (Jato-Espino et al., 2014). MCDM provides a basis for a meaningful comparison among the options, where alternatives are assessed in terms of determined criteria.

With reference to the potentially significant influence of lean concepts on sustainable competitive advantage, and since the success of developing lean system is highly dependent on the selecting and applying the right technique/s, this study endeavors to assist decision makers in *MCoutinho Group* to choose the most relevant alternative/s – lean technique/s – using MCDM tools based on the company's preferences and requirements. Hence the main objectives of this study can be mentioned as below:

1. To compare different lean tools and their impact on the specified criteria based on experts' opinions.

2. To conclude and select (an) appropriate lean tool/s as the starting point for the company's adoption of a lean approach as a means to improve its efficiency.
3. The application of MCMD should also allow to uncover the main criteria for reducing waste based on the company preferences.
4. Also it should reveal the gap between criteria considered in conducted surveys and the ones indicated in the real market

Hence, from the strategic point of view, choosing a lean system totally based on the company's rather than employing systems based on other criteria such as familiarity can result in competitive advantage for *MCoutinho Group*, by reducing the waste and improving the efficiency. It aids the company to benefit from existing capabilities and resources to cover the main requirements.

The outcome of the adopted procedure and the selected lean tool(s) can be expected to lead to operational improvements and productivity enhancement in the firm thanks to reducing defects. The tools potentially provide efficient use of resources and facilities as well as greater interaction between team members.

MCDM application also saves on cost and time caused by trial and error in identifying (an) appropriate lean tool/s. Moreover, an overall cost reduction as a result of implementing (a) proper lean technique/s is expected. Greater sustainability due to reduction on waste, coupled with providing a safer and hygienic work environment are social expected benefits of the implementation of the results of this study.

2. Literature Review

Gaining a sustainable competitive advantage in the current fast paced competitive environment is a very tough challenge for companies. It requires a careful consideration of various aspects, such as product quality improvement, lead and delivery time reduction, decrease in unit cost and price of finished products, among others. Considering these aspects highlights the critical importance of an efficient production process. For the purpose of setting up an efficient production process, lean facilitates the process via implementing a systematic approach to reduce/eliminate waste through continuous improvement (Daneshjo et al., 2018).

The beneficial influence of lean management in operational processes is almost not arguable (So and Sun, 2010). Cost reductions, decreases in lead time and inventory levels, as well as many other advantages achieved by implementing lean tools and methods have been reported in the literature (e.g., Rahman et al., 2010; Alves et al., 2011; Mandal and Sarkar, 2012; Belekoukias et al., 2014; Marodin et al., 2019).

Despite the substantial benefits of lean applications, successful implementation of the lean concept takes time, money, energy, and a strong team commitment (Motwani, 2003) which should be considered carefully. Otherwise, the company will be confronted with wastes in time, costs and resources (Rose et al., 2011). Hence, making decision in adopting a proper lean system is of great importance to achieve the desired outcomes.

Considering that there are more than hundred lean tools available (Pavnaskar et al., 2003), selecting the appropriate option/s for a company can be a significant challenge; and the success or failure of implementing the lean system could depend on this decision (Anvari et al., 2014; Hojjati and Anvari, 2014). Taking such an important decision highlights the critical role of decision-making in choosing lean tools and in management more generally.

Nobel Prize winner Herbert A. Simon expressed decision-making as the essence of management: "I shall find convenient to take mild liberties with the English language by using ‘decision making’ as though it were synonymous with ‘managing’" (Simon, 1960, p. 1). Furthermore, decisions themselves have been defined as "the end of deliberation and the beginning of action" (Buchanan and O Connell, 2006, p. 1).

However, making decision is one of the most (possibly the most) critical responsibilities of managers. In case of selecting appropriate lean tool/s, making suitable decisions considering different requirements and various lean tools in order to obtain the desirable goals, seems complicated and vague. Therefore, employing an effective technique that improves the chance of making proper decisions is of great importance. To deal with such an issue in this case – MCoutinho –, our proposal is Multi-Criteria Decision-Making (MCDM).

This chapter is divided into three parts. In the first part, the lean concept and the definition of waste in lean will be provided. Lean principles and some effective lean tools will also be defined. In the second part, decision-making and its importance in management will be discussed. And finally in the third part, MCDM methods and their processes will be reviewed, and some useful tools for implementing MCDM process will be explained.

2.1. An Introduction to the Concept of Lean

Toyota Production System (TPS) which has been launched and developed by Taiichi Ohno is known as the origin of lean. Reducing/removing waste, as well as creating value through applying Just-in-time (JIT) and *Jidoka*, are the major focuses of TPS (Ohno, 1988). Just-in-time (JIT) is about "producing the right product at the right time, while keeping a minimum level of stock, reducing buffer inventories, decreasing working capital and minimizing time to market" (Almeida, 2017, p. 12). By producing the product at the time when customer needs it, Just-in-time (JIT) reduces waste and improves quality and performance (Womack et al. 1990). *Jidoka*, in turn, is also known as autonomation or "automation with human intelligence". The method is employed to increase the quality of the product by using machines. *Jidoka* provides the ability to detect defects in the system and stops them immediately (Sugimori et al., 1977).

Although the lean concept had been introduced years earlier, in the 1940s, by Toyota, the term “lean” was made popular by Womack, Jones and Roos (1990). The authors noted the remarkable performance of the Japanese system against the mass production system used in western countries at the time. According to the authors, based on the Toyota Production System, only a small fraction of total time and activities add value to the process and the rest of the time and attempts are spent on non-added value tasks (Melton, 2005).

Lean Manufacturing (LM) has been defined by Taj (2005) as a waste eliminated manufacturing system. In fact, LM practices concentrate on eliminating waste in the production process and continuing improvement procedures to launch a flawless product or service quality. Hence, since 1960, a set of attitudes, principles, and procedures have been developed to achieve the desired outcomes and implement the process precisely (Rose et al., 2011).

The Lean concept is thus no longer just a manufacturing perspective, but has been developed to other areas such as construction, project management, procurement, and even healthcare and military. Therefore, the lean concept has been utilized with different name and terms in different articles. It has been known as “lean production”, “lean manufacturing”, “lean thinking”, and “lean management” which all express quite a synonyms idea (Gozlan, 2015).

2.1.1. Defining Waste

The Japanese term *muda* is known as the origin of the concept of waste, which refers to any activities with no added value to the end user (Ohno, 1988). Based on Ohno’s definition (1998), waste has been categorized into seven types:

1. Transportation: redundant movement of resources, parts, or finished goods are classified as transportation waste. For instance: moving materials from one construction site to another site (Elnamrouty and Abushaaban, 2013).
2. Inventory: Any resources, products, or materials that are stored while there is not any request for them immediately. Habitually, inventory is a valuable product or material that is waiting either to be sold to the customer or further transformed into something of greater value (Gay, 2016).
3. Motion: People or machinery movements, such as bending, lifting or searching for tools, which are not required and do not increase value (Simboli et al., 2014).
4. Waiting: Idle time, when the process is not moving while it is waiting for equipment, material, information, and so on (Simboli et al., 2014).
5. Overproduction: Producing more product or earlier than it is required (Simboli et al., 2014).
6. Over-processing: A process that adds more value to a product than the customer actually needs is known as an over-process. For instance, polishing a surface more than customer demand is an over processed activity. Over-processing can be caused by a lack of clear standards and specifications (Simboli et al., 2014).

7. Defects: Scrapped production or products which need to be repaired are categorized as defects (Almeida, 2017).

In addition to the aforementioned types of waste, unused human potential has been categorized as the eighth type of waste. Accordingly, failing to utilize human resources' capabilities properly or delegating tasks without adequate training is proposed to result in waste (Gibbons et al., 2012)

During the production process, waste of any type, should be recognized and highlighted by the lean system, and subsequently, to minimize the recognized waste lean principles and tools were developed (Almeida, 2017).

2.1.2. Lean Principles

The principles underlying the Lean approach have been defined by Womack and Jones (1997) as below:

1. Identify value: Value is identified with respect to customers' requirements and viewpoint (Abdi et al., 2006).
2. Map the value stream: In the second stage, the value stream, as well as the necessary steps for delivering the product, are outlined. During this phase, the activities that do not add value to the product can be identified and removed. Activities are classified into the following groups (Womack and Jones, 1997):
    a. Value-Added: Activities that should be maximized since they are necessary to raise the benefit of a product or service. Owing to the fact that the customer pays for the product or service, the value must satisfy customers' demands, hence, value-added activities need to be defined according to customers' point of view (Abdi et al., 2006).
    b. Value-Enabling: Activities which do not add value directly, but are required for the production process. These activities can be removed eventually, but not instantly.
    c. Non-Value-Added: Unnecessary activities that should be removed instantly, inasmuch as they do not bring advantage to the process or product.
3. Create flow: Creating flow is about making "the value-creating steps occur in tight sequence so that products will flow smoothly toward the customer" (Rauch et al., 2016, p.615). The smoothness of the production process needs to be continuously assured in this step, through the removal of any disruption, delay or barrier.

4. Establish pull: In order to avoid producing more than market demand, a pull approach should be developed to meet customer requests. Accordingly, a service or product should be provided when a customer requires it. Consequently, unrequested value delivery, inventory turnover, and therefore waste, will be reduced.
5. Seek perfection: For the sake of reducing time and cost at each step, in the fifth principle, some methods and measurements are applied by the Lean Practitioner to pursue perfection. As it has been stated by Abdi et al. (2006), "the pursuit of perfection is an endless process, because the value of all activities can be constantly analyzed, evaluated and improved".

Recently, the importance of the people involved in issue recognition has been identified as an additional lean principle. Lean thinkers try enhance efficiency by persuading people into participating in defect detection process (Oehmen et al., 2012). By providing training sessions for employees and encourage them to report waste, their involvement as an active participant in the lean process gets boost, and the better outcome is supposed (Oehmen et al., 2012).

2.1.3. Lean Tools and Techniques

As mentioned above, a lean system utilizes tools to minimize waste and maximize operational performance (Womack and Jones, 1990). Each tool has its own advantages and can best deal with specific issues (Marodin et al., 2019). Below, a short description of some of the most commonly used lean tools which have been adopted in more than 40 projects in Portugal is provided (Alves et al., 2011).

I. 5S

"A place for everything, and everything in its place"

Benjamin Franklin

5S is a fundamental technique with five pillars (Sort-out, Set in order, Shine (or cleanliness), Standardize and Sustain) which are also known as 5 pillar of a visual workplace (Becker, 2001). It is a systemized visual technique which makes the workplace safe and well organized (Joshi, 2015). Generally, productivity is supposed to be improved through implementing the five steps: putting things in order, placing them in a right position, cleaning and creating a faultless workplace, making things distinctly visible through personal and environmental cleanness, and providing training and discipline in the work place to make proactive changes in team behavioral patterns (Joshi, 2015; Kobayashi et al., 2008).

II. Kanban

“Simplicity, carried to the extreme, becomes elegance.”

Jon Franklin, 1994

The term Kanban is a Japanese word composed of two parts: Kan (visual) and Ban (card). This operational method was developed by Taiichi Ohno to improve efficiency by simplifying the work process. Based on the method, visual cards are utilized to establish effective communication between teams and team members, wherein employees can be easily aware of work schedule and requirements (Series, 2017). Kanban simultaneously facilitates inventory reduction and increases the level of customer service (Monden, 2011).

III. Cellular Manufacturing

In cellular manufacturing, all the required resources and operations for providing a valuable service or production are gathered in a small lot. The “manufacturing system is decomposed into several manageable subsystems, named manufacturing cells”, which leads to improved productivity and flexibility (Wu et al., 2007). For the sake of receiving feedback quickly when operations confront problems, as well as to increase interoperability, typically a U-shape layout is formed in the cells (Miltenburg, 2001).

IV. Pull System

A pull system aims at providing a service or product when it is pulled by customer requirements, as opposed to push-based systems in which production channel pushes the products up to customers based on demand forecasting (Koo, 2020). Consequently, a pull system results in better resource optimization, in order to produce the right quantity, and minimizes waste by avoiding overstocking (Kariuki and Mburu, 2013).

V. Single Minute Exchange of Die (SMED)

The main issue that SMED (also known as Quick Changeover) concentrates on is changeover time. "The essence of the SMED system is to convert as many changeover steps as possible to "external" (performed while the equipment is running), and to simplify and streamline the remaining steps" (Vorne, 2019). The intention is to reduce changeover times to less than 10 minutes (Single Minute). Some of the advantages of the technique are: cost reduction, decreased lot size, reduction in inventory levels, and increased satisfaction of customer needs (Vorne, 2019).

VI. Value Stream Mapping (VSM)

VSM aims at providing an in-depth analysis platform, by highlighting critical steps to improve efficiency. Thus, based on VSM, all the steps required to create value from the beginning of the process to end user can be visualized in detail (Jeong and Yoon, 2016). VSM tries to increase quality via identifying value-adding activities to achieve reduction in lead time and inventory and so, also waste is identified (Sundar et al., 2014).

VII. Visual Controls

Principle 7 from The Toyota Way; which is the evolved version of TPS and consist of principles that highlights Toyota managerial approach and production system (Gao and Low, 2014), states: "Use visual controls so no problems are hidden" (Ko, 2017, p.330). Visual Controls are applied to identify production flow issues immediately. They facilitate the transfer of information between people, so team members can recognize whether the process is taking place to improve productivity or not. Graphs, gauges, signs, and digital information can be utilized as Visual Control tools. For instance, "bordering", which specifies the place of tools and equipment is known as a Visual Control tool (Moser and Dos Santos, 2003).

VIII. Production Leveling (Heijunka)

Considering the Toyota theory that "Production must be viewed as something that naturally and faithfully conforms to firm orders" (Coleman and Vaghefi, 1994, p.31), Production Leveling aims to tackle large fluctuations – avoiding peaks and valleys – in operations caused by customer requirements. It intends to use higher capabilities by controlling product variability (Sundar et al., 2014). It reduces the inventories and aids the organization to efficiently plan and control the production procedure (Rewers et al., 2017).

IX. Standardized work

Standardized work has been defined by Sundar et al. (2014, p. 1880) as "a set of analysis tools that result in a set of Standard Operating Procedures (SOPs)" (i.e., Work In Progress, steps of the process, work control and so on). Thus, tasks and the time needed for completing tasks will be clear to everybody in the process.

X. Poka-Yoke (mistake proofing)

Poka-Yoke is an effective error detection method which highlights or prevents an error from arising. Any mechanism that aids manufacturing systems to avoid (*yokeru*) mistakes (*Poka*) is known as a mistake-proofing system (Fisher, 1999).

The difference between defects and errors has been explained by Shingo (1986, p. 50): "The causes of defects lie in worker errors, and defects are the results of neglecting those errors. It follows that mistakes will not turn into defects if worker errors are discovered and eliminated beforehand. Defects arise because errors are made; the two have a cause-and-effect relationship. Yet errors will not turn into defects if feedback and action take place at the error stage".

XI. Line balancing

The purpose of Line balancing is to achieve an optimum balance between the numbers of staff and machinery and product demand. By implementing it, productivity increases while lead time and the required number of people for producing a product decrease (Sundar et al., 2014).

XII. Kaizen (continuous improvement)

"*Kaizen* refers to any activities that continually improve all business functions or processes and involves every employee from the CEO to the assembly line workers" (Kanbanchi, 2019). It aims to reduce waste gradually by involving all the talents and knowledge of the people in the operation (Abdulmalek et al., 2006). Accordingly, incremental improvements are achieved by small positive (*Zen*) change (*Kai*) (Dearsystems, 2018). In fact, it is not a specific tool, but it an umberella term that covers other tools such as *Kanban* or *Poka-Yoke* (Recht and Wilderom, 1998).

In short, these different tools and techniques have been introduced and developed to minimize waste and achieve higher quality, lower cost, shorter lead times and higher morale (Womack and Jones, 1997).

Table 2.1 summarizes the tools and their key proponents.

Lean tools and techniques	***Description***	***References***
5S	Provides an effective work place through the standardization and visualization of procedures.	(Abdulmalek and Rajgopal, 2007)
Cellular Manufacturing	Organizes resources into cells to accelerate and facilitate the operational process.	(Abdulmalek and Rajgopal, 2007)
Kanban	A signaling system that simplifies work and develops a pull approach.	(Abdulmalek and Rajgopal, 2007; Series, 2017)
Kaizen (continuous improvement)	An "ongoing improvement involving everyone—top management, managers and workers". An umbrella that covers other tools.	(Recht and Wilderom, 1998, P.7)
Line balancing	Maximizes the balance between workers and workloads to smooth the work in progress (WIP).	(Lam et al., 2016)
Poka-Yoke (mistake proofing)	Highlights mistakes, avoids them, and removes the underlying cause of mistakes.	(Fisher, 1999)
Production Leveling (Heijunka)	Increases the use of capacity by controlling and levelling the production process.	(Hüttmeir et al., 2009)
Pull system	Customer demand pulls the service which leads to decrease in work-in-progress.	(Andrés-López, et al., 2015)
Single Minute Exchange of Die (SMED)	Reduces line or machine change times, which leads to lot size reduction and work flow improvement.	(Dave and Sohani, 2012)
Standardized work	Establishes a detailed framework to provide a step-by-step guidance which results in higher quality, safety, and productivity.	(Emiliani, 2008)
Value Stream Mapping (VSM)	Assists in distinguishing and eliminating all kinds of waste in the value stream by tracking the information and material flow in the whole supply chain.	(Abdulmalek and Rajgopal, 2007)
Visual Controls	Enhances the transparency to detect problems immediately through the use of visual indicators.	(Picchi et al., 2004)

Table 2.1: Lean tools and techniques

2.2. Decision-Making in Management

The enormous significance of decision-making in our lives has been vividly described by Albert Camus: “Life is the sum of all your choices”. Buchanan and O Connell (2006, p. 1) go a step further and state that "history, by extrapolation, equals the accumulated choices of all mankind". Although, as these statements demonstrate, decision-making is involved in every aspect of human life, its role in management is of outstanding importance. Indeed, decision-making has been proposed to be the inevitable and major role of managers or leaders (Ahmed and Omotunde, 2012), even "to explicitly avoid making a decision is in itself to make a decision" (Al-Tarawneh, 2012, p.2).

Given that reaching a decision can be a complicated process, and that it can have considerable and long-lasting influence on a company, decision-making is not only the main function of managers, but might arguably be their toughest role as well (Al-Tarawneh, 2012).

Decision-making is defined as a process which considers all the alternatives and selects the one that best fulfills the established purposes, values and aims. It involves recognizing, surveying, and analyzing all the alternatives based on decision maker’s preferences to select the most appropriate one (Al-Tarawneh, 2012).

Decision-making is a cognitive problem-solving process which ends when the final choice is selected among the various options (Shahsavarani and Azad Marz, 2015). This process in management takes place by choosing an alternative to meet a specific purpose, and this purpose is generally created and affected by constraints imposed due to changes in internal or external environments (Negulescu, 2014).

The process follows a set of principles. It starts by identifying the purpose or decision problem, and it evolves by understanding the purpose, and determining the alternatives that can fulfill the defined purpose (Negulescu, 2014). Hence, in order to provide a standard decision making process, the most widely used approach called “the decision-making process in seven steps” can be referred (Negulescu, 2014). It follows seven steps including: "defining the problem, identifying and limiting the factors, development of potential solutions, analysis of the alternatives, selecting the best alternative, implementing the decision and establishing a control and evaluation system" (Negulescu, 2014, p.114).

Uncertainty which is known as the "lack of knowledge about the probabilities of the future state of events" (Sniazhko, 2019, p.2), is an inevitable part of the decision-making process. When there is only one option with a fixed outcome and no uncertainty, there is no need for any decision-making. Decision makers try to decrease uncertainty through decision-making techniques, to reach a decision that raises the possibilities of success in meeting their specified objectives (Ahmed and Omotunde, 2012). Any decision in real life involves a degree of uncertainty. Thus, even by covering different aspects as well as adopting helpful tools, to finally come to a decision, would not assure achieving the desired outcomes (Buchanan and O Connell, 2006). Taking into account the aforementioned issue, Multi-Criteria Decision-Making (MCDM) is a valuable method in dealing with uncertainty in complex situations even when data is imprecise (Kazimieras et al., 2019). MCDM, by applying some computational tools, aids decision makers to assess available alternatives in terms of existing criteria to rank and select the best possible option (Yazdani and Graeml, 2014).

2.3. Multi-Criteria Decision-Making (MCDM)

The Multi-Criteria Decision-Making (MCDM) is an efficient operational research method for evaluating potential alternatives, considering various conflicting criteria. Criteria may be different in terms of measurement units, quality characteristic and relative weights (Erdogan et al., 2017). MCDM methods take these differences into account and can thus assist decision makers to compare available alternatives and select the best possible solution among them (Moghtadernejad et al., 2018).

Making decision in business environments is a challenging procedure, owing to the complex character of the alternatives and criteria involved in such decisions (Xidonas et al., 2009). Relying on wrong information or paying attention to the wrong attributes can lead to an inaccurate assessment of alternatives, which could have a damaging impact on the financial performance of a company (Xidonas et al., 2009). MCDM system has been proposed as an aid for dealing with such complex issues (Xidonas et al., 2009).

MCDM has been expressed as a complex dynamic procedure which is a combination of two levels, namely managerial and engineering. At the managerial level, "the multicriteria nature of decisions is emphasized" (Opricovic and Tzeng, 2004, p.445). The goals are established at this level and the final decision is made by decision makers, by selecting the optimal alternative. In fact, the proposed solutions which have been provided at the engineering level will be accepted or rejected by decision makers at the managerial level. At the engineering level, by considering the different criteria, the alternatives and their impacts on goals are determined and then a final ranking of alternatives is achieved using MCDM tools (Opricovic and Tzeng, 2004).

A comprehensive range of different qualitative and quantitative indicators - financial, operational, environmental, and ethical - could be considered by the MCDM process (Linkov et al., 2009). Indeed, this is one of the main beneficial aspects of MCDM: that various and even conflicting attributes can be used and incorporated to plan and establish a management procedure (Kou et al., 2011).

MCDM improves efficiency and explicitness of decision process, thus quality of the decision will be increased (De Brito and Evers, 2016). Furthermore, MCDM promotes the role of participants in the decision process, facilitates compromise and group decisions, and provides an adequate platform for stakeholders to communicate their personal preferences (De Brito and Evers, 2016, p.1020).

2.3.1. MCDM Characteristics

Based on the mathematical nature of MCDM techniques, they are usually categorized into two groups: Multi-Attribute Decision-Making (MADM) and Multi-Objective Decision-Making (MODM). In MADM, based on a set of defined criteria, different available options are compared and ranked to achieve the optimum outcome (Hatami-Marbini et al., 2013). In fact, "A general MADM application involving a number of *I* alternatives assessed by a total of *J* criteria can be represented by a comparison matrix of *I* rows and *J* columns, where *Aij* corresponds to the score of the *j*th criteria for the *i*th alternative evaluated" (Goulart Coelho et al., 2017, p.4). On the other side, MODM intends to specify a set of optimum options in terms of imposed constraints. In MODM the alternatives are not predefined, but some restrictions are introduced as decision variable vectors to find a set of optimum options through minimizing or maximizing objective functions (Kumar et al., 2017; Goulart Coelho et al., 2017).

MADM techniques are mostly used for strategic decisions, such as choosing an appropriate treatment technique (Spengler et al., 1998) or the location of a waste facility (Goulart et al., 2017); while MODM methods are more relevant to operational situations, namely routine optimization decisions (Chang and Pires, 2015).

Although MODM has been indicated as a powerful method (Moghtadernejad et al., 2018; Goulart Coelho et al., 2017), the computational complexity and technical issues to solve MODM problems have limited its application (Wallenius et al., 2008; Moghtadernejad et al., 2018). A review of 260 articles conducted by Goulart Coelho et al. (2017) with respect to MCDM use in Waste Management (WM) shows that MADM techniques have been implemented in 78% of the articles, MODM methods have been adopted in 19%, and the other remaining articles - 3% - applied both techniques.

2.3.2. MCDM Process

The five elements that form an MCDM problem are: “goal, decision makers’ preferences, alternatives, criteria and outcomes” (Kumar et al., 2017). In an MCDM process, these elements are implemented in five steps (Goulart Coelho et al., 2017):

1. *Determining the aim*

   For the purpose of performing a precise and comprehensive evaluation, the specification of an objective is the starting point (Goulart Coelho et al., 2017). Indeed, in decision-making, identifying and presenting the problem and/or goal clearly is often presented as the most essential part of the process (Morrissey and Browne, 2004). Both the problem and the goal should be specific, reasonable, and measurable (Karmperis et al., 2013).

2. *Choosing adequate criteria*

   Prabhu et al., (1998, p.3) define criterion as "a principle or standard that a thing is judged by". Goulart Coelho et al., (2017, p.5) define criteria as “the major issues related to a subject and provide sense and operationality to the goals without itself being a direct measure of performance”. However, the evaluated outcomes are highly affected by changes in criteria selection, therefore in order to deliver an accurate assessment and judgment, the indicators/criteria must be selected carefully. Furthermore, choosing the right number of criteria is another critical point. Given that by selecting too many criteria the complexity of the MCDM process will be increased, it can exert a negative impact on the final results (Karmperis et al., 2013). In order to identify the most appropriate and practical attributes, the selection procedure is generally executed with the cooperation of a group of experienced, professional specialists in the field (Esfahanipour and Davari Ardakani, 2015).

3. *Data normalization*

Normalization has been defined as a "transformation process" which unifies all the units or scales of the criteria to provide a comparable situation (Vafaei et al., 2018; Garcia-Sánchez et al., 2015). During the process of collecting criteria, each criterion measurement unit might be different from another one, in which case a meaningful comparison is not possible. Therefore, a normalization technique must be applied to put all the criteria in a dimensionless class (Vafaei et al., 2018).

Although linear transformation technique is commonly used to normalize attributes, in terms of implementing different MCDM methods (Ebert and Welsch, 2004), the optimal optimization techniques may vary. For instance, in an investigation conducted by Chakraborty and Yeh (2007), it has been asserted that for an MCDM method called Simple Additive Weight (SAW) method, the optimal normalization technique among four different ones (vector, linear max-min, linear max, and linear sum) is the vector technique. Another research carried out by the authors on the same normalization techniques for another MCDM method, i.e. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) shows the same result (Chakraborty and Yeh 2009); whereas the research conducted by Milani et al. (2005) on the effect of normalization techniques on ranking results indicates that ranking alternatives using different techniques namely, vector, linear max-min, linear max, and linear sum has the same results.

4. *Weighting criteria*

As previously mentioned, alternatives are prioritized according to the assigned criteria. In other words, alternatives are highly affected by different criteria and specifically by their relative importance. Obviously, one or some criteria are more important than the others. Consequently, a criterion with higher importance must have a higher impact on the final outcome. This relative importance is specified by allocating weights (Wang et al., 2009).

Since the MCDM method is a human judgment process, and weight allocation is made in terms of decision-makers' preferences and judgement, the precise numerical evaluation of weighting criteria is not achievable (Achillas et al., 2013, Roszkowska, 2013). But it has been indicated by Macharis et al. (2004) that criteria can be weighted properly, particularly when there are not too many attributes.

5. *Sensitivity analysis*

   As noted above, the weighting of criteria is typically based on experts' or decision makers' opinions. The final decision is thus variable based on changes in the weight of any criterion. Hence, it can be critical to decision-makers to identify the criterion with the highest sensitivity compared to others. This sensitive criterion which has the greatest impact on the ultimate result can be found through sensitivity analysis (Memariani et al., 2009).

2.3.3. MCDM Tools

Over the years, many MCDM tools have been introduced to assist decision-makers in drawing meaningful pairwise comparisons of their available alternatives. These tools have been divided in three categories by Goulart Coelho et al. (2017): value-based, outranking, and distance-based methods.

The value-based methods comprise Multi-Attribute Value Theory (MAVT), and Multi-Attribute Utility Theory (MAUT). The difference is that MAUT methods use the utility function to cover uncertainties, whereas MAVT methods use value functions (Goulart Coelho et al., 2017). In fact, in MAVT methods, the aggregation of the value functions regarding each attribute defines the overall performance of an alternative, whereas in MAUT theory, which has been developed by Fishburn, Keeney, and Raiffa in the 1960s and 1970s to assist decision-makers in situations with potential risk, the overall performance is described by a utility function (Goulart Coelho et al., 2017; Shanmuganathan et al., 2018).

The outranking tools take into account several criteria to form a series of pairwise comparisons between alternatives by employing a value function method. These pairwise comparisons make a preference/outranking relation among alternatives to recognize if an alternative is more favorable than another or not (Bouyssou, 2001; Goulart Coelho et al., 2017). Preference ranking organization method for enrichment evaluation (PROMETHEE) which is known as a simple, user friendly tool, adopts the outranking approach (Pohekar and Ramachandran, 2004). Another widely-used outranking tool is ELECTRE which was first introduced by Bernard Roy in the late sixties (Bouyssou, 2001).

In a distance-based approach, the best alternative has the shortest (longest) distance from the ideal (worst) option. In other words, each alternative is compared with other alternatives by considering its distance from the ideal or worst scenario (Huang et al., 2011). Technique for Order Preference by Similarity (TOPSIS) is one of the most frequently used tools in this category which has been designed by Hwang and Yoon in 1981 (Opricovic and Tzeng, 2004).

In the following sections, three widely used MCDM techniques, as well as methods for aggregating results are described.

2.3.3.1. Simple Additive Weighting (SAW)

The SAW method or weighted linear combination or scoring method is a value-based method and known as the most frequently used MCDM tool (Roszkowska, 2013; Adriyendi, 2015; Sahir et al., 2017; Pires et al., 2019). It is based on calculating the sum of the weighted average of normalized criteria (Sahir et al., 2017). This calculation can be performed in three steps. In the first step, in order to make the alternatives comparable, the decision matrix has to be normalized into a scale. In the second step, the weight of each criterion is applied and finally the sum of the values in each row is computed (Roszkowska, 2013).

2.3.3.2. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

As mentioned before, TOPSIS is a distance-based method which is known as one of the most widely used tools in this category. Its extensive application covers different fields and topics, such as supply chain management to choose a supplier or location, or even in military settings to select an effective and efficient system for missile weapons (Li et al., 2010).

In this technique, the positive ideal solution (PIS) as well as the negative ideal solution (NIS) are identified, and eventually the alternatives are measured and compared based on the distances they have from these two solutions (Esfahanipour and Davari Ardakani, 2015). The distances are calculated following the Euclidean distance method (Triantaphyllou et al., 1998). Subsequently, the option with the longest distance from NIS and the shortest distance to PIS is selected as the best option, which maximizes the beneficial criteria and minimizes the non-beneficial criteria (Esfahanipour and Davari Ardakani, 2015).

Its considerable flexibility with high degree of accuracy and its consideration of the best and the worst solutions at the same time, give TOPSIS a positive advantage over other MCDM tools (Esfahanipour and Davari Ardakani, 2015).

2.3.3.3. VIšekriterijumsko KOmpromisno Rangiranje (VIKOR)

Similar to the TOPSIS method, VIKOR is a distance based method which measures the "closeness" of each alternative to the "ideal" option based on each criterion function. In TOPSIS, two "reference" points, i.e. positive ideal solution and negative ideal solution are defined, and the distances from these two points determine the most beneficial solution, but the relative importance of these distances is not taken into account. The VIKOR method fills this gap (Opricovic and Tzeng, 2004).

The two techniques also employ different methods of normalization: TOPSIS uses vector normalization to remove unit functions, whereas VIKOR uses linear normalization to avoid the possible dependence on evaluation units that resulted from vector normalization (Opricovic and Tzeng, 2004).

VIKOR method has been developed to optimize complex decision making systems by providing compromise solutions resulting from compromise ranking-list. In this method the closest feasible solution to the ideal is identified as the compromise solution and the agreement that comes from the mutual concession determines the term compromise (Opricovic and Tzeng, 2004).

2.3.4. Aggregate Methods

Applying different MCDM tools can lead to different results. Aggregate methods namely Borda, Copeland, and Average (mean) have been developed to deal with this issue and unify all the ranking results resulted from different MCDM methods (Jozi et al., 2015).

2.3.4.1. Borda

Borda is recognized as the most used aggregate method. In the Borda method, a comparison matrix between alternatives is created where M represents that one alternative is preferred to another in the row from different MCDM tools to the alternative in the column, and X represents the alternative is not preferred to another alternative in the row. Taking into account the "m" alternatives, through a pairwise comparison, the alternative with "m-1" points is ranked first and the alternative with "m-2" points is ranked second down to 0 which represents the lowest ranked alternative (Favardin et al., 2002; Klamler, 2005; Jozi et al., 2015).

2.3.4.2. Copeland

The Copeland method is similar to the Borda method, but considers the number of losses in addition to the number of wins. In fact, it can be said that the Copeland method starts where the Borda method finishes (Jozi et al., 2015).

In this method, by subtracting the number of each alternative's losses from its wins, the rank of the alternative is recognized. Therefore, a higher grade signifies a higher ranking of the alternative (Jozi et al., 2015).

2.4.4.3. Average Method

Based on this method, the mean of each alternative's rank achieved through different MCDM tools, prioritizes the alternatives (Pourjavad and Shirouyehzad, 2011). Hence, a matrix which includes the rank (S_{ij}) of each alternative (A_i) in different methods ($M_1, M_2, \dots, M_k$) is formed. Then the mean of the ranks is calculated to make a paired comparison between the alternatives, in which a lower mean represents the higher rank (Table 2.2) (Zavadskas et al., 2017).

	M_1	M_2	…	M_k	Mean
A_1	S_{11}	S_{12}	…	S_{1k}	$\frac{\sum_{j=1}^{k} S_{1j}}{k}$
A_2	S_{21}	S_{22}	…	S_{2k}	$\frac{\sum_{j=1}^{k} S_{2j}}{k}$
…	…	…	…	…	…
A_n	S_{n1}	S_{n2}	…	S_{nk}	$\frac{\sum_{j=1}^{k} S_{nj}}{k}$

Table 2.2: Average method

Where $i = 1, 2, \dots, n$; $j = 1, 2, \dots, k$.

Taking into account the aforementioned points, in the following section it is intended to utilize MCDM tools for facilitating the selecting process of appropriate lean system/s regarding specified criteria.

3. Methodology

Given the fact there is a multitude of lean tools, and that these tools have been recognized as the basis of lean systems, decision makers in *MCoutinho Group* encountered the challenge of selecting the proper one/s with regard to their demands. To deal with such an issue, after identifying the most commonly used lean tools, as well as MCoutinho Group'scompany requirements and preferences, Multi-Criteria Decision-Making (MCDM) was adopted to assist decision makers in making their decisions. The process of evaluating alternatives (e.g., lean tools) based on defined preferences and selecting the appropriate alternative is a common MCDM problem (Vinodh et al., 2012; Pullan et al., 2013).

Below, *MCoutinho Group* the sponsor case of this research will be introduced. Then the procedure of data collection including interviews and literature review, which resulted in defining criteria and alternatives, as well as the process of gathering experts' assessments on the identified criteria and alternatives will be expressed. These assessments were analized using three techniques - SAW, TOPSIS, and VIKOR - which are some of the most reliable and propably most frequently used MCDM techniques (Singh and Malik, 2014).

3.1. MCoutinho Group

MCoutinho Group is Portuguese company with over 60 years of experience in automotive market, focusing on car parts and accessories distribution, financing, insurance and so on. These services are provided from two logistics centers in Portugal; located in Porto and Lisbon.

The group's businesses are divided into two main areas i.e. dealerships and specialized businesses. The dealerships part is categorized into new cars, and service and repairs, which cover 18 automotive brands. In the new cars area, more than 80 sales persons are working in 48 points of sale. They offer a complete service including insurance and warranty extensions. The service and repairs part comprises 22 workshops that provides different services such as rapid service, bodyshop, and mobility solutions.

Specialized businesses consist of used car sales, car rentals, body shop, and parts and after-market platform. The used car sales section has been distributed in 8 points of sale offering used and semi-new cars. Car rental segment provides short, medium and long term contract with customers.

Bodyshop repair centers have been developed to cover services like claims management, mobility solutions, alternative repair proposition in addition to body shop services.

The parts platform is made up of 4 logistic brands. First, *MCoutinho Peças* which is a spare parts and accessories distribution branch formed in 1999 and supports 32 automotive brands. *Az Auto* is the second branch, developed to operate independent parts distribution and provide services that add value to the automotive parts market. In this context, training academy, technical support, and IT support besides aftermarket parts distribution have been developed in this branch. The third branch is *Reno*, which is known as the first Portuguese Franchise for mechanic and collision workshops. And the last one is *Logparts*, which is a spin-off branch for the management of the automotive logistics of the business, namely warehouse management, stock management, and transport management. The group has more than 770 collaborators, and their last year net sale was around 45 million euros.

3.2. Data Collection

3.2.1 Data Collection Procedure

The facts related to the object of research and the environments in which they exist (people, materials, process or phenomena) are data. Thus, gathering these facts via a systematic procedure is data collection (Chaleunvong, 2009).

There are two primary methods for collecting these data: quantitative and qualitative. The information obtained using a qualitative method cannot be calculated. Still, it can be demonstrated in words and behaviour. Whereas it is possible to assess the information gathered using a quantitative method using a probability approach. The data collection was implemented in this thesis using both qualitative and quantitative methods, which involved the gathering of empirical data through interviews and questionnaires.

In the MCDM process, first, the requirements and preferences (i.e. criteria) of the company that need to be covered by lean tools should be identified. Then, recognised experts give weights to these criteria, based on their understanding of the significance of each criterion. Finally, these outcomes are utilized to assess and rank the pre-determined lean tools (e.g. alternatives) through different MCDM techniques, to assist decision makers in chosing (a) lean tool/s.

In an assessment process, the first important problem, as identified by Esfahanipour and Davari (2015), is the identification of appropriate attributes for the evaluation process. Such determinative criteria must be well defined as a core part of the evaluation process in close coordination with a group of experts.

3.2.2 Interviews

It was assumed that the most effective mean of recognizing the company's operating demands in the short term of this study was to identify them through consultation and discussion with experts from the company itself. Accordingly, four interviews were held with managers and staff of the company. Before each interview, the purpose of the inquiry and the interview process had been planned and designed based on the review of the literature. For the interviews, a semi-structured approach was used, where the interviewer had a list of general questions or topics, but could adjust the sequence of the questions depending on the course of the conversation (Bell and Bryman, 2018). This approach facilitated the procedure to expose and realize more details and possible answers, while leading the conversation to finding the most significant attributes which needed to be covered. It allowed the interviewer to ask more questions to gain clarity. In general terms, these questions were: “What concerns does management board have about the future of the company?”, “What are the needs and preferences of the customers and market?”, “What challenges does company have to meet customers’ and market’s needs?”, and “How can we deal with these challenges?”

Of the four conducted interviews, three of them were held face-to-face, and one over video call. A total of five managers and staff of *MCoutinho* were participated in the interviews. The first interview was held with the general manager of Porto center of the group at Iscte. Inasmuch as it was the first interview, and a broad range of aspects such as company objectives, its position in the market, and customers’ requirements, were discussed. The interview took more than two hours. The reposndent provided a broad overview of the company’s situation and operational process, adding the firm’s preferences as well as customers’ needs and expectations. During the interview, the need for reducing waste was discussed.

The second interview was a remote meeting with three members of the company (general manager, product manager, and a team leader) using Skype, to expand the information gathered from the first interview. In this interview, challenges in the company and waste in particular were discussed in detail, and the potential impact of lean management on waste minimization were explained. This interview took around one hour, and the next meeting in the company was arranged.

Since the operational team might have some detailed information, talking to a person from the operational team with such information was an essential part of these interviews. This person was the company's product manager, who had a considerable knowledge in the product process and the team situation and requirements. This interview was conducted in the company distribution center located in Porto, and took more than one and a half hours.

Although, because of the great knowledge of the product manager and his dominance over production process and customers' demand, the need for another interview was obviated, in order to cover the missing points if any, another meeting with two other members of the team together with the product manager were held. This last interview took around one hour, and the main attributes for selecting a lean tool were reviewed and completed. Finally, these three members were asked to provide a list of main attributes they believed an effective lean tool must cover by conducting a brainstorming session.

However, due to MCDM context which defines criteria as the major issues or concerns related to the subject, attributes must be selected by specialist in the subject (Goulart Coelho et al., 2017); in this case, decision makers of the group. However, although through interviews and brainstorming session it was intended to guide decision makers to the most critical requirements, ultimately, it was decision makers who had to decide which criteria they needed to be met by lean tool. Therefore their decision in selecting most significant criteria established four key criteria gathered in table 3.1.

Criteria	**Description due to interviewees preferences**
User-friendliness	Refers to the level of complexity of the tool - how easy it is to understand and perform by different level of employees in the team without involving top managers in early stages of the process.
Long-Term Impact	Defines the constancy and steadiness of the tool; to what extent it can become a permanent system with low regular changes over time.

Payback Period	The ratio between result and cost. Taken from another perspective, it represents how fast a tool can pay back its implementation costs.
Risk Mitigation	Represents the negative effects of changing the existing system as well as the cost and time needed to implement the new system.

Table 3.1: Established criteria

Although the main criteria from the decision maker's perspective were determined, in order to arrive at a more complete list of attributes, a specific literature research was conducted. This review was intended to reinforce potential results by adding to the criteria the attributes most frequently considered in the academic research in the field. After reviewing 26 articles it was learned that five main criteria are repeated across studies. Since it seemed these five attributes are replicated constantly, thus the demand for determining most repetitive attributes was satisfied and reviewing more articles for such purpose was stopped. As a result, among the 23 extracted criteria (Appendix A) the most repeated criteria namely, cost, quality, lead time, productivity, and inventory were selected (Table 3.2).

Criteria	**Description**	**The number of repetitions in the studies**
Cost	Represents all the necessary expenses for making a product. It includes the labor, material, and overhead costs in producing a finished product or service.	20
Lead Time	The time which a customer needs to wait for receiving a product or service, which includes the time that elapses between placing an order and its receipt.	17
Quality	A characteristic of a product or service that bears on its ability to provide customer satisfaction.	17
Productivity	The ratio between the outputs (goods or services) and the inputs required to produce them.	12
Inventory	Work In Progress (WIP) and stocks held by the company to deliver goods or services.	12

Table 3.2: Most repetitive criteria in literature

In order to determine the final list of lean tools to be evaluated, two major characteristics derived from the interviews and the literature were considered. These major characteristics were:

1. That the tools should be well-known and have been used and tested over the years (rather than selecting newer or less well-known tools).
2. That the effect of the country culture should be taken into account (as emphasized by different studies (e.g. Marodin et al., 2019; Taj and Morosan, 2011; Ghosh, 2012), which means the selected tools should have been implemented in Portugal before.

Thus, the investigation carried out by Alves et al. (2011), which studied 20 well-known lean tools used in 41 projects in companies based in Portugal over a decade was used as a reference to select the list of lean tools. Also, in order to avoid excessive complexity in the MCDM process, which could have a negative effect on the final results, it was decided to reduce the number of alternatives (lean tools) to ten. Accordingly, the ten prominent, most commonly cited tools were chosen. These tools were: 5S, Kanban, Cellular Manufacturing, Single Minute Exchange of Die (SMED), Value Stream Mapping (VSM), Visual Controls, Production Leveling (Heijunka), Standardized Work, Poka-Yoke (Mistake Proofing), and Line Balancing.

3.2.3 Questionaire

With the intention of gathering different perspectives from experts in the field of lean management to help decision makers in selecting suitable lean tool/s, a closed-ended type of questionnaire was designed. This type of questionnaire suits well with the nature of MCDM, wherein alternatives are evaluated and ranked based on the weight and scale of criteria. With this method, a set of responses are given and respondents are asked to answer to the questions by selecting from provided responses. Scaled, multiple-choice, and yes/no questions are categorized into closed-ended type (Roopa and Rani, 2012).

The questions of the study were designed and formed in Google Forms (Appendix B), and participants were asked to rate the impact of different lean tools on the set of previously defined criteria. Therefore, the questionnaire can be categorized as structured, since the questions were predetermined, and fixed, with the same order and wording for all the participants.

Due to the effective role of the country and region's culture in the results of lean tools' implementation, in order to select the appropriate experts for the survey, contacts were selected by focusing on the experts living in Portugal. All the experts for this research have worked in universities or companies in Portugal, and have published various papers on lean major or supervised students in the field. The way of reaching the specified respondents was through e-mail.

The process of selecting experts was performed in three steps. It started by searching academic members who work on lean management as their field of interest or who have done research and published in the field. These members were selected from universities in Portugal, by searching in all management departments as well as mechanical, industrial and civil engineering departments. In the second step, the professors' name were searched in Scopus, for their publications. From the publications, their co-authors were identified, and their contacts gathered as well. In the final step, from this contact information, the co-authors who were from Portuguese universities were added to the expert list.

Through taking these steps, more than 30 contacts were gathered in the first step, and around 30 contacts were achieved in the next two steps. Consequently, a list containing more than 60 contacts of Portuguese professors, researchers, and experts were gathered, which resulted in 7 responses. Although the response rate – about 12 percent – may be low, given that the purpose of the study was to adopt the MCDM procedure and the nature of MCDM processes does not set minimum limits for the number of participants (Harputlugil et al., 2011), the number of received responses were satisfying.

3.3. Criteria Weighting; Shannon Entropy

After receiving the questionnaire responses, and before analysing them using the Multi-Criteria Decision-Making tools, weights needed to be attributed to the criteria identified. There are two key methods in assigning weights to criteria: opinion-based (or subjective) and data-based (or objective) methods. In the opinion-based method, individual viewpoints are taken into account by means of polls involving experts and stakeholders; in the data-based methods, weights are computed using mathematical or quantitative models using objective information in a decision matrix (Goulart Coelho et al., 2017; Roszkowska, 2013). While the subjective method benefits from the expertise of the experts, it does not take into account the uncertainty in expert judgment (Alemi-Ardakani et al., 2016). On the other hand, the objective method tackles different shortages such as lack of experience, and decision makers' limited capability in "analyzing and correlating attributes and intangible nature of criteria", but decision makers or respondents' expertise is not considered in this method (Alemi-Ardakani et al., 2016; p.429). Considering these advantages of the objective method, it was the one chosen for the study.

Shannon Entropy is one of the most commonly used and reliable objective methods, based on probability theory. It measures the uncertainties of information by calculating the probability of the occurrence of an event and the distribution of data (Kang et al. 2007). Considering MCDM problems, each criterion represents an event, and the probability of occurrence of each event represents the weight of that criterion (Kang et al. 2007; Wang and Lee 2009). Based on Shanon Entropy, first, the decision matrix created from responses must be normalized:

$$r_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \tag{3.1}$$

Where the X_{ij} is the performance rating of i-th alternative with respect to j-th criterion.

In the next step the entropy values (e_j) is calculated as:

$$e_j = -k \sum_{j=1}^{n} r_{ij} \ln(r_{ij}) \tag{3.2}$$

Where $= 1, 2, 3, \dots, m$, $j = 1, 2, 3, \dots, n$, and constant $k = (\ln(m))^{-1}$

Then the degree of divergence of each criterion is measured as:

$$d_j = 1 - e_j \tag{3.3}$$

The higher amount of d_j represents the higher importance of the criterion j th.

Finally the objective weight of each criterion is calculated as:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{3.4}$$

After weighting criteria, alternatives need to be assessed and ranked in terms of weighted criteria. This evaluation was performed using three techniques namely; SAW, TOPSIS, and VIKOR.

3.4. Simple Additive Weighting (SAW)

SAW is a simple widely-used method which is based on the “weighted sum of performance ratings on each alternative on all attributes” (Sahir et al., 2017; p.43). This evaluation is performed through the following procedure.

In the first step the decision-making matrix (D) comprising alternatives and criteria is generated.

$$A = \{A_i | i = 1, 2, 3, \dots, m\} \tag{3.5}$$

$$C = \{C_j | j = 1, 2, 3, \dots, n\} \tag{3.6}$$

$$D = (X_{ij})_{m \times n} = \begin{bmatrix} X_{11} & X_{12} & . & . & . & X_{1n} \\ X_{21} & X_{22} & . & . & . & X_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ X_{m1} & X_{m2} & . & . & . & X_{mn} \end{bmatrix} \tag{3.7}$$

Where $A_1, A_2, \dots, A_m$ are feasible alternatives, $C_1, C_2, \dots, C_n$ are criteria, and X_{ij} is the performance rating of *i*-th alternative with respect to *j*-th criterion.

Beneficial criteria can be normalized as below:

$$r_{ij} = \frac{X_{ij}}{\sum_{i=1}^{m} X_{ij}} \text{ Or } r_{ij} = \frac{X_{ij}}{Max\langle X_{ij}\rangle} \tag{3.8}$$

And for non-beneficial criteria:

$$r_{ij} = 1 - X_{ij} \text{ Or } r_{ij} = \frac{min\langle X_{ij}\rangle}{X_{ij}} \tag{3.9}$$

By applying the weight of each criterion, the weighted normalized decision matrix is achieved:

$$V_{ij} = r_{ij} \times W_j \tag{3.10}$$

Where W is weight vector and each W_j represents the weight of *j*-th criterion, and it satisfies:

$$W = [W_1, W_{2,} \dots, W_n], W_1 + W_2 + \cdots + W_n = 1 \tag{3.11}$$

And finally the sum of values determines the score of each alternative:

$$S_i = \sum_{j=1}^{n} V_{ij} , i = 1, 2, \dots , m \tag{3.12}$$

3.5. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS evaluate alternatives in terms of their distances from two points; Positive and negative ideal solutions. In fact, the best alternative has the shortest distance from the positive ideal solution (PIS) and longest distance from the negative ideal solution (NIS). Accordingly, all the alternatives are ranked based on these distances (Zyoud and Fuchs-Hanusch, 2017). In order to assess and rank the alternatives in the TOPSIS method the following steps need to be performed.

Step one: providing decision matrix (equations 3.5, 3.6, and 3.7).

Step two: normalizing the decision matrix.

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \tag{3.13}$$

Step three: weighting the normalized decision matrix using equation (3.10).

Step four: determining the positive ideal solution (PIS) and the negative ideal solution (NIS). Which for beneficial criteria we have:

$$A^* = \{V_1^*, V_2^*, \dots , V_n^*\} = \{Max\ V_{i1}, Max\ V_{i2}, \dots , Max\ V_{in}\} \tag{3.14}$$

$$A^- = \{V_1^-, V_2^-, \dots , V_n^-\} = \{\min V_{i1}, \min V_{i2}, \dots , min\ V_{in}\} \tag{3.15}$$

And for non-beneficial criteria:

$$A^* = \{V_1^*, V_2^*, \dots , V_n^*\} = \{\min V_{i1}, \min V_{i2}, \dots , min\ V_{in}\} \tag{3.16}$$

$$A^- = \{V_1^-, V_2^-, \dots , V_n^-\} = \{Max\ V_{i1}, Max\ V_{i2}, \dots , Max\ V_{in}\} \tag{3.17}$$

Step five: Measuring the distance between each alternative and the PIS and the NIS:

$$S_i^* = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_i^*)^2}\ , i = 1, 2, \dots, m \qquad (3.18)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_i^-)^2}\ , i = 1, 2, \dots, m \qquad (3.19)$$

Step six: calculating each alternative relative closeness to the PIS:

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-}\ , 0 \leq C_i^* \leq 1 \qquad (3.20)$$

When $C_i^* = 1$, the alternative is the best option, and when the $C_i^* = 0$, the alternative is the worst one.

Step seven: the alternatives can be ranked based on their C_i^*.

The option with the longest distance from NIS and the shortest distance to PIS is selected as the best option, which maximizes the beneficial criteria and minimizes the non-beneficial criteria (Esfahanipour and Davari Ardakani, 2015).

3.6. VIšekriterijumsko KOmpromisno Rangiranje (VIKOR)

Similar to TOPSIS, VIKOR is a distance based method which measures the "closeness" of each alternative to the "ideal" option based on each criterion function. It intends to "find a compromise solution emerging out of a set of conflicting criteria" (Tian et al., 2018; p.638) to cover the relative importance of the distances (Opricovic and Tzeng, 2004). In order to perform VIKOR method following steps need to be taken (Opricovic and Tzeng, 2004; Tong et al., 2007; Acuña-Soto et al., 2019):

Step one: create the decision matrix, $D = \left(X_{ij}\right)_{m\times n}$ (equations 3.5, 3.6, and 3.7).

Step two: normalize the decision matrix (equations 3.8 and 3.9).

Step three: define the weighted normalized decision matrix (equation 3.10).

Step four: determine the positive ideal solution and the negative ideal solution.

Which for beneficial criteria we have:

$$F^{*} = \{f_1^{*}, f_2^{*}, \dots , f_n^{*}\} = \{Max\, r_{i1}, Max\, r_{i2}, \dots , Max\, r_{in}\} \tag{3.21}$$

$$F^{-} = \{f_1^{-}, f_2^{-}, \dots , f_n^{-}\} = \{\min r_{i1}, \min r_{i2}, \dots , min\, r_{in}\} \tag{3.22}$$

And for non-beneficial criteria:

$$F^{*} = \{f_1^{*}, f_2^{*}, \dots , f_n^{*}\} = \{\min r_{i1}, \min r_{i2}, \dots , min\, r_{in}\} \tag{3.23}$$

$$F^{-} = \{f_1^{-}, f_2^{-}, \dots , f_n^{-}\} = \{Max\, r_{i1}, Max\, r_{i2}, \dots , Max\, r_{in}\} \tag{3.24}$$

Step five: compute utility (S_i) and regret measures (R_i).

$$S_i = \sum_{j=1}^{n} w_j \times \frac{f_j^{*} - r_{ij}}{f_j^{*} - f_j^{-}} \tag{3.25}$$

$$R_i = Max\left\{w_j \times \frac{f_j^{*} - r_{ij}}{f_j^{*} - f_j^{-}}\right\} \tag{3.26}$$

Step six: determine the VIKOR index.

$$\mathrm{Q}_i = v\left[\frac{S_i - S^{*}}{S^{-} - S^{*}}\right] + (1 - v)\left[\frac{R_i - R^{*}}{R^{-} - R^{*}}\right] \tag{3.27}$$

Where $S^{*} = min_i S_i$, $S^{-} = Max_i S_i$, $R^{*} = min_i R_i$, $R^{-} = Max_i R_i$, $i = 1,2, \dots , m$

And $v \in [0,1]$ represents the strategy weight of “the majority of criteria” (or “the maximum group utility”) which is usually assumed to be equal to 0.5.

Step seven: rank the alternatives based on the S_i, R_i and Q_i values by sorting them in decreasing order.

Step eight: select the alternative with the lowest Q_i as the best alternative if it satisfies two following conditions:

C1. "Acceptable advantage":

$$\mathrm{Q}_1 - \mathrm{Q}_2 \geq \frac{1}{m-1} \tag{3.28}$$

Where considering the results of Q_i, Q_1 is the best ranked alternative and Q_2 is the second one, and m is the number of the alternatives.

C2. "Acceptable stability in decision making":

The best selected alternative (step eight), also must be ranked as the best one by S_i or/and R_i.

If one of the conditions is not satisfied, then propose a set of compromise solutions as follows:

- If only condition C2 is not satisfied, propose Q_1 and Q_2 , or
- If the condition C.1 is not satisfied, propose alternatives $i = 1,2, \dots, M.$ where $\mathrm{Q}_M - \mathrm{Q}_1 < \frac{1}{m-1}$ determines the M for maximum i.

In the next chapter, the results of the obtained data will be measured and analyzed via adopting these three MCDM tools (SAW, TOPSIS, and VIKOR) to rank alternatives, and select the most appropriate one/s based on specified demands, as well as making some recommendations.

4. Results and Discussion

In order to select suitable lean tool(s) to reduce waste and improve the efficiency in *MCoutinho Group* as a specific case with unique specifications, Multi-Criteria Decision-Making (MCDM) was utilized. First, nine criteria were defined through meetings with the company's management board and the relevant literature. Having determined the lean tools to be assessed and the criteria upon which they were to be evaluated, in the next step, the required data for implementing the MCDM process were obtained through a questionnaire, from a panel of seven experts. Subsequently, the data were analyzed using three MCDM techniques to rank the defined lean tools. In the following sections, the results of the MCDM process will be analyzed and discussed.

4.1. Decision Matrix and Data Normalization

The first step after receiving the questionnaires, was to create a decision-matrix wherein each element (or cell) was equal to the sum of the performance rating of *i*-th alternative with respect to *j*-th criterion derived from seven questionnaires (Table 4.1).

$$X_{ij} = \sum_{k=1}^{7} (X_{ij})_k \quad (4.1)$$

Where i represents the number of alternative ($i = 1, 2, 3, \dots, 10$), j refers to the number of criterion($j = 1, 2, 3, \dots, 9$), k represents the questionnaire number filled by an expert ($k = 1, 2, 3, \dots, 7$)

Decision Matrix	User-friendliness	Long-Term Impact	Payback Period	Risk	Cost	Quality	Lead-Time	Productivity	Inventory
5S	48	38	39	37	39	45	41	42	40
Kanban	36	31	35	32	31	36	31	38	38
Cellular Manufacturing	24	34	25	29	37	43	44	39	42
Single Minute Exchange of Die (SMED)	34	40	39	34	47	39	44	39	42
Value Stream Mapping (VSM)	36	34	38	36	40	35	41	41	39

Visual Controls	43	38	40	26	45	44	42	38	36
Production Leveling (Heijunka)	28	32	38	30	39	35	33	37	43
Standardized Work	32	39	36	32	42	42	45	40	39
Poka-Yoke (Mistake Proofing)	43	40	41	27	45	47	29	39	35
Line Balancing	24	34	37	30	40	29	30	30	42
SUM Pij	348	360	368	313	405	395	380	383	396

Table 4.1: Decision-matrix

In order to form all the criteria in a dimensionless class to provide a meaningful comparison, data normalization (r_{ij}) was done using linear sum technique (Table 4.2).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{4.2}$$

Where i represents the number of alternative ($i = 1, 2, 3, \ldots, 10$), j refers to the number of criterion ($j = 1, 2, 3, \ldots, 9$).

Normalized	User-friendliness	Long-Term Impact	Payback Period	Risk	Cost	Quality	Lead-Time	Productivity	Inventory
5S	0.1379	0.1056	0.1060	0.1182	0.0963	0.1139	0.1079	0.1097	0.1010
Kanban	0.1034	0.0861	0.0951	0.1022	0.0765	0.0911	0.0816	0.0992	0.0960
Cellular Manufacturing	0.0690	0.0944	0.0679	0.0927	0.0914	0.1089	0.1158	0.1018	0.1061
Single Minute Exchange of Die (SMED)	0.0977	0.1111	0.1060	0.1086	0.1160	0.0987	0.1158	0.1018	0.1061
Value Stream Mapping (VSM)	0.1034	0.0944	0.1033	0.1150	0.0988	0.0886	0.1079	0.1070	0.0985

Visual Controls	0.1236	0.1056	0.1087	0.0831	0.1111	0.1114	0.1105	0.0992	0.0909
Production Leveling (Heijunka)	0.0805	0.0889	0.1033	0.0958	0.0963	0.0886	0.0868	0.0966	0.1086
Standardized Work	0.0920	0.1083	0.0978	0.1022	0.1037	0.1063	0.1184	0.1044	0.0985
Poka-Yoke (Mistake Proofing)	0.1236	0.1111	0.1114	0.0863	0.1111	0.1190	0.0763	0.1018	0.0884
Line Balancing	0.0690	0.0944	0.1005	0.0958	0.0988	0.0734	0.0789	0.0783	0.1061

Table 4.2: Normalized decision-matrix

4.2. Weighting Criteria

The relative importance and impact of each criterion on the final outcome were specified by allocating weights. As such, Shanon Entropy was utilized to weight the criteria. So owing to the normalized decision-matrix, the entropy values (e_j) was calculated as (Table 4.3):

$$e_j = -k \sum_{j=1}^{n} r_{ij} \ln(r_{ij}) \qquad (4.3)$$

Where $i = 1, 2, 3, \ldots, 10$, $= 1, 2, 3, \ldots, 9$, and constant $k = (\ln(m))^{-1}$

By knowing m = 10, k = 0.4343

Entropy Value	User-friendliness	Long-Term Impact	Payback Period	Risk	Cost	Quality	Lead-Time	Productivity	Inventory
ej	0.9892	0.9983	0.9968	0.9974	0.9974	0.9959	0.9942	0.9985	0.9991

Table 4.3: Entropy of each index

Then the degree of divergence (d_j) of each criterion was measured as (Table 4.4):

$$d_j = 1 - e_j \qquad (4.4)$$

Divergence	User-friendliness	Long-Term Impact	Payback Period	Risk	Cost	Quality	Lead-Time	Productivity	Inventory
dj	0.0108	0.0017	0.0032	0.0026	0.0026	0.0041	0.0058	0.0015	0.0009

Table 4.4: Divergence

Since a higher level of d_j represents a higher level of importance of the criterion, user-friendliness appears as the most important criterion and lead-time, quality, and payback period were placed in that order after user-friendliness.

Finally, the normalized weight of each criterion was achieved (Table 4.5) through the formula:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{4.5}$$

Normalized Weight	User-friendliness	Long-Term Impact	Payback Period	Risk	Cost	Quality	Lead-Time	Productivity	Inventory
Wj	0.3251	0.0516	0.0965	0.0785	0.0785	0.1237	0.1732	0.0449	0.0279

Table 4.5: Normalized weight of each criterion

The results show that user-friendliness achieved the highest weighting. This suggests that a lean tool can be highly useful and effective, but if the tool is not easy to implement and utilize, it will likely not fully accomplish its goals and results. This attribute was also highly stressed by the management team, in spite of being less frequently mentioned in the literature.

The results suggest that “user-friendliness” requires to be covered in the future studies as a highly effective criterion, since it has not been considered as much as other attributes in the conducted surveys. Indeed, while reviewing 26 articles to list the most commonly-repeated attributes in lean approach, user-friendliness appeared in only one paper, as “Simplification” (Alves et al. 2011).

As expected, the next highest weights were assigned to time, quality, and the combination of cost and time (payback period). In previous studies (De Toni and Tonchia, 1996; Behrouzi and Wong, 2011; Garza-Reyes et al. 2012), these attributes of time, quality and cost have typically been the most often emphasized criteria to be considered in choosing lean tools.

4.3. Simple Additive Weighting (SAW) Method

The simplicity of the SAW method, which is based on calculating a weighted average sum, has made it one the most frequently used MCDM tools (Roszkowska, 2013; Adriyendi, 2015; Sahir et al., 2017; Pires et al., 2019). With this method, using the normalized decision-matrix (r_{ij}) (Table 4.2) and the weights (W_j) obtained from the Shanon Entropy method (Table 4.5), the lean tools were ranked by calculating the sum of the weighted average for each tool (S_i). As a result, higher results represent a higher ranking (Table 4.6).

$$S_i = \sum_{j=1}^{n} V_{ij} \tag{4.6}$$

Where $i = 1, 2, \dots, 10, = 9$, and the weighted normalized decision-matrix (V_{ij}) is calculated as:

$$V_{ij} = r_{ij} \times W_j \tag{4.7}$$

Lean Tools	S
5S	0.1178755
Visual Controls	0.1112628
Poka-Yoke (Mistake Proofing)	0.1071235
Single Minute Exchange of Die (SMED)	0.1051592
Value Stream Mapping (VSM)	0.1024533
Standardized Work	0.1021912
Kanban	0.0938221
Cellular Manufacturing	0.0893465
Production Leveling (Heijunka)	0.089161
Line Balancing	0.081505

Table 4.6: SAW ranking results

With regard to the criterion with the highest weight - user-friendliness – the results show that the 5S technique was ranked first based on the participating expert's opinions. The simplicity of this tool thus makes it a fundamental lean tool: in addition to its positive impact on quality, time, productivity, and employees commitment (Hernández Lamprea,2015), its ease of use makes it potentially able to be applied by everyone in the team, regardless of hierarchical position, which is a highly important factor for the company management team.

Visual Controls was positioned in the second place. This tool is also known for its ease of use, as it identifies waste rapidly and promotes continuous improvement, resulting in efficiency improvement in production systems (Moser and Dos Santos, 2003). *Poka-Yoke* (Mistake Proofing) and Single Minute Exchange of Die (SMED) were respectively placed in the third and fourth positions.

4.4. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is a distance-based method, where to rank lean tools, their distances from the Positive Ideal Solution and the Negative Ideal Solution (NIS) are measured and compared. In order to measure the distances, the first step is to normalize the generated decision-matrix (Table 4.1) using vector normalization (Equation 4.8). The results are presented in Table 4.7.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4.8}$$

Where i represents the number of alternative ($i = 1, 2, 3, \dots, 10$), j refers to the number of criterion($j = 1, 2, 3, \dots, 9$), and (r_{ij}) is the normalized data.

Normalized	User-friendliness	Long-Term Impact	Payback Period	Risk	Cost	Quality	Lead-Time	Productivity	Inventory
5S	0.4258	0.3371	0.3459	0.3282	0.3459	0.3992	0.3637	0.3725	0.3548
Kanban	0.3193	0.2750	0.3105	0.2838	0.2750	0.3193	0.2750	0.3371	0.3371
Cellular Manufacturing	0.2129	0.3016	0.2218	0.2572	0.3282	0.3814	0.3903	0.3459	0.3725
Single Minute Exchange of Die (SMED)	0.3016	0.3548	0.3459	0.3016	0.4169	0.3459	0.3903	0.3459	0.3725

Value Stream Mapping (VSM)	0.3193	0.3016	0.3371	0.3193	0.3548	0.3105	0.3637	0.3637	0.3459
Visual Controls	0.3814	0.3371	0.3548	0.2306	0.3992	0.3903	0.3725	0.3371	0.3193
Production Leveling (Heijunka)	0.2484	0.2838	0.3371	0.2661	0.3459	0.3105	0.2927	0.3282	0.3814
Standardized Work	0.2838	0.3459	0.3193	0.2838	0.3725	0.3725	0.3992	0.3548	0.3459
Poka-Yoke (Mistake Proofing)	0.3814	0.3548	0.3637	0.2395	0.3992	0.4169	0.2572	0.3459	0.3105
Line Balancing	0.2129	0.3016	0.3282	0.2661	0.3548	0.2572	0.2661	0.2661	0.3725

Table 4.7: Normalized decision-matrix using vector normalization

In the next step, by knowing the weights resulted from Shanon Entropy, the weighted normalized decision-matrix was determined (Table 4.8) in terms of equation 4.7.

V	User-friendliness	Long-Term Impact	Payback Period	Risk	Cost	Quality	Lead-Time	Productivity	Inventory
5S	0.1384	0.0174	0.0334	0.0258	0.0272	0.0494	0.0630	0.0167	0.0099
Kanban	0.1038	0.0142	0.0300	0.0223	0.0216	0.0395	0.0476	0.0151	0.0094
Cellular Manufacturing	0.0692	0.0156	0.0214	0.0202	0.0258	0.0472	0.0676	0.0155	0.0104
Single Minute Exchange of Die (SMED)	0.0981	0.0183	0.0334	0.0237	0.0327	0.0428	0.0676	0.0155	0.0104
Value Stream Mapping (VSM)	0.1038	0.0156	0.0325	0.0251	0.0278	0.0384	0.0630	0.0163	0.0096
Visual Controls	0.1240	0.0174	0.0342	0.0181	0.0313	0.0483	0.0645	0.0151	0.0089
Production Leveling (Heijunka)	0.0808	0.0147	0.0325	0.0209	0.0272	0.0384	0.0507	0.0147	0.0106
Standardized Work	0.0923	0.0179	0.0308	0.0223	0.0292	0.0461	0.0691	0.0159	0.0096
Poka-Yoke (Mistake Proofing)	0.1240	0.0183	0.0351	0.0188	0.0313	0.0516	0.0446	0.0155	0.0087

Line Balancing	0.0692	0.0156	0.0317	0.0209	0.0278	0.0318	0.0461	0.0120	0.0104

Table 4.8: Weighted normalized decision-matrix

Then, the positive ideal solution (PIS) and the negative ideal solution (NIS) were determined (Table 4.9) as follows:

$$\text{PIS} = V_i^* = \{Max\, V_{i1}, Max\, V_{i2}, \dots, Max\, V_{in}\} \tag{4.9}$$

$$\text{NIS} = V_i^- = \{\min V_{i1}, \min V_{i2}, \dots, \min V_{in}\} \tag{4.10}$$

Where $i = 1, 2, \dots, 10, n = 9$

	User-friendliness	Long-Term Impact	Payback Period	Risk	Cost	Quality	Lead-Time	Productivity	Inventory
PIS = V_i^*	0.1384	0.0183	0.0351	0.0258	0.0327	0.0516	0.0691	0.0167	0.0106
NIS = V_i^-	0.0692	0.0142	0.0214	0.0181	0.0216	0.0318	0.0446	0.0120	0.0087

Table 4.9: Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS)

The distance between each alternative and the PIS (S_i^*) and the NIS (S_i^-) were measured (Table 4.10) in the next step.

$$S_i^* = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_i^*)^2} \tag{4.11}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_i^-)^2} \tag{4.12}$$

i	S_i^-	S_i^*
1	0.0755	0.0088
2	0.0370	0.0446
3	0.0284	0.0713
4	0.0426	0.0415
5	0.0426	0.0381
6	0.0629	0.0175

7	0.0197	0.0626
8	0.0392	0.0469
9	0.0609	0.0295
10	0.0126	0.0762

Table 4.10: Distance between each alternative and the PIS and the NIS

And finally, the relative closeness of each alternative to the PIS (C_i^*) was calculated (Table 4.11) to rank the lean tools based on their C_i^*, where the tools with a higher C_i^* have a longer distance from NIS and shorter distance to PIS.

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-}, 0 \leq C_i^* \leq 1 \quad (4.13)$$

5S	C1	0.8954
Kanban	C2	0.4533
Cellular Manufacturing	C3	0.2848
Single Minute Exchange of Die (SMED)	C4	0.5068
Value Stream Mapping (VSM)	C5	0.5281
Visual Controls	C6	0.7819
Production Leveling (Heijunka)	C7	0.2395
Standardized Work	C8	0.4549
Poka-Yoke (Mistake Proofing)	C9	0.6739
Line Balancing	C10	0.1423

Table 4.11: Relative closeness of each alternative to the PIS

The outcomes of TOPSIS show the same results as the SAW method for the first three best tools, where 5S, Visual Controls, and *Poka-Yoke* (Mistake Proofing) achieved the highest rankings. This outcome again insists on applying fundamental lean tools which increase the transparency and visibility in the process. Besides their positive impact on different attributes, all the three tools (i.e.

5S, Visual Controls, and *Poka-Yoke* (Mistake Proofing) are known as user-friendly tools which provide "unobstructed process throughput" (Spath, 2011; p.251), which likely led to them being ranked above the other tools. But in contrast with SAW wherein SMED was the fourth ranked tool, Value Stream Mapping (VSM) placed in the fourth position with TOPSIS.

Although the result of implementing both SMED and VSM could be the same, the attributes they concentrate on to obtain results are different. While SMED considers time reduction as the main criterion, VSM tries to increase quality by identifying value-adding activities to achieve reductions in lead time and inventory (Sundar et al., 2014). The different attributes covered by these two tools could be the main reason for the difference in their rankings with different MCDM techniques.

4.5. VIšekriterijumsko KOmpromisno Rangiranje (VIKOR)

VIKOR is a distance based method like TOPSIS. Accordingly, the "closeness" of each lean tool to the "ideal" option needs to be measured aiming to determine the most beneficial tools. "The solution is obtained by combining the maximum group utility (S) and individual regret of the opponent (R) in the form of a compromise solution which directs the decision-makers to the final result" (Akram et al., 2019; p.2).

In the first step, in contrast with TOPSIS wherein vector normalization was applied to normalize the decision-matrix (r_{ij}), in VIKOR method linear normalization (Equation 4.2) was utilized (as applied in SAW method). The results of the normalization can be found in Table 4.2.

Then, the positive ideal solution (F^*) and the negative ideal solution (F^-) were determined (Table 4. 12) using the following equations:

$$F^* = \{f_1^*, f_2^*, \dots, f_n^*\} = \{Max\, r_{i1}, Max\, r_{i2}, \dots, Max\, r_{in}\} \quad (4.14)$$

$$F^- = \{f_1^-, f_2^-, \dots, f_n^-\} = \{min\, r_{i1}, min\, r_{i2}, \dots, min\, r_{in}\} \quad (4.15)$$

F*	0.1379	0.1111	0.1114	0.1182	0.1160	0.1190	0.1184	0.1097	0.1086
F-	0.0690	0.0861	0.0679	0.0831	0.0765	0.0734	0.0763	0.0783	0.0884

Table 4.12: Positive and negative ideal solution

Utility (S_i) and regret measures (R_i) were computed (Table 4.13) in the next step.

$$S_i = \sum_{j=1}^{n} w_j \times \frac{f_j^* - r_{ij}}{f_j^* - f_j^-} \tag{4.16}$$

$$R_i = Max\left\{w_j \times \frac{f_j^* - r_{ij}}{f_j^* - f_j^-}\right\} \tag{4.17}$$

Lean Tools	Utility Index		Regret Index	
5S	S1	0.1303	R1	0.0433
Kanban	S2	0.6241	R2	0.1626
Cellular Manufacturing	S3	0.6152	R3	0.3251
Single Minute Exchange of Die (SMED)	S4	0.3037	R4	0.1897
Value Stream Mapping (VSM)	S5	0.4000	R5	0.1626
Visual Controls	S6	0.2660	R6	0.0785
Production Leveling (Heijunka)	S7	0.6552	R7	0.2710
Standardized Work	S8	0.3687	R8	0.2168
Poka-Yoke (Mistake Proofing)	S9	0.3612	R9	0.1732
Line Balancing	S10	0.8025	R10	0.3251

Table 4.13: Utility and regret measures

Considering the strategy weight of "the majority of criteria" (v) equal to 0.5, the VIKOR index (Q_i) was calculated (Table 4.14).

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1 - v)\left[\frac{R_i - R^*}{R^- - R^*}\right] \tag{4.18}$$

Lean Tools	VIKOR Index	
5S	Q1	0.0000
Kanban	Q2	0.5789
Cellular Manufacturing	Q3	0.8607
Single Minute Exchange of Die (SMED)	Q4	0.3886
Value Stream Mapping (VSM)	Q5	0.4122
Visual Controls	Q6	0.1633
Production Leveling (Heijunka)	Q7	0.7943
Standardized Work	Q8	0.4850
Poka-Yoke (Mistake Proofing)	Q9	0.4022
Line Balancing	Q10	1.0000

Table 4.14: VIKOR index

Finally, the lean tools were ranked (Table 4.15) based on S_i, R_i and Q_i values, where lower values reflect a higher ranking (Tables 4.13 and 4.14).

Rank	Based on VIKOR index	Based on Utility index	Based on Regret index
1	5S	5S	5S
2	Visual Controls	Visual Controls	Visual Controls

3	Single Minute Exchange of Die (SMED)	Single Minute Exchange of Die (SMED)	Value Stream Mapping (VSM)
4	Poka-Yoke (Mistake Proofing)	Poka-Yoke (Mistake Proofing)	Kanban
5	Value Stream Mapping (VSM)	Standardized Work	Poka-Yoke (Mistake Proofing)
6	Standardized Work	Value Stream Mapping (VSM)	Single Minute Exchange of Die (SMED)
7	Kanban	Cellular Manufacturing	Standardized Work
8	Production Leveling (Heijunka)	Kanban	Production Leveling (Heijunka)
9	Cellular Manufacturing	Production Leveling (Heijunka)	Cellular Manufacturing
10	Line Balancing	Line Balancing	Line Balancing

Table 4.15: Ranking based on S_i, R_i and Q_i values

In order to select the lean tools with the lowest Q_i as the best alternatives, they must satisfy the two following conditions:

Condition 1. “Acceptable advantage”:

$$Q_1 - Q_2 \geq \frac{1}{m-1} \tag{4.19}$$

Where considering the results of Q_i, Q_1 is the best ranked alternative and Q_2 is the second one, and m is equal to 10. So the result of $(\mathrm{Q}_1 - \mathrm{Q}_2)$ is equal to 0.1633 which is higher than the result of $(\frac{1}{m-1})$ = 0.1111. Therefore, the first condition has been satisfied.

Condition 2. "Acceptable stability in decision making":

The best selected alternative, must also be ranked as the best one by S_i or/and R_i. Consequently, both conditions have been satisfied. Therefore, according to this method, Q_1 (5S) can be selected as the best and Q_2 (Visual Controls) is selected as the second best alternative.

Although in the VIKOR technique the two best alternatives were to the same as the results achieved with the last two methods, the third best option (i.e. Single Minute Exchange of Die (SMED)) was not the same as with the other methods. *Poka-Yoke* (Mistake Proofing) which was the third best option in the last two methods, ranked fourth with VIKOR. It is precisely because different processes of evaluating alternatives by various MCDM techniques can result in different results that aggregate methods have been developed to unify all the ranking results.

4.6. Aggregate Methods

Three aggregate methods were utilized to unify the results. Although the outcomes of all the MCDM techniques applied in this study resulted in the same conclusions for the best and the second best tools, the aggregation process was conducted to fulfil two purposes. First, to comply with all the required steps for an MCDM procedure. Second, to unify the ranking results, in order to determine and position the third and the fourth best tools among the five best alternatives.

4.6.1. Borda

Considering the Borda method, wherein "m" is the number of alternatives compared, which is equal to 5 in this pairwise comparison, "m-1" wins places the alternative in the first rank, "m-2" wins puts the alternative in the second place, down to 0 which represents the fifth ranked alternative. With this method, *Poka-Yoke* (Mistake Proofing) and Single Minute Exchange of Die (SMED) were positioned at the third and fourth places respectively after 5S and Visual Controls (see table 4.16).

Borda	5S	Visual Controls	Poka-Yoke (Mistake Proofing)	Single Minute Exchange of Die (SMED)	Value Stream Mapping (VSM)	Wins
5S	-	M	M	M	M	4
Visual Controls	X	-	M	M	M	3
Poka-Yoke (Mistake Proofing)	X	X	-	M	M	2
Single Minute Exchange of Die (SMED)	X	X	X	-	M	1
Value Stream Mapping (VSM)	X	X	X	X	-	0

Table 4.16: Borda method results

4.6.2. Copeland

The Copeland method is like a continued version of Borda, where the losses of alternatives are considered as well as their wins. The results (table 4.17) were the same as with the Borda method, with 5S, Visual Controls, *Poka-Yoke* (Mistake Proofing) and Single Minute Exchange of Die (SMED) ranked from number 1 to number 4 respectively.

Copeland	5S	Visual Controls	Poka-Yoke (Mistake Proofing)	Single Minute Exchange of Die (SMED)	Value Stream Mapping (VSM)	Wins	Losses	points
5S	-	M	M	M	M	4	0	4
Visual Controls	X	-	M	M	M	3	1	2
Poka-Yoke (Mistake Proofing)	X	X	-	M	M	2	2	0
Single Minute Exchange of Die (SMED)	X	X	X	-	M	1	3	-2
Value Stream Mapping (VSM)	X	X	X	X	-	0	4	-4

Table 4.17: Copeland method results

4.6.3. Average Method

In this method, the mean of the ranks are calculated; then, by providing a paired comparison between the alternatives, the lower mean represents the higher rank. Taking into account the results presented in table 4.18, the evaluations show the same results as the two previous method. Thus, it can be stated that after 5S and Visual Controls, the best two other options are *Poka-Yoke* (Mistake Proofing) and Single Minute Exchange of Die (SMED).

Average Method	SAW	TOPSIS	VIKOR	Mean
5S	1	1	1	1
Visual Controls	2	2	2	2
Poka-Yoke (Mistake Proofing)	3	3	4	3.33
Single Minute Exchange of Die (SMED)	4	5	3	4
Value Stream Mapping (VSM)	5	4	5	4.67

Table 4.18: Average method results

4.7. Discussion and Implementation

4.7.1. Discussion

The results of the study indicate a strong connection between the top three lean tools based on *MCoutinho Group* Preferences, namely around the concept of "transparency improvement" (Moser and dos Santos, 2003). Moser and dos Santos (2003) note that this concept is the core principle of several lean tools, including5S, Visual Controls, Kanban, and *Poka-Yoke* (Mistake Proofing). Transparency improvement highlights that the faster and more easily waste can be identified, the sooner and better it can be removed or minimized. Improving transparency and visualization has been shown to encourage progressive and continuous improvements in systems (Moser and dos Santos, 2003). Consistent with this idea of continuous improvement, each of the top ranked tools identified in this study can be seen as a level up or a complementary tool for the previous one.

Having an error-free environment necessitates a solid basis and standardization help assess production processes more accurately and identify the opportunities for improvement (Spath, 2011). As Spath, (2011, p.249) notes "It is impossible to accurately understand current practices and process risks when the people involved have their own unique way of doing the work". The results of the current study also highlight the significance of this aspect. The first ranked alternative, i.e. 5s, is a fundamental technique with five pillars (Sort-out, Set in order, Shine (or cleanliness), Standardized, and Sustain) which are also known as the five pillars of a visual workplace (Becker, 2001). This is consistent with Spath (2011) who notes that 5S is a systematic and solid foundation which provides work standards. Furthermore, it has been suggested that 5S should be performed in the early steps of the lean management procedure, and later integrated with other tools (Moulding, 2010). As such, it is often suggested that Visual Controls be adopted in the Set in order and Standardized stages of 5S (Becker, 2001; Lixia and Bo, 2008).

Visual Controls is thus a complementary tool for 5S, providing workspace layout improvements and evolving standardization into higher levels, which increases the orderliness and neatness of the process in the company (Lixia and Bo, 2008), as well as its efficiency (Moser and Dos Santos, 2003). Spath (2011; p.254) notes that "Visual Controls are often developed as part of 5S events to organize workflow". In addition, and consistent with the importance of "user-friendliness" uncovered in this research, Spath (2011; p.254) notes that "Visual Control is a simple and direct nonverbal method for relaying information to others. It allows staff to understand the current situation, understand the process, or recognize when something is out of place".

Integrating *Poka-Yoke* (Mistake Proofing) with two previous tools (5s and Visual Controls), has been described as progressing from a fundamental technique (5s) towards more advanced tools (*Poka-Yoke*) (Tezel and Aziz, 2015). *Poka-Yoke* is a visual guarantee tool, which by adopting special mechanisms, ensures the right outcomes, thus leading to increases in quality and decreases in time wasting (Sundar et al., 2014).

The fourth ranked tool in the study is Single Minute Exchange of Die (SMED). Coupled with the aforementioned tools, SMED can be used in order to diminish the cost and lead time and increase flexibility and productivity. This tool can reduce the lot size by providing rapid changeovers from running of one process to running the next. It is interesting to note that, our results are consistent with Dave and Sohani (2012) who stressed that SMED should be combined with other lean tools - specifically with 5S and Visual Controls - and that this combination will improve the efficiency and effectiveness of the tool.

The results also reveal two additional significant points. First, they highlight the essential role of user-friendliness in selecting a lean tool. The user-friendliness of a tool can be a key element in allowing a company to fully benefit from it. Second, some specific criteria were determined in this study based on *MCoutinho Group* preferences. These criteria which may be different from what already considered in previous research, stressed the considerable importance of customizing lean systems and selecting lean tool/s based on the type of company and its operation system. In this regard, Anvari et al., (2014) highlighted that the success and failure of a lean system is highly depended on selecting a proper lean tool, and without considering the company's needs and preferences, the proper lean tool may not be selected.

4.7.2. Implementation

As the results indicated, to achieve the desired outcomes and reduce waste in this specific case of MCoutinho, and bearing in mind the company's own criteria, the main factor which needs to be covered by a lean tool is, improving transparency. Furthermore, the results suggest that, this aim needs to be achieved via applying fundamental tools. Hence, implementing 5S, for example, as a fundamental tool which increases the visibility in the process, can help address this goal.

Implementing 5S necessitates taking five steps. In the first step, *Seiri* (sort or sort-out), necessary and unnecessary items in the work place must be identified. Items are reviewed, and the unnecessary items are removed or relocated (Spath, 2011), and necessary items are put in an appropriate place (Bullington, 2003). Necessary items which are used frequently must be kept in a close, easily accessible places, and infrequently used items should be placed away but in the accessible area (Spath, 2011). Providing such a process helps team to re-assess the items or materials they use to make sure what they utilize is the most suitable tool for the process (Agrahari, et al., 2015).

In the second step – *Seiton* (set in order) –items must be kept in the correct places, for the sake of easy retrieval; hence workers need to be trained and encouraged to put items back in their determined places (Agrahari, et al., 2015). This step increases visibility in the work area and faults can be identified and corrected easily, "which is one of the main reasons why the implementation of Visual Controls is encouraged during this step" (Agrahari, et al., 2015, p.181). Visual signs and labels need to be used to make sure all the items are readily accessible and easy to find (Tezel and Aziz, 2016).

After taking last two steps, for the third step – *Seiso* (shine) – the work environment should be cleaned and any cause of untidiness removed (Singh et al., 2014). By cleaning up the work area and removing dust and dirt, the root of waste can be more easily identified, and faults in production, work accidents, and inefficiency will be reduced (Singh et al., 2014). To fully benefit from this step, all the employees must be involved in the process (Agrahari, et al., 2015). They must "gather the data of what they feel needs to be cleaned and how often it should be cleaned" (Agrahari, et al., 2015, p.182). In order to increase the effect of this step, the name of person who is responsible for cleaning each area as well as daily rosters should be provided and placed in each area (Singh et al., 2014; Agrahari, et al., 2015).

After implementing the last three steps, a standardized procedure must be established (Agrahari, et al., 2015). This step – *Seiketsu* (standardized) – intends to gain full advantage of the last three steps by providing a daily correct attitude in employees (Singh et al., 2014). Hence mangers and team leaders' role in encouraging employees to follow the defined standard is of utmost importance (Spath, 2011). The defined standard must be simple, with a daily checklist that precisely determines the responsible of the task, actions that must be performed, action time, control process, cleaning and maintenance schedules (Agrahari, et al., 2015). This checklist must be placed at appropriate places with visual signs and labels (Agrahari, et al., 2015). Therefore, implementing Visual Controls in this step to expose mistakes is essential (Singh et al., 2014).

The fifth step – *Shitsuke* (sustain) – tries to sustain the success of 5S over time. Therefore, it concentrates on tightening a discipline to aid the company to maintain the objectives (Agrahari, et al., 2015). In this step, the significant influence of following 5S process on productivity and safety must be explained by managers or team leaders. Moreover, a plan for providing periodical training must be launched by management to keep knowledge of employees about 5S updated (Singh et al., 2014). "Over time, maintaining an organized and clean environment will become part of the work culture" (Spath, 2011, p.254). However, naturally, this process needs to be adapted to the specifics of *MCoutinho Group*.

By implementing these five pillars of 5S it is supposed to increase efficiency in the company, detect defects, improve morale in employees, and subsequently reduce waste (Spath, 2011). Also, as it has been suggested before, for advancing the lean system in the company *Poka-Yoke* and SMED can be employed in the future.

5. Conclusions

5.1. Conclusions and Recommendations

Higher demand levels, variations in customer orders, and customized products play a significant role in waste generation. This, in turn, leads companies to adopt different systems to face this challenge and remain competitive in the market. Hundreds of studies have been done to emphasize the significant impacts of lean management on reducing different types of waste and increasing value. However, the amount and variety of lean tools which are an inseparable part of lean system, make the process of choosing which ones to implement difficult.

By virtue of the considerable significance of decision-making in every aspect of our life, which encompasses the decisions taken by business managers, this research aimed at enhancing the decision process and its results in choosing the most relevant alternative/s – lean technique/s – based on *MCoutinho Group*'s preferences, through Multi-Criteria Decision-Making (MCDM).

In this respect, by implementing the MCDM procedure, it was intended to gather different perspectives from experts in the field, and analyze them to help the management board of the *MCoutinho Group* to make an appropriate decision and increase the chance of achieving competitive advantage via reducing waste, based on their requirements.

The company's demands for reducing waste along with the most critical attributes for dealing with this issue from company's viewpoint were determined in through interviews. A specific literature review was further carried out to add to that initial criteria. The results led to nine criteria including: user-friendliness, long-term impact, payback period, risk mitigation, cost, lead time, quality, productivity, and inventory.

Considering two main points, the company's preferences and the cultural impact of the region, 10 prominent lean tools were selected, namely 5S, Kanban, Cellular Manufacturing, Single Minute Exchange of Die (SMED), Value Stream Mapping (VSM), Visual Controls, Production Leveling (*Heijunka*), Standardized Work, *Poka-Yoke* (Mistake Proofing), and Line Balancing.

After obtaining expert opinions on the effect of each lean tools on the specified criteria through a questionnaire, the results were weighted, and analyzed using Shannon Entropy, Simple Additive Weighting (SAW), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), VIšekriterijumsko KOmpromisno Rangiranje (VIKOR), and Aggregate methods. Finally, the main conclusions can be stated as:

First, the results of Shanon Entropy revealed the considerable importance of the level of user-friendliness of a lean tool. This is a particularly interesting outcome, because there appear to be few studies pointing to and analysing this attribute. Yet in the current study, it got the highest weight, based on participating experts' point of view. The other highly weighted criteria i.e. Lead-time, Quality, and Payback Period - which is a combination of cost and time - were consistent with previous research such as Behrouzi and Wong (2011), Mandal and Sarkar (2012), and Garza-Reyes et al. (2012).

Second, 5S was selected as the first option for the company to implement. This is consistent with previous research (Moulding, 2010, and Spath, 2011), which presents 5S as a fundamental technique, to be used in the early steps of lean management procedure. Its user-friendliness, as well as its ability to reduce time loss, make it a popular and effective tool. It also needs to be mentioned that this result is totally in accordance with what requires to be done to meet the challenge imposed by COVID-19. In addition to the influences 5S has on efficiency, it highly stresses the significance of the clean and hygienic work place. This aspect can address perfectly the issues we are dealing with at the present.

Third, Visual Controls and Poka-Yoke (Mistake Proofing) were situated respectively in the second and third places. This emphasizes the significant effect of "transparency" in minimizing waste (Moser and Dos Santos, 2003). By adopting these tools, resolution in the process can be increased; therefore, waste will be identified and minimized quicker and more smoothly. Visual Controls and Poka-Yoke (Mistake Proofing) improve the standardization in the system which develops the orderliness and neatness of the process. Hence they are known as great complementary tools for 5S (Lixia and Bo, 2008, and Tezel and Aziz 2015).

Fourth, with the aim of achieving better outcomes in cost and time reduction, as well as increasing flexibility and productivity in the company, Single Minute Exchange of Die (SMED) as the fourth ranked tool was highly recommended to be used. Moreover, this tool has a great integration with other lean tools, specifically 5S and Visual Controls. As indicated by Dave and Sohani (2012), the efficiency and effectiveness of SMED can be developed through this integration.

These proposed lean tools, that have been selected based on the requirements of the company and expert recommendations, are likely to be able to provide a competitive advantage for the company. Adopting such tools furthermore improves the operational processes in the company. Waste will be reduced, productivity will be increased and overall time and cost will be lowered. A safer and more efficient work environment for employees can be provided while company benefits from its own resources.

5.2. Recommendations for Future Study

In this study, user-friendliness emerged as a fundamental criterion for selecting an appropriate lean tool; yet it has not been largely overlooked in previous research. It would be of interest, therefore, more deeply research this criterion as well as its impact on the success of lean tool.

Providing a similar study in other companies or other market sectors and comparing the results with the ones obtained in this study and highlighting the differences and similarities is recommended for the future work. Analyzing the reason of these differences and similarities can represent remarkable achievements.

Finally, it is suggested to provide a study on implementation of the proposed tools to analyze their practical impacts on waste minimization and determine the pros and cons of each tool in the real case.

Definitely, pandemic disease and its negative impact on social life made the process of gathering data more difficult. Closer contact with experts and discussing lean tools applications in detail and the way they can be implemented efficiently could lead to more accurate and detailed results.

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7. Appendix A: Criteria Extracted from Articles

Authors	Cost	Customer Service	Inventory	Lead Time	Lot Size
Alves et al. (2011)	X	X	X	X	X
Hojjati et al. (2014)	X			X	
De Toni and Tonchia (1996)	X			X	
Gurumurthy and Kodali (2008)	X				
Mandal and Sarkar (2012)	X	X		X	
Rose et al. (2011)	X				
Marodin et al. (2019)			X	X	
Manzouri et al. (2014)	X		X		
Belekoukias et al. (2014)	X				
Garza-Reyes et al. (2012)	X			X	
Rahman et al. (2010)	X	X			
Cua et al. (2006)	X				
Taj and Morosan (2011)					
Lawrence and Hottenstein (1995)		X		X	
Thun et al. (2010)	X		X	X	
Bortolotti et al. (2013)	X		X	X	
Searcy (2009)	X		X	X	
Hallgren and Olhager (2009)	X				
Behrouzi and Wong (2011)	X			X	
Dora et al. (2013)			X	X	
Sakakibara et al. (1997)	X		X	X	
Womack and Jones (1997)			X	X	
Lathin and Mitchell (2001)	X		X	X	
Ferdousi and Ahmed (2009)				X	
Meckelprang and Nair (2010)	X		X		
Liu et al. (2009)	X		X	X	
SUM	20	4	12	17	1

Authors	Number of Workers	Productivity	Quality	Simplification	Transparacy
Alves et al. (2011)	X	X	X	X	X
Hojjati et al. (2014)					
De Toni and Tonchia (1996)			X		
Gurumurthy and Kodali (2008)		X	X		
Mandal and Sarkar (2012)			X		
Rose et al. (2011)					
Marodin et al. (2019)			X		
Manzouri et al. (2014)			X		
Belekoukias et al. (2014)			X		
Garza-Reyes et al. (2012)		X	X		
Rahman et al. (2010)		X			
Cua et al. (2006)			X		
Taj and Morosan (2011)			X		
Lawrence and Hottenstein (1995)		X	X		
Thun et al. (2010)		X			
Bortolotti et al. (2013)					
Searcy (2009)		X	X		
Hallgren and Olhager (2009)		X	X		
Behrouzi and Wong (2011)			X		
Dora et al. (2013)		X			
Sakakibara et al. (1997)			X		
Womack and Jones (1997)		X			
Lathin and Mitchell (2001)		X	X		
Ferdousi and Ahmed (2009)		X	X		
Meckelprang and Nair (2010)					
Liu et al. (2009)					
SUM	1	12	17	1	1

Authors	Turn Over	Value	Flexibility	Morale	Innovation
Alves et al. (2011)					
Hojjati et al. (2014)	X	X			
De Toni and Tonchia (1996)					
Gurumurthy and Kodali (2008)			X	X	X
Mandal and Sarkar (2012)					
Rose et al. (2011)					
Marodin et al. (2019)	X				
Manzouri et al. (2014)					
Belekoukias et al. (2014)			X		
Garza-Reyes et al. (2012)					
Rahman et al. (2010)					
Cua et al. (2006)			X		
Taj and Morosan (2011)			X		
Lawrence and Hottenstein (1995)					
Thun et al. (2010)			X		
Bortolotti et al. (2013)			X		
Searcy (2009)					
Hallgren and Olhager (2009)			X		
Behrouzi and Wong (2011)					
Dora et al. (2013)					
Sakakibara et al. (1997)			X		
Womack and Jones (1997)	X				
Lathin and Mitchell (2001)					
Ferdousi and Ahmed (2009)					
Meckelprang and Nair (2010)			X		
Liu et al. (2009)					
SUM	3	1	9	1	1

Authors	Robustness	Feasiblity	On Time Delivery	Transportation	Speed
Alves et al. (2011)					
Hojjati et al. (2014)					
De Toni and Tonchia (1996)					
Gurumurthy and Kodali (2008)					
Mandal and Sarkar (2012)	X				
Rose et al. (2011)		X			
Marodin et al. (2019)			X		
Manzouri et al. (2014)				X	
Belekoukias et al. (2014)					X
Garza-Reyes et al. (2012)					
Rahman et al. (2010)			X		
Cua et al. (2006)			X		
Taj and Morosan (2011)					
Lawrence and Hottenstein (1995)					
Thun et al. (2010)			X		
Bortolotti et al. (2013)			X		
Searcy (2009)					
Hallgren and Olhager (2009)			X		
Behrouzi and Wong (2011)			X		
Dora et al. (2013)					
Sakakibara et al. (1997)			X		
Womack and Jones (1997)					
Lathin and Mitchell (2001)					
Ferdousi and Ahmed (2009)					
Meckelprang and Nair (2010)			X		X
Liu et al. (2009)					
SUM	1	1	9	1	2

Authors	Dependability	Product Volume	Management Opinion
Alves et al. (2011)			
Hojjati et al. (2014)			
De Toni and Tonchia (1996)			
Gurumurthy and Kodali (2008)			
Mandal and Sarkar (2012)			
Rose et al. (2011)			
Marodin et al. (2019)			
Manzouri et al. (2014)			
Belekoukias et al. (2014)	X		
Garza-Reyes et al. (2012)			
Rahman et al. (2010)			
Cua et al. (2006)			
Taj and Morosan (2011)			
Lawrence and Hottenstein (1995)			
Thun et al. (2010)			
Bortolotti et al. (2013)		X	
Searcy (2009)			
Hallgren and Olhager (2009)	X		
Behrouzi and Wong (2011)			
Dora et al. (2013)			
Sakakibara et al. (1997)			X
Womack and Jones (1997)			
Lathin and Mitchell (2001)			
Ferdousi and Ahmed (2009)			
Meckelprang and Nair (2010)			
Liu et al. (2009)			
SUM	2	1	1

8. Appendix B: Google Form Questionnaire

1. 1. For each of the lean tools presented below, please rate their "level of user-friendliness", on a scale of 1 to 7 (where 1 = not user friendly at all and 7 = Extremely high user friendly)

"User-Friendliness" refers to the level of complexity of the tool: how easy it is to understand and perform and the physical system requirements for its installation.

Mark only one oval per row.

	1 (Not user friendly at all)	2 (Very low)	3 (Low)	4 (Moderate user friendly)	5 (High)	6 (Very high)	7 (Extremely high user friendly)
5S	◯	◯	◯	◯	◯	◯	◯
Kanban	◯	◯	◯	◯	◯	◯	◯
Cellular Manufacturing	◯	◯	◯	◯	◯	◯	◯
Single Minute Exchange of Die (SMED)	◯	◯	◯	◯	◯	◯	◯
Value Stream Mapping (VSM)	◯	◯	◯	◯	◯	◯	◯
Visual Controls	◯	◯	◯	◯	◯	◯	◯
Production Leveling (Heijunka)	◯	◯	◯	◯	◯	◯	◯
Standardized Work	◯	◯	◯	◯	◯	◯	◯
Poka-Yoke (Mistake Proofing)	◯	◯	◯	◯	◯	◯	◯
Line Balancing	◯	◯	◯	◯	◯	◯	◯

2. 2. Please rate each of the Lean tools presented below in terms of its "Long-Term Impact", on a scale of 1 to 7 (where 1 = no long-term impact at all and 7 = extremely high long-term impact)

"Long-Term Impact" refers to the stability of the tool – the extent to which it can become a permanent system requiring few regular changes over time.

Mark only one oval per row.

	1 (No long-term impact at all)	2 (Very low)	3 (Low)	4 (Moderate long-term impact)	5 (High)	6 (Very high)	7 (Extremely high long-term impact)
5S	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Kanban	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Cellular Manufacturing	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Single Minute Exchange of Die (SMED)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Value Stream Mapping (VSM)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Visual Controls	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Production Leveling (Heijunka)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Standardized Work	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Poka-Yoke (Mistake Proofing)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Line Balancing	⬭	⬭	⬭	⬭	⬭	⬭	⬭

3. 3. Please rate the impact of each Lean tool on "Payback Period", on a scale of 1 to 7 (where 1 = not fast at all and 7 = extremely fast)

"Payback Period" refers to Result/Cost ratio; i.e. how fast the tool allows the company to recover the costs of its implementation.

Mark only one oval per row.

	1 (Not fast at all)	2 (Very low)	3 (Low)	4 (Moderate fast)	5 (High)	6 (Very high)	7 (Extremely fast)
5S	◯	◯	◯	◯	◯	◯	◯
Kanban	◯	◯	◯	◯	◯	◯	◯
Cellular Manufacturing	◯	◯	◯	◯	◯	◯	◯
Single Minute Exchange of Die (SMED)	◯	◯	◯	◯	◯	◯	◯
Value Stream Mapping (VSM)	◯	◯	◯	◯	◯	◯	◯
Visual Controls	◯	◯	◯	◯	◯	◯	◯
Production Leveling (Heijunka)	◯	◯	◯	◯	◯	◯	◯
Standardized Work	◯	◯	◯	◯	◯	◯	◯
Poka-Yoke (Mistake Proofing)	◯	◯	◯	◯	◯	◯	◯
Line Balancing	◯	◯	◯	◯	◯	◯	◯

4. 4. Please rate the impact of each Lean tool on "Risk Mitigation", on a scale of 1 to 7 (where 1 = not risk-mitigating at all and 7 = extremely risk-mitigating)

"Risk Mitigation" refers to the tool's ability to reduce the negative impact (in terms of cost and time) caused by its implementation and the change in the existing system.

Mark only one oval per row.

	1 (Not risk-mitigating at all)	2 (Very low)	3 (Low)	4 (Moderate risk-mitigating)	5 (High)	6 (Very high)	7 (Extremely risk-mitigating)
5S							
Kanban							
Cellular Manufacturing							
Single Minute Exchange of Die (SMED)							
Value Stream Mapping (VSM)							
Visual Controls							
Production Leveling (Heijunka)							
Standardized Work							
Poka-Yoke (Mistake Proofing)							
Line Balancing							

5. 5. Please rate the impact of each Lean tool on "Cost Reduction", on a scale of 1 to 7 (where 1 = not cost-reducing at all and 7 = extremely cost-reducing)

"Cost Reduction" refers to the tool's ability to reduce the costs of making the company's products.

Mark only one oval per row.

	1 (Not cost-reducing at all)	2 (Very low)	3 (Low)	4 (Moderate cost-reducing)	5 (High)	6 (Very high)	7 (Extremely cost-reducing)
5S	◯	◯	◯	◯	◯	◯	◯
Kanban	◯	◯	◯	◯	◯	◯	◯
Cellular Manufacturing	◯	◯	◯	◯	◯	◯	◯
Single Minute Exchange of Die (SMED)	◯	◯	◯	◯	◯	◯	◯
Value Stream Mapping (VSM)	◯	◯	◯	◯	◯	◯	◯
Visual Controls	◯	◯	◯	◯	◯	◯	◯
Production Leveling (Heijunka)	◯	◯	◯	◯	◯	◯	◯
Standardized Work	◯	◯	◯	◯	◯	◯	◯
Poka-Yoke (Mistake Proofing)	◯	◯	◯	◯	◯	◯	◯
Line Balancing	◯	◯	◯	◯	◯	◯	◯

6. 6. Please rate the impact of each Lean tool on "Product quality improvement", on a scale of 1 to 7 (where 1 = no impact on quality improvement at all and 7 = extremely high impact on quality improvement)

"Product quality Improvement" refers to the tool's impact on product features that can provide customer satisfaction.

Mark only one oval per row.

	1 (No impact on quality improvement at all)	2 (Very low)	3 (Low)	4 (Moderate impact on quality improvement)	5 (High)	6 (Very high)	7 (Extremely high impact on quality improvement
5S	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Kanban	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Cellular Manufacturing	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Single Minute Exchange of Die (SMED)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Value Stream Mapping (VSM)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Visual Controls	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Production Leveling (Heijunka)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Standardized Work	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Poka-Yoke (Mistake Proofing)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Line Balancing	⬭	⬭	⬭	⬭	⬭	⬭	⬭

7. 7. Please rate the impact of each Lean tool on "Lead-Time Reduction", on a scale of 1 to 7 (where 1 = no impact on lead-time reduction at all and 7 = extremely high impact on the lead-time reduction)

"Lead-Time Reduction" refers the reduction in the time that elapses between placing an order and its receipt.

Mark only one oval per row.

	1 (No impact on lead-time reduction at all)	2 (Very low)	3 (Low)	4 (Moderate impact on lead-time reduction)	5 (High)	6 (Very high)	7 (Extremely high impact on lead-time reduction)
5S	○	○	○	○	○	○	○
Kanban	○	○	○	○	○	○	○
Cellular Manufacturing	○	○	○	○	○	○	○
Single Minute Exchange of Die (SMED)	○	○	○	○	○	○	○
Value Stream Mapping (VSM)	○	○	○	○	○	○	○
Visual Controls	○	○	○	○	○	○	○
Production Leveling (Heijunka)	○	○	○	○	○	○	○
Standardized Work	○	○	○	○	○	○	○
Poka-Yoke (Mistake Proofing)	○	○	○	○	○	○	○
Line Balancing	○	○	○	○	○	○	○

8. 8. Please rate the impact of each Lean tool on "Productivity Increase", on a scale of 1 to 7 (where 1 = no impact on productivity at all and 7 = extremely high impact on productivity)

"Productivity Increase" represents the ability of the tool to increase the ratio between the company's outputs (goods or services) and the inputs required to produce them.

Mark only one oval per row.

	1 (No impact on productivity at all)	2 (Very low)	3 (Low)	4 (Moderate impact on productivity)	5 (High)	6 (Very high)	7 (Extremely high impact on productivity)
5S	◯	◯	◯	◯	◯	◯	◯
Kanban	◯	◯	◯	◯	◯	◯	◯
Cellular Manufacturing	◯	◯	◯	◯	◯	◯	◯
Single Minute Exchange of Die (SMED)	◯	◯	◯	◯	◯	◯	◯
Value Stream Mapping (VSM)	◯	◯	◯	◯	◯	◯	◯
Visual Controls	◯	◯	◯	◯	◯	◯	◯
Production Leveling (Heijunka)	◯	◯	◯	◯	◯	◯	◯
Standardized Work	◯	◯	◯	◯	◯	◯	◯
Poka-Yoke (Mistake Proofing)	◯	◯	◯	◯	◯	◯	◯
Line Balancing	◯	◯	◯	◯	◯	◯	◯

9. 9. Please rate the impact of each Lean tool on "Inventory Reduction", on a scale of 1 to 7 (where 1 = no impact on inventory reduction at all and 7 = extremely high impact on inventory reduction)

"Inventory Reduction" refers to the reduction in Work In Progress (WIP) and stocks held by the company to deliver goods or services

Mark only one oval per row.

	1 (No impact on inventory reduction at all)	2 (Very low)	3 (Low)	4 (Moderate impact on inventory reduction)	5 (High)	6 (Very high)	7 (Extremely high impact on inventory reduction)
5S	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Kanban	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Cellular Manufacturing	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Single Minute Exchange of Die (SMED)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Value Stream Mapping (VSM)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Visual Controls	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Production Leveling (Heijunka)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Standardized Work	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Poka-Yoke (Mistake Proofing)	⬭	⬭	⬭	⬭	⬭	⬭	⬭
Line Balancing	⬭	⬭	⬭	⬭	⬭	⬭	⬭