**Diana Margarida Pereira de Almeida**

Licenciada em Ciências de Engenharia e Gestão Industrial

# Construction of Lean and Green indexes to measure companies' performance

Dissertação para obtenção do Grau de Mestre em
Engenharia e Gestão Industrial

Orientadora: Helena Maria Lourenço Carvalho Remígio, Professora Auxiliar, Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa

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FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

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# Resumo

A procura pela redução dos custos e tempo despendidos nos processos com vista ao aumento da eficiência, leva as empresas a procurarem paradigmas de gestão inovadores que sustentem as suas necessidades de crescimento e melhoria contínua. O paradigma *Lean* tem grande relevo nesta necessidade de redução de desperdícios nas empresas, em especial nas empresas de manufatura.

Por outro lado, as preocupações das empresas em reduzir o desperdício têm vindo a ganhar uma nova vertente não só material, mas também a nível ambiental com a introdução do paradigma *Green*. Como tal, têm vindo a ser adotadas práticas nas empresas de manufatura que visam reduzir o impacto das suas atividades sobre o meio ambiente.

Apesar de muitas empresas de manufatura já implementarem práticas de redução de desperdícios que visam a aplicação dos paradigmas *Lean* e *Green*, muitas delas não conseguem entender concretamente se os seus esforços são suficientes para que a aplicação dessas práticas seja bem sucedida, ou mesmo se a sua real performance na implementação dessas práticas reflete a avaliação que têm de si próprias.

Desta forma, a presente dissertação tem como principal objetivo, para além da análise do desenvolvimento dos paradigmas *Lean* e *Green* ao longo dos anos, a construção de dois índices (o *Lean Index* e o *Green Index*), permitindo a medição de performance das empresas de manufatura Portuguesas no que diz respeito à implementação de práticas *Lean* e *Green*.

Os dados utilizados para a criação dos índices *Lean* e *Green* são relativos à implementação do European Manufacturing 2012 em Portugal. As questões do inquérito relacionadas com a implementação de práticas Lean e Green representam as variáveis no modelo de construção dos índices. Para a construção das expressões representativas dos índices *Lean* e *Green* foi aplicada a Análise Fatorial para atribuição de ponderações e agregação das variáveis.



**Palavras-chave:** Paradigma *Lean*; Paradigma *Green*; Índices; Análise Fatorial; Medição de performance.

## Abstract

The demand for costs and time reductions in companies' processes, in order to increase efficiency, leads companies to seek innovative management paradigms to support their needs for growth and continuous improvement. The Lean paradigm has great relevance in companies' need for waste reduction, particularly in manufacturing companies.

On the other hand the demand of companies for waste reduction has gained a new dimension not only at the material level, but also at the environmental level with the introduction of the Green paradigm. As such, manufacturing companies have been adopting practices that reduce the impact of their activities on the environment.

Although nowadays many manufacturing companies already implement waste reduction practices related to Lean and Green paradigms, many of them are unable to understand specifically if their efforts are enough for the application of these practices to be successful or even if their actual performance in implementing Lean or Green practices reflects the self-assessment that they have of themselves.

Thus, besides the study of the development of Lean and Green paradigms in recent years, the present dissertation has the important objective of the construction of two indexes (the Lean Index and the Green Index) enabling the measurement of the performance of Portuguese manufacturing companies relating the implementation of Lean and Green practices.

The data used to create the Lean and Green indexes where obtained from the implementation of the European Manufacturing Survey 2012 in Portugal. The survey questions related to the implementation of Lean and Green practices are used as variables in the development of the model for the two indexes. For the construction of representative expressions of Lean Index and Green Index it was applied the Factorial Analysis for assigning the variables weights and aggregation.



**Keywords:** Lean paradigm; Green paradigm; Indexes; Factorial Analysis; Performance measurement.

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## List of abbreviations and symbols

AHP - Analytical Hierarchy Process

ASC - Agile Supply chains

$(B_x)_j$ - company $j$ behaviour related to the paradigm $x$ ($x = G$ or $x = R$).

$(B_x)_j$ - company $j$ behavior according to the paradigm $x$ ($x = G$ or $R$).

EMS – European Manufacturing Survey

ENMs - Energy Management System

EPE - Environmental performance evaluation

FA - Factorial Analysis

FASCI - fuzzy ASC index

*GI* - Green Index

GL - Green Logistics

GLPI - Green Logistics Performance Index

HEA - Home electronic appliance

ISI - Fraunhofer Institute for Systems and Innovatio

ISO - International Organization for Standardization

JIT - Just-in-Time

KMO - Kaiser - Meyer - Olkin measure of sampling adequacy

*LI* - Lean Index

PCA - Principal Component Analysis

$(P_{xi})_j$ - Implementation of practice i level according to the paradigm $x$ for company $j$

$R_j$ - Average fuzzy ratings

$S$ - Total Score Performance

$S_G$ - Green variables total score

$S_G$ *(Max)* - Maximum value that each Green variable total score can take

$S_G$ *(Min)* - Minimum value that each Green variable total score can take

$S_{Gmax}$ - Maximum value that SG can take

$S_{Gmin}$ - Minimum value that SG can take

Sig - Significance value (Bartlet's test)

$S_L$ - Lean variables total score

$S_L$ *(Max)* - Maximum value that each Lean variable total score can take

$S_L$ *(Min)* - Minimum value that each Lean variable total score can take

$S_{Lmax}$ - Maximum value that $S_L$ can take

$S_{Lmin}$ - Minimum value that $S_L$ can take

$S_{max}$ - Maximum value that $S$ can take

SMED - Single Minute Exchange of Die

$S_{min}$ - Minimum value that $S$ can take

SPSS - Statistical Package for Social Sciences

TPM - Total Preventive Maintenance

TQM - Total Quality Management

UNIDEMI - Unit of Mechanical and Industrial Engineering

VSM - Value Stream Mapping

$w_G$ - Weight of  resilient paradigm

WIP - Work in progress

$W_j$ - Average performance weights

$w_R$ - Weight of green paradigm

$w_{xi}$ - Weight of practice $i$ of paradigm $x$.

# 1 Introduction

This chapter aims to provide an introduction to this dissertation. Here are discussed the research context, motivation, objectives and research questions. It is also included in this chapter a brief description of the research methodology used, concluding with a description of the dissertation structure.

## 1.1 Context

Nowadays, the markets are in constantly change, which leads to an increased competitiveness. Thus it arises the need for companies to adopt a policy of continuous improvement at all levels, such as processes, strategies to adopt or organizational level. It becomes essential achieving a high level of excellence, allowing opportunities for improvement and growth to render organizations more competitive. The adoption of Lean and Green strategies is crucial for the companies' development.

Management paradigms as Lean and Green have been adopted in companies worldwide, particularly in manufacturing companies (Azevedo *et al.*, 2012a). Regarding to the Lean paradigm in manufacturing, it can be said that this concept stipulates the attainment of continuous improvement of the wastes elimination (Devadasan *et al.*, 2012). Companies also have recognized the Green paradigm as a way to achieve a more efficient management. The Green management approach, is characterized for having the ability to induce the reduction of companies' costs through more efficient use of resources such as water, energy or raw materials (Azevedo *et al.*, 2012a). Measuring the impact of the implementation of Green practices in companies is a way of companies perceive the environmental impact of their activities through the analysis of their degree of implementation of the underlying strategies.

Companies need to have a real sense about their results, being also possible to compare it with the assessment that they have of themselves, validating expectations, or if they achieve underwhelming results, providing information so that they should continue efforts to improve the implementation of the practices. On the other hand, with the assessment, it is also possible that similar companies can compare to each other, and so define improvement strategies to meet the challenges and constant changes in competitive markets.

## 1.2 Objective

Despite the existing extensive research on Lean and Green management paradigms, studies in this area have not developed issues related to the measurement and assessment of companies' performance regarding the degree of implementation of representative practices related to Lean and Green paradigms implementation.

The focus of this dissertation relies on the analysis of Lean and Green practices adoption in the context of Portuguese manufacturing companies. The main objective of this dissertation is the creation of two indexes (the Lean Index and the Green Index). These two indexes are design to measure the Portuguese manufacturing companies performance in the implementation of practices related to Lean and Green paradigms.

The obtained indexes will be applied to real cases to illustrate the index application and obtain a representative result of the degree of implementation of Lean and Green practices in those companies.

## 1.3 Methodology

The methodology used in this research comprises two main phases. The first phase consists on the literature review related to Lean and Green paradigms. In this phase are presented the foundations for understanding the Lean and Green paradigms. Through the study of the literature, it is possible to identify the benefits of implementing these paradigms as well as their evolution over the years, with special attention to its application in the context of manufacturing companies.

On the other hand, in the second phase, the practical phase of this study is developed. It is supported by the concepts acquired in the first phase and presents itself as the main way to achieve the dissertation objective, in other words, the construction of Lean and Green indexes. The indexes will be constructed using the data obtained from the European Manufacturing Survey (EMS) in Portuguese companies. For each index relevant practices are proposed representing the variables, representative of Lean and Green paradigms. For each of these paradigms is proposed a model for assigning the practices weights using a statistical technique the Factorial Analysis (FA) using the Principal Component Analysis (PCA) method to extract the factors. The construction of the indexes is based on the methodology presented by Lau (2011).

## 1.4 Contents

The structure of this dissertation is divided on five chapters and two appendices. This chapter provides a global view of this dissertation, focusing on the proposed objectives and justification of the chosen theme. This dissertation presents research about the application of Lean and Green concepts in manufacturing companies, focusing on the creation of a method that allows measuring the performance of companies in the implementation of these concepts. The methodology to achieve this goal comprises a bibliographical research phase and a second phase characterized by the analysis of the available data and indexes construction. This methodology is developed over the next chapters.

In Chapter 2 are addressed issues related to Lean and Green paradigms, their application in manufacturing companies as well as its effects on their performance. The chapter contains a literature review of these issues and it concludes with the proposal of Lean and Green practices to consider as variables in the Lean and Green indexes proposed in this dissertation.

In the third chapter is presented information that supports the creation of the basis of the indexes. In this chapter is also described the Factor Analysis, a statistical technique that supports and guides the researcher in the construction of new indexes. Conditions of applicability of this technique are also reviewed on this chapter.

Chapter 4 is the one that presents greater prominence in this dissertation; it presents the development and construction of Lean and Green indexes through the application of Factor Analysis. It is also given to known, the source and characterization of the data used for this purpose. Also it is described a practical application of indexes created using the data used in their own building. The results for each company considered are presented, thus producing a score that characterizes their performance concerning the implementation of Lean and Green practices.

Finally, Chapter 5 presents the main conclusions of the dissertation as well as proposals for future work.

# 2 Background

## 2.1 Manufacturing management paradigms

The manufacturing management paradigms have been widely studied over the last decades by several authors. The models or paradigms are considered typical examples of something that has been used throughout history, as a manufacturing aid in the task of managing the production (Filho & Fernandes, 2009). O'Brien (2013) described the successive changes about manufacturing paradigms over the last 50 years. The author highlighted not only changes at the level of thoughts about manufacturing concepts, but also the consequent change in its associated paradigms, that have been performing changes in business productivity, as well as the quality of its goods and services. According to the author, these changes had their major boost with the first publication of The International Journal of Production Research in 1961. In the literature on Manufacturing Management are discussed many paradigms (Filho & Fernandes, 2009), that with the application of practices related to them, have the common goal to help companies to support, maintain and improve their competitiveness in today's globalized markets. Some authors have been exploring and developing new paradigms associated with Manufacturing, wishing to distinguish themselves from those who have been gaining importance and recognition in recent decades.

Among the traditional paradigms mentioned in various papers concerning the paradigms associated with the manufacturing, stand out Lean Manufacturing, Agile Manufacturing, Mass Customization Manufacturing (Filho & Fernandes, 2009; Zhen, 2012), but also the Flexible Manufacturing, Computer-Integrated Manufacturing, Just-in-Time Manufacturing, Green Manufacturing, Virtual, Marketing-Manufacturing Integration and Re-Manufacturing (Zhen, 2012). Filho & Fernandes (2009) consider that the introduction of these manufacturing concepts is due to Henry Ford with the application of Mass Manufacturing, created at the beginning of the 20th Century, followed by the creation of the Lean Manufacturing paradigm, that started in Japan and is associated with the Toyota Production System (Hajmohammad *et al*., 2013). Despite Lean Manufacturing started to emerge in the mid fifties, it was only consolidated in the 1970s (Filho & Fernandes, 2009). Other manufacturing paradigms and practices had its development in the following years.

However, with the increasing globalization and expansion of markets in recent years it has been possible to observe the increasing development of new concepts in manufacturing management. Having in mind the reduction of time, energy and money spent in manufacturing processes, new approaches regarding these concerns were adopted. Although the connotation with traditional paradigms such as Lean and its focus on reduction of waste, these new approaches regarding the reduction of time, energy or money, elevate the concept of waste reduction to a level that combines this subject with the concern of the effects of activities on the environment. Although organizations often adopt ecological practices with the obligation to meet the requirements of legislation, (Azevedo *et al*., 2013) its environmental performance can also lead to competitive advantage.

Pampanelli *et al*. (2013) states that the introduction of Green practices in companies has no longer been an optional decision in their management strategies. Increasingly management policies in manufacturing companies take into account the implementation of Lean and Green practices. In recent studies, the relationships between Lean Manufacturing practices and environmental management practices has been studied, as well as, their influence on business results and companies performance (Yang *et al*., 2011). Some researchs has been developed suggesting that management practices based on Lean paradigm and consequently its influence in supply management, can be decisive regarding the environmental performance of the company and can be regarded as resources that ease the adoption of environmental practices (Hajmohammad *et al*., 2013).

Nowadays, companies have been suffering an increasing pressure to integrate the models of sustainable development (Hajmohammad *et al*., 2013). With the development of know-how and production capabilities, companies have been able to implement practices that make them achieve cleaner production, with constant research and development of theories in this area. Several studies have been studying the relationship between production and environmentally conscious practices in order to improve productivity and performance of manufacturing (Florida, 1996).

With the introduction and popularization of the manufacturing practices that are based on the concept of waste reduction, companies were, over the past few years, forced to compete with each other based on the increased levels of quality, flexibility and timeliness (Kennedy & Widener, 2008). In order to achieve these goals, there have been changes in companies' operational strategy so that, in companies should be a focus the implementation of the waste reduction practices (Kennedy & Widener, 2008).

### *2.1.1 Lean paradigm*

From designing the assembly line and consequent development of the Toyota Production System, the efficiency has been a major goal of the manufacturing companies. The Lean Manufacturing paradigm focuses on the systematic disposal of companies' operations through a set of practices of cooperative work, fulfilling the purpose of producing goods and services to demand rate (Yang *et al.*, 2011).

Companies working with the Lean paradigm uses much less resources compared to those that still operate as mass producers. Feld (2001) refers to this approach in a highly intuitive way, indicating that the Lean Production *vs* Mass Production presents a ratio which translates to:

> "½ the human effort in the factory, ½ the manufacturing space, ½ the investment tools, ½ the engineering hours and ½ the time to develop new products"

The application of Lean paradigm in business reflects the demand for increasing value added activities, by waste reduction to maintaining profitability and satisfying customer's needs. The Lean Manufacturing paradigm can be explained briefly as a set of practices applied to manufacturing operations of the company, aimed at reducing waste and non-value added activities (Yang *et al.*, 2011). Lean Manufacturing is a multifaceted concept, which can be subdivided into other practices such as, among others, Just-in-Time (JIT), Total Quality Management (TQM), Total Preventive Maintenance (TPM), Human Resource Management, Pull or Productive Maintenance (Yang *et al.*, 2011). Furthermore, the parameters for assessing the Lean level in a company, should not only cover the internal concerns of the company as investment priorities or the Lean practices and waste, but also consider issues related to their suppliers and customers (Azevedo *et al.*, 2012a).

In the last decades, companies have been adopting Lean Management in several sectors, allowing them, in many cases, improve their performance and competitiveness. Although many companies have achieved success with the implementation of Lean Management, others did not get the expected results, due to their inability to sustain their performance over the medium and long term (Martínez-Jurado & Moyano-Fuentes, 2013). Despite the fact that these companies are considered a failure regarding the implementation of the lean practices, these cases stimulate great interest among researchers, who often intend to examine the reasons for their inability to sustain the results of the Lean Management practices. Thus, there is also a growing interest in the literature on Lean Management and its integration with other practices, especially those that are related to environmental sustainability. According Martínez-Jurado & Moyano-Fuentes (2013) besides its quest for improved results, the companies implementing Lean Management, they also aspire to be seen as leaders and managers aware of the impact of their activities.

It is vital for the success and continuing implementation of Lean Management practices that they are not applied only to intra-organizational aspects, but are also disseminated to the supply chain. In this area, a major challenge for companies that drive Lean practices is to lead the increasing integration and involvement of key suppliers and customers. So it is interesting to analyze the application of Lean Management practices focusing not only the company but also its supply chain (Martínez-Jurado & Moyano-Fuentes, 2013).

The implementation of Lean practices is often considered the most important way to manufacturing companies achieve high performance, largely because it is a complete business system that combines a large number of management practices like work teams, cellular manufacturing, supplier management, among others. In this way, the Lean strategy quickly became a dominant paradigm in the context of manufacture (Vinodh & Joy., 2012). However, despite the Lean paradigm has been studied by several authors as Lewis (2000) or Hines *et al.* (2004), the Lean's definition still generates some disagreement and confusion mainly on the choice of the features that should be associated with the concept (Pettersen, 2009). These disagreements can lead to difficulties in assessing the effectiveness of the implementation of the concept itself in companies. As such, in recent years there are several authors who have published literature in which the central theme is the Lean Manufacturing applied in the context of individual companies (Shah & Ward, 2003). In these studies it is possible to identify some practices that are usually associated with Lean Manufacturing.

Kumar & Abuthakeer (2012) referred that Lean is a set of useful tools (practices) in identifying and constant elimination of waste. However, the authors go further, identifying the main practices through which the Lean paradigm is applied. Are they the Value Stream Mapping (VSM), 5S, Single Minute Exchange of Die (SMED), Six Sigma or, similar to what Yang *et al.* (2011) reported, the authors also highlight practices such as TQM or TPM. Another very popular method of implementation of Lean is through Value Stream Mapping (VSM) (Lian & Van Landeghem, 2007). Lian & Van Landeghem (2007) believe that VSM emerged in recent years as the best way to implement Lean so much on factories, both at productive level, inside the factories, but also in terms of supply chains. The authors referred that this method describes the setting of the value flows through its mapping.

The nuclear issue of Lean Manufacturing is that every integral practices can work together, synergistically, creating a system. This system is then able to produce finished products to customer and fulfilling the demand with little, or sometimes, with no waste (Shah & Ward, 2003). Thus, Lean Manufacturing is then defined as a business system that integrates necessarily more than just production processes.

For a successfully implementation of Lean practices in manufacturing companies, it is critical that companies have a high level of flexibility, responding quickly to customer needs and adopting a strategy of market differentiation quite distinct from the traditional strategy, which relies more on cost leadership.

Feld (2001) states that Lean Manufacturing is based on five key elements:

1. Manufacturing Flow, that is the aspect that deals with the design standards and the physical changes that are deployed;

2. Organization, which focuses on the identification of people's functions, training in new ways of working and communicating;

3. Process control, is the aspect directed to monitoring, control, stabilization, always looking for new ways to improve the process.

4. Metrics, that addresses the visible part of the look and the results of performance measures; focusing on improving; and useful too in team rewards and recognition

5. Logistics: Which defines the operational rules, mechanisms for planning and control of material flows.

According to the author, these five elements cover the entire range of issues that arise during the implementation of Lean Manufacturing. Although each of those elements has an important individual contribution, the success of implementation of Lean Manufacturing is the integration of all elements taking into account that each focuses on a particular area. The Manufacturing Flow element sets the foundation for change and acquisition of Lean concepts. Most Lean Manufacturing initiatives are focused on this primary element, as in Process Control and Logistics area.

According to Feld (2001) the lack of interest in admitting the system as a whole, is still a retrograde thinking because the change in organizational culture and improvements in logistics infrastructures lead to the institutionalization of the improvements, providing a sustained change within the organization. When a company initiatives focus only on the mechanics and techniques (which are indicators of the manufacturing flow and process control), the ability of the workforce is not being improved. Nowadays it is easy to find in companies, someone who is able to read and perform number analysis about the behavior of demand, calculate takt time, or for example apply a more efficient layout. However, these are practices and methods that have been used over many years of industry development, which may indicate that the continuing use of the same actions and working methods without any level of evolution or development will not bring to the company competitive advantages that allow them to stand out from their competitors. The real competitive advantage is built through stimulation of skills in the workforce, which can only be achieved through the merger of three principles:

1. Achieve a transfer of knowledge through building a skilled workforce;

2. Involvement of all employees within the company, driving the collective energy in the same direction;

3. Provide expectations and common goals for the workforce and accountability to get the job done.

The advantage for a company that has this capability is the impossibility of it being copied, lost or acquired by competition.

#### *2.1.1.1 The Lean Manufacturing system structure*

Other authors have been addressing this issue of Lean Manufacturing. For example, Dennis (2007), relates that before we understand the Lean paradigm, it is necessary to understand the system that it is supplanting, i.e. the mass production. The mass production was first implemented by Henry Ford. This concept refers to the process of creating a large number of similar products efficiently, i.e. the production in large quantities of standardized products frequently by using the technology of the assembly line.

Dennis (2007) refers to Lean paradigm as being responsible for doing more with less. In other words, Lean allows producing more using fewer resources, meaning less time, space, human effort, machinery and materials, not forgetting the importance of meeting customer requirements.

The Lean system was designed by Taiichi Ohno (Dennis, 2007), but other personalities were giving their contribution to extend and deepen the concept such as Hiroyuki Hirano with the development of 5S system; Seiichi Sekine through the concept of TPM; Kenichi Sekine with Continuous Flow; Shingro Shingo developing Jidoka and SMED. However, the consolidation of the overall concept was only possible with an integration of all others. Dennis (2007) used a “Lean house” as an analogy to illustrate this integration between Lean Manufacturing and its related practices (Figure 2.1). This house demonstrates the structure that supports the Lean Manufacturing concept, from its base, its structural walls, reaching its objectives, represented symbolically by the roof. In the structure, the walls of the house, are the JIT delivery of parts of products and the Jidoka also known as automation with a human mind. The last module of the Lean house, the roof, is related to customer focus, which means delivering to the customer high quality products at the lowest possible cost and following a short lead time. In addition to the surrounding structure, Dennis (2007) also established that the heart of the whole system is the Involvement, or "flexible motivated members continually seeking a better way."

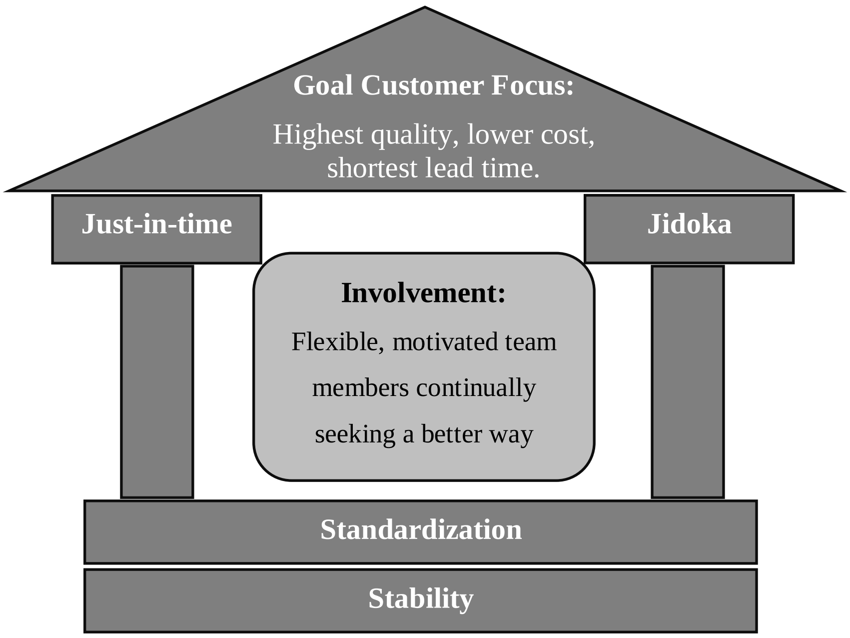



Figure 2.1 - The Lean Manufacturing system
Adapted from *Dennis (2007)*

### *2.1.1.2 Lean Manufacturing system basis*

Stability and standardization are the basis of Lean System Construction. Dennis (2007) refers that there is no improvement without stabilize the 4M's, i.e., stabilize **M**an/woman, **M**achine,

**M**aterials and the **M**ethod. The stability is closely tied to the 5S system. The 5S supports practices such as TPM  and standardized work practices that are essential to the stability of the process and machines, and also supports the application of the concept JIT, by providing information that assists in making decision.

The 5S system is a concept related to the development of a clean, well-ordered workplace and comprises the following notions (Dennis, 2007):

**- Sort** out what isn't necessary (for example parts, work in progress, scrap, storage shelves, documents). While some of these materials are essential to achieve the objective of the job, others are not, sometimes preventing the flow of work, and may cause some problems and contributing to the increase in long lead times.

**- Set in order** the remaining materials, minimizing the waste motion

**- Shine** (and inspect).It is important to establish methods of cleaning to achieve the goals. The 5S workplace should be equipped with cleaning materials and it is important to do some of the work the 5S minutes of cleaning. This item also includes the inspection, which translates into the ability of the worker to recognize changes in the equipment through the knowledge it acquires to accomplish its regular state and condition inspections.

**- Sustain** the 5S practices developed. It is important to create a solid foundation in business practices for the implementation of 5S, viewing them as the natural method of operating through involvement of all team members. This involvement of the entire company to accept and contribute to the continuity of the 5S system is only possible through the promotion of new ideas, communication and training.

**-Standardize** the work. It is important because it provides to the employee information about how to perform the tasks correctly. Include for example information about the type of tools to use which perform tasks (when and by whom). According Dennis (2007), standardized work is one of the safest, easiest and most effective ways of doing the job.

The concept of Standardization has been generating great benefits in manufacturing such as:

1. Process stability, closely related to repeatability. It is important all the time to meet up data on productivity, quality, cost, lead time, safety and environmental targets.

2. Clear stop and start points for each process, giving the possibility of seeing the production status in a flash.

3. Organizational learning. Standardized work enables the preservation of know-how and expertise. In the case of an experienced worker leaves the company, their experience will not disappear.

4. Audit and problem solving. Standardized work provides access to the current status of the production system, easing the identification of problems by tracking vital checkpoints and process steps.

5. Employee Involvement and Poka-Yoke. The standardized work are developed by cooperation of various elements of the company that go from the system team members up to supervisors and engineers, identifying new simple, inexpensive, error-proofing opportunities or Poka-Yoke devices. The Poka-Yoke method represents the defects and errors prevention originating in the mistake (Szewieczek, 2009). This is a technique to prevent human error at work, applied through the installation of devices that either prevent or detect potentially anomalies, both for the quality of the product and for the health and safety of workers. These error prevention devices can be of three types: physical, by blocking the flow of mass, energy or information, not depending on users' interpretation (e.g. a wall); it may be functional if they might be turned off due to an event (e.g. a lock or password); and finally they can be symbolic if they require interpretation (e.g. a safety sign) (Saurin *et al*., 2012).

6. Kaizen, which is the continuous improvement of a complete value stream or an individual process in order to generate even more value with less waste. This continuous improvement effort is executed by all company members and focuses mainly as Lean own in waste reduction (Augusto *et al*, 2006).

7. Training. This is a very important point achieved through the implementation of standardized work since it provides the basis for employee training. Once the operator becomes familiar with work standardizes formats, turns out to be natural for him to perform the work according to standards. Since this is a very simple process of training, is very easy to respond positively to changes in the process.

TPM is a natural consequence of the 5S system. According to Roberts (1997), TPM is a concept of maintenance schedule. TPM has its focus on maintenance, which translates into a necessary and vitally important part of business. Currently the TPM are no longer considered as non-profit activities since downtime for maintenance are part of the production day, and in some cases is an integral part of the manufacturing process. This reflects the need to train workers to ensure proper operation and safety in the equipment use, providing changes in the employees' mindsets regarding their job responsibilities, always aiming zero breakdowns (Roberts (1997); Dennis (2007)).

#### *2.1.1.3 Lean Manufacturing system walls*

Returning now to the structure of Lean aforementioned, it is important to focus on one of its main pillars, JIT. According to Dennis (2007) JIT means producing the right item at the right time, in right quantity. Toyota was a pioneer in the introduction of this concept in 1950, when trying to answer very specific problems such as tough competition, the problem of low volume, contrasting with the highest diversity of products demanded by fragmented markets, constant changes in technologies, high costs of capital or the issue of capable work demanding higher levels of involvement (Dennis, 2007). The author states that this principle is based on certain rules:

1. Produce just what the customer ordered;
2. Placement of demand for that work can progress smoothly by the plant;
3. Link all processes to customer demand using simple visual tools (Kanbans)
4. Maximize the people and machinery flexibility.

According Dennis (2007) JIT system is based on two components:

1. Kanban is a system of visual tools (usually rectangular cards) that synchronize and provide instruction to suppliers and customers (inside and outside the plant). Kanban represents the authorization to produce or withdraw parts. It can also contain various information about the supplier of the part or product, the customer, about the location of storage, and information about transportation.

2. The level of output (or Heijunka), which supports kaizen, standardized work, in order to maintain the production rate without peaks or downs, allowing easy adaptation to oscillations in demand.

In turn, Kanban and Heijunka application dependent on other factors, namely (i) quick machine changeover, that allows a quick response to daily customer orders; (ii) visual management through the implementation of the 5S system; (iii) capable processes (means capable workers, methods and machines).

Unlike conventional mass manufacturers, that **push** the product through the system, not taking into account the current demand for the application of the rules governing the JIT, it is necessary to take the opposite approach, this is **pull**. Pull means that nobody upstream should produce the goods or service until the customer downstream asks for it (Dennis, 2007), bringing a big advantage at the level of reduction of parts stores. According to Powell *et al*. (2013) the Pull associated with manufacture is one of the most important principles Lean paradigm, in which tasks are being "pulled" by successive workstations as are required, and any workstation located upstream should not be produce/accomplish tasks before the downstream station asks for it. Pull system has the ability to control the work in progress (WIP), achieving large reductions in cycle time level. It is also useful in reducing operating costs by, for example, eliminating the need to order or generate large amounts of raw materials, WIP and finished goods or reducing excessive inventory. According to Dennis (2007) Pull system is also a way of achieving improvements in quality levels by not allowing defects production in large batches, being easier to detect those in which there are such abnormalities. The author states that Pull system may also be advantageous in terms of health and safety of workers. In relation to health, for example, there may be improvements at ergonomic level, by reducing the size and number of part bins, so there is less heavy lifts, and for example, a reduction in the number of trucks forklifts, which generates an improvement of safety level.

As previously mentioned, the JIT is an extensive subject, comprising other numerous concepts. Dennis (2007) described that beyond its great purpose of production of certain components, in the right quantity at the right time, the JIT is intervening in the production leveling and includes kanban methodologies, taking into account the concept of Pull systems. All these practices are useful not only in production but also in another relevant aspect regarding the Leans' application, the conveyance, through the possibility of determining fixed time and fixed quantity. Value stream mapping is a concept associated with the JIT. This is the language that allows the identification of improvement opportunities (kaizen) as well as the current condition of the system.

Jidoka is the other pillar of the Lean system. This was nicknamed by Toyota as "automation with a human mind" (Dennis, 2007), implying as its name indicates, the intelligence of workers allied to errors identification by machines. This concept provides to the operator or to the machine, autonomy to be able to stop the process when an abnormality is detected. The main idea is to prevent the generation and propagation of defects, eliminating any anomalies in processing and production flow. Stopping the process, either by the operator or the machine, the problem is visible to all the workers or supervisors, triggering a concerted effort to identify the root cause, eliminating it and preventing the recurrence of the problem by reducing the likelihood of further stops.

#### *2.1.1.4 Lean Manufacturing system core*

To be able to build a Lean production system, it is essential to take into account that the structure should have a strong organizational core. The core of the Lean system described by Dennis (2007) presented with house-shaped structure, is based on the Involvement of team members. With the Involvement is possible to develop the capabilities of team members, improving the company prospect for long-term success. Supervisors and managers have an important role in its implementation, must underpin and support the development and participation of all workers, this concept should be managed as production and quality usually has been managed (Dennis, 2007).

### *2.1.2 Green paradigm*

There are multiple reasons for the adoption of Green practices. Companies have increasingly into account the concerns of its customers with the environment. Consumers have attention to the benefits obtained through consumption of Green products, being more attentive to environmental issues. Asefeso (2013) states that customer demand for more information about the products they buy makes companies make efforts to meet the requirements and concerns of customers. Many companies then began educating its structure to be able to prepare answers for their clients, for example, about whether their processes are according to Green practices or for example, what is the environmental impact of the companies' activities, or questions about the adoption of a recycling system. These concerns also address a more economic context for companies, they also having some advantages in that which is the goal of any manager; cost reduction. Green Manufacturing can be effective in achieving this goal, through money saved by doing recycling and waste reduction.

Although currently the benefits achieved with the implementation of Green Manufacturing practices are already quite widespread, there are still companies who are unaware of these potential benefits of using it. It is noteworthy that, in addition to the general benefits already detailed, others more practical and direct advantages can be listed as resulting from the application of Green practices such as lower waste-disposal and training costs, or fewer environmental licensing and reduced material costs (Asefeso, 2013).

The evolution of the production systems allow an increase in the know-how and in the capability of companies to develop their production through a cleaner method, becoming important to continue the studies about the potential to improve environmental performance, as well as focus the activities that affects the companies' environmental externalities. Green Manufacturing is an important part of business (Dornfeld *et al*., 2013). Nowadays, companies are finding there are multiple benefits of using Green Manufacturing being increasingly aware that the implementation of this concept is based on reasons that go beyond the simple commitment to be environmentally friendly (Asefeso, 2013).

To define what represents the Green Manufacturing it is interesting to understand what refers the Green concept. According to Dornfeld *et al*. (2013) Green is defined as a concern with environmentalism, caring for the preservation of environmental quality and, as such, the approach to issues such as recycling or the ability of the materials used being biodegradable and non-polluting. However, this concept alone does not say much in the specific context of industrial activities. The application of this concept to manufacture results on the concept of Green Manufacturing characterized as a process or system which has a minimal or nonexistent negative impact on the environment.

Companies are pressed to integrate sustainable development policies, including the environmental dimension in its traditional performance metrics. Some studies in the area lead to the idea that the relationship between Lean Management and Supply Management is important with regard to the environmental performance of the organization, and these two features facilitate the adoption of environmental practices (Hajmohammad *et al*., 2013). In this context, Hajmohammad *et al*. (2013) developed a conceptual model that suggests that Lean and Supply management have effects on the development of environmental practices, these practices that are important to measure the companies' performance in the application of Green

Manufacturing. Moreover, over the years it has been possible to watch the increasing awareness about environmental risks, as well as the focus on competitiveness based on the efficiency of production systems.

Green Manufacturing is a new paradigm of manufacturing and as such, covers a group of strategies or techniques integrated in management (related to the environment), working together to achieve certain goals (Deif, 2011). Green Manufacturing paradigm is no longer just a trend in manufacturing, and over the years it becomes one of its key pillars. Asefeso (2013) states that companies that have been adopting the Green Manufacturing paradigm present high quality products. Thus they are confirming that Green Manufacturing is a management decision that contributes to the companies' success in today's competitive markets.

The Green Manufacturing is regarded as a management policy in a company, especially with the emergence of problems related to large energy expenditure (Asefeso, 2013). By applying small changes, the overall operation of the company can become more environmental friendly. Some of these small changes are based on the appliance of concepts related to Green Manufacturing including (Asefeso, 2013):

- The use of raw ingredients "which can and does include organic ingredients if pricing is reasonable as much as possible if the finished product is biodegradable".

- "Does not use hazardous chemical conditioners, chemical anti-bacterial or chemical preservatives if any of the products that might end up in waste system (landfills) or in the environment."

- Provide a cleaner source of energy through new technology. "This will decrease energy consumption."

- Conversion of pollutants and wastes into by products and promotion of their use.

- Use of process improvements to maximize the yeld and the minimization of produced waste.

- It can be expensive to convert from previous manufacturing practices because it is going to involve numerous changes.

Green manufacturing concept employs various Green strategies (objectives and principles) and techniques (innovations and technologies), in order to a company more ecologically and environmentally efficient. Some examples of these applications are production with lower consumption of materials and energy, or the replacement of raw materials for products more environmentally friendly (non-toxic and recyclable products for example) (Deif, 2011).

According Li *et al*. (2013) as Manufacturing activities represent a significant share of total energy expenditure, the Green Manufacturing plays a key role in reducing atmospheric emissions. By trying to minimize the impact of greenhouse gases, the reduction in consumption of energy and natural resources, the Green Manufacturing enhances not only the rapid growth of renewable energy and clean technology in the industrial sector, but also assumes a beneficial role not only at the economical level but also at the social level (Li *et al*., 2013).

The Green Manufacturing concept did not come alone. With the spread of the set of practices associated with Lean paradigm, it was natural that the emergence of this concept, such as Lean, aims to minimize waste but at the environmental sphere. Darmawan *et al*. (2014) claim that there is a close connection between these two concepts, indicating that the application of Green methodologies to a production system helps it to become a Lean system. While Lean Manufacturing practices focus on preserving value with less work (Pampanelli *et al*., 2013; Dornfeld *et al*., 2013), Green application in the context of manufacture is intended to minimize damage to the environment by applying to such environmental production practices. Dornfeld *et al*., (2013) stated that Green Manufacturing is more focused on the continuity of global economy without further damaging the environment, so being the focus of using this concept the environmental impact resulting from the activities instead of creating value for the customer.

Pampanelli *et al*. also suggest two of main practices associated with the Green paradigm:

1. Cleaner production: it is characterized as a preventive initiative and is designed to minimize waste and emissions and maximize productive output. Strategies to reduce emissions and waste in the process are outlined by analyzing the flow of materials and energy. With these actions can be avoided large waste in various sectors such as waste water, gases or heat.

2. Eco-efficiency: it focuses on increasing productivity using fewer resources, so less waste and pollution. This is a comprehensive concept and it is relate with other critical factors such as the reduction of the intensity and toxicity of material for goods and

services, increased use of recyclable materials, reducing energy costs and maximizing the utilization of resources

With the implementation of the Green practices is intended that, on the one hand there is an increase in productivity by reducing the use of natural resources and on the other hand, that there is a reduction of the environmental impact caused by industrial activities.

Green Manufacturing embraces a wide range of productive activities from development of Green technology products, implementation of advanced manufacturing and production technologies, introduction of energy efficient, environmentally friendly manufacturing processes and systems (Li *et al.*, 2013), whether in the factory as the organizational level and throughout the associated supply chain. Li *et al.* (2013) reported that the Green Manufacturing success has on its basis an element of great importance - the automation. Several associated innovations have been applied in the industrial context for the implementation of Green practices. For example, are highlighted techniques related to the control for startup and shutdown of machines that are very important in controlling and reducing energy consumption.

#### *2.1.2.1 Adoption of Green practices through Standardization*

The control of energy consumption is a major concern of Green Manufacturing. Moreover, companies have had a growing environmental awareness and consequent concern with their image and social performance. As such it is important for companies to adopt the approaches listed in the International Organization for Standardization (ISO) standards related to Green practices (Zailani *et al.*, 2012). Two standards raised in this context are for example the ISO 50001 and ISO 14031.

ISO 50001 is an international energy management standard, establishing a guide for companies to manage their energy resources, including their purchase and use. With its implementation, is expected to reach major long-term increases in energy efficiency (20% or more) and the reduction of greenhouse gases worldwide (McKane, 2010). This standard specifies requirements for establishing, implementing, maintaining and improving an energy management system, with the purpose to assist an organization to follow a systematic approach in achieving continual improvement of energy performance (energy efficiency, use and consumption) (ISO 50001, 2011). The ISO 50001 marks the worldwide introduction of the Energy Management System (ENMs). As one of the main standards of ISO management system, ISO 50001 has attracted much attention among industries, and is expected that it is probable that it may become part of the requirement of the supply chains in the future (HKEIA, 2013). According to HKEIA, (2013) ISO 50001 can be used for certification of the company in accordance with the parameters of the standard, but the advantages of adoption can expand on a global scale, taking effect on about 60% of energy use in the world. With the application of this standard in business, it is possible to achieve a more efficient use of available energy sources, thereby increasing competitiveness and reducing emissions of greenhouse gases as well as other negative environmental impacts related.

Industrial facilities are a major energy consumer, as such, they must join forces to reduce this consumption, with the goal of preserving the environment. The implementation of energy saving measures encourages companies to manage their energy-related issues through a systematic approach to ensure continuous improvement of its energy performance.

Technologies and energy saving equipment are just some of the methodologies for improving energy efficiency. A more sensible and systematic approach to improving the energy performance of a sustainable company is to establish and implement a standardized process based power management structure.

ISO 14031 standard refers to Environmental Performance Evaluation (Bennett & James, 1998). Besides the creation of Energy Management Systems, companies that have concerns about the impact of their activities on the environment, have been seeking ways to understand, demonstrate and improve their environmental performance. An organization that has an environmental management system should compare their environmental performance with its environmental policy, objectives, targets and other performance criteria. The environmental performance evaluation (EPE) is the objective of ISO 14031. This standard is an internal management tool that provides management with reliable and verifiable information to determine whether the environmental performance of an organization is appropriate to the criteria established by the organization's management. If an organization does not have an environmental management system, EPE can assist companies in order to determinate the subjects to be treated as significant or establish the criteria for their environmental performance and use it to assess their performance (ISO, 2005). According to the ISO 14031 standard, the EPE and environmental audits play a key role in helping managers to review the status of their environmental performance and identify areas where further improvements are needed. EPE is a continuous process of collecting and evaluating data and information in order to provide a current assessment of the performance as well as performance trends over time.

## 2.2 Implementation of Lean and Green practices in manufacturing companies and measurement of their performance

Relative performance evaluation is important to help the companies to be able to monitor their performance. The Benchmark refers to a methodology to compare the performance of a company with a set of other companies. The group of companies that make up the set for comparison, can be defined in various ways, but ultimately, the definition adopted depends on the utility of performance results to the end user involved (Feeny & Rogers, 2003).

The increasing competitive markets, confronts companies with the need of use management tools that allow them to diagnose the critical factors of the business, with the aim of developing strategies to achieve their goals. Performing Benchmarking is the search of the best methods used in different business processes and functions, with special focus on those whose impact on performance, enables secure and sustain competitive advantages (IAPMEI, 2014). Benchmarking exists to fulfill this need being widely requested by companies as a tool to support the improvement of its performance. In this way, Benchmarking is characterized as being an analytical tool that can help to understand the complex nature of the companies' performance. Thus, Benchmarking represent a means to support the improvement process, establishing itself as a form of learning, since the search for best practices implies a careful analysis of the various ways to implement the processes and methods of work adopted by companies.

In this way, Feeny & Rogers (2003) suggest that the comparative analysis of the group may involve a comparative process between companies' effort in relation to their results. On the other hand, it may also be interesting to do this by analyzing the relative comparison between business parameters. Finally, it may also be interest to assess which company has a superior performance compared to some established limit for best practices.

Some studies have been undertaken regarding the measurement of corporate performance for some management practices. Particularly in Lean subject, there are several of these examples as Marodin & Saurin (2013) identified and suggested research areas related to Lean practices. The authors identified the factors that influence the implementation of Lean practices and presented in four subcategories (work organization, external environment, technology and human factors). Thus, there are several areas affected by the implementation of Lean practices. However, to achieve the objective of quantifying the degree of application, given the vastness of factors and areas covered, it is necessary to choose the measures which may be considered useful in the construction of metric measurement systems.

The Lean practices mentioned in section 2.1.1, focus on areas and particular aspects of the productive process, in order to eliminate waste, while increasing quality levels while the costs and time associated with the process are decreasing (Kumar & Abuthakeer, 2012). So, it is relevant a study about the quantification of the application of practices associated with the Lean, which takes into account all the tools/practices considered to be significant for this purpose.

Similarly to the Lean paradigm, it is also important to identify the practices that allow the definition of the Green paradigm application in a company. The practices listed in the literature review of the Green paradigm present in sub-chapter 2.1.2, when applied in manufacturing companies, are a way for application, analysis and expansion, of the Green Manufacturing paradigm itself through company. Regarding the implementation of Green practices, despite being a huge improvement at an environmental level, and the possibility to make better exploitation of materials and resources used, not everything is positive about it implementation. Although the companies have a growing awareness of the benefits that Green can provide, it remains difficult for some of them achieve this implementation, due to implicit costs that are often very high due to the need for conversion of previous manufacturing practices which involves several changes around all levels of the company.

Taking as background all the literature on practices applied in Lean and Green context, well as their relationship with the kind of data that will be used in the development of the models proposed in this dissertation, in section 4.3 will be propose the practices that will be used to define the Lean and Green construct.

## 2.3 Green and Lean indexes in manufacturing companies

Some evaluation indexes for the various management practices have been developed by many authors as Lau (2011), Azevedo *et al*. (2013) or Azevedo *et al*. (2012b), not only in the context of production in manufacturing companies, but also for example regarding to supply chains. The literatures present several studies about the development of indexes that aim to aid in the measurement of the performance of companies in the implementation of manufacturing practices.

Lau (2011) developed a study aiming to compare the performance of two countries (China, a developing country, and Japan, a developed country) with regard to the Green Logistic Performance theme. For that purpose, the author developed an index that calls itself Green Logistics Performance Index (GLPI) and used as an example for the study, the data from a survey of Green Logistics performance practices of home electronic appliance (HEA), investigating and comparing Chinese and Japanese manufacturers. The aim of the constructions of the GLPI is the easy comparison of performance among industries and countries. The major research focus is placed on three major areas of logistics in the HEA supply chain, i.e. purchases, packaging and transport, where the Green activities can bring meaningful benefits. Lau (2011) justifies the use of this methodology stating that the aggregate findings should reflect more or less the current situation, although there might be possibilities of under- or over-assessment of performance on certain activities by individual respondents. Lau refers to the emphasis on the relationship, rather than absolute performance using just a five-point scale, furthering lessens the impact of any random assessment bias. The Principal Component Analysis (PCA) was used to obtain the weights in order to develop the GLPI used for an overall comparison of Green Logistics (GL) performance between the two countries. The 15 GL activities in question were represented by the abbreviations $A_1$, ..., $A_{15}$, where these variables can take values from a five-point scale (values between 1 to 5). By applying the PCA method, the performance scores of activities $A_1$ to $A_{15}$ reported were obtained, being possible to obtain the value corresponding to the total score for performance (*S*). Lau (2011) describes the measure *S* by the expression presented in Equation (2.1):

$$\begin{aligned} S &= 0{,}924A_1 + 0{,}979A_2 + 0{,}951A_3 + 0{,}688A_4 + 0{,}862A_5 + 0{,}912A_6 \\ &+ 0{,}922A_7 + 0{,}842A_8 + 0{,}765A_9 + 0{,}649A_{10} + 0{,}777A_{11} + 0{,}974A_{12} \\ &+ 0{,}949A_{13} + 0{,}864A_{14} + 0{,}880A_{15} \end{aligned} \tag{2.1}$$

Since obtaining the *S* value is then possible to obtain the expression for the proposed composite index, GLPI, which adopt values between 0 and 100. The $S_{min}$ and $S_{max}$ variables are, respectively the minimum and maximum values that S can achieve by replacing the variables $A_1$, ..., $A_{15}$ by the minimum and maximum values of the scale that they can take (1-5). The expression of GLPI is described in Equation (2.2):

$$GLPI = \frac{(S - S_{min}) \times 100}{S_{max} - S_{min}} \tag{2.2}$$

The design methodology of GLPI has enough interest in the context of this dissertation, since its principles can be applied to the creation of Lean and Green indexes. So this relationship will be developed later in section 4.4.

Other authors have been exploring the development of indexes not only for Green practices, but also linking them to other concepts such as resilience. Azevedo *et al*. (2013) suggested an Ecosilient Index to assess the greenness and resilience of automotive companies and the associated supply chain using the Delphi technique. Their main objective was to propose an integrated index called Ecosilient to reflect the resilience and Green companies on their supply chain. The application of the proposed index was illustrated using a case study in the automotive sector, applying in particular on the link between supplier and manufacturer. To that end, the authors used the Delphi technique in order to obtain the weights for the paradigms of the supply chain, which was considered the focus of study. As Azevedo *et al*. (2013) discuss, the Delphi technique is a tool used to develop weights using the views of academics/experts on topics related to the research in question. The Delphi technique is a method which provides for the consensual validity of all evaluators by providing feedback to the responses of other evaluators, so is a useful communicating tool to reach consensus among entities given a problem (Azevedo *et al.*, 2012b). As the authors stated, the indicators for each company can be calculated by aggregating the individual corresponding sub-indicators according to their importance. For each company j was presented a generic formula for the index $B_x$ (where x is the paradigm in question, x = G: Green or x = R: Resilience), Equation (2.3)).

$$(B_x)_j = f[w_{x1} \times (P_{x1})_j, \dots, w_{xy-1} \times (P_{xy-1})_j, w_{xy} \times (P_{xy})_j] \tag{2.3}$$

Where:

1. $(B_x)_j$: company *j* behavior according to the paradigm *x* (*x* = *G* or *R*).

2. $(P_{xi})_j$: company *j* the implementation of practice *i* level according to the paradigm *x*. A total of *y* practices are considered for each paradigm. Each practice implementation level is assessed in a five point scale where 1 means “practice not implemented” and 5 “practice totally implemented”.

3. $w_{xi}$ means: weight of practice *i* of paradigm *x*.

For each company the $B_x$ behavior ranges from 1 (not practice paradigm implemented) to 5 (all seven practices are implemented paradigm). Thus Ecosilient Index for a particular company (Ecosilient$_j$) is a composite indicator, described in Equation (2.4):

$$Ecosilient_j = f[w_R \times (B_R)_j, w_G \times (B_G)_j] \tag{2.4}$$

Where:

1. $(B_x)_j$ represents the company j behaviour related to the paradigm $x$ ($x = G$ or $x = R$).

2. $w_R$ and $w_G$ symbolize the weight of green and resilient paradigms. The weight values represent the significance of each paradigm for Supply Chain competitiveness.

Other techniques are available for assessment of the multiple manufacturing paradigms. Vinodh *et al*. (2011) argue for the need of using fuzzy logic due to the impreciseness and vagueness associated with decision-making problems. The authors present a study in which they used fuzzy association rules for leanness evaluation. According the authors the fuzzy methodology is described as:

"Fuzzy set theory is one of the useful tools where problems related to vague logics are dealt. Fuzzy set theory allows representation of partial member- ship of elements in more than one set, .i.e. an element can be a member of more than one set at the same time. According to fuzzy set theory, the sets that we use in classical set theory is called a crisp set and one or more sets are associated with a crisp set which are called fuzzy sets whose elements are fuzzy numbers (integers between 0 and 1)."

In order to evaluate the performance of Agile Supply chains (ASC), Vinodh *et al*. (2013) created an evaluation model. The calculation of the model was performed using fuzzy logic approach. The method for assignment of the performance variables was based on the expert's opinions. During the conduct of the study, the linguistic terms were used to assess the performance ratings and importance weights of ASC attributes. In the study, the average fuzzy ratings are represented by *Rj* and average performance weights by *Wj*. The *Rj* and *Wj* expressions are presented in Equation (2.5) and Equation (2.6):

$$R_j = \frac{\left(R_{j1}(+)R_{j2}(+)\ldots\ldots R_{jm}\right)}{m} \tag{2.5}$$

$$W_j(x_{j,}y_{j,}w_j) \;= \frac{(w_{j1}(+)w_{j2}(+)\ldots\ldots w_{jm})}{m} \tag{2.6}$$

Where, $R_j$ is the average fuzzy ratings; $R_{jm}$ is the fuzzy performance ratings; $W_{jm}$ is the performance weights; $W_j$ represents the average performance weights and $x_j$, $y_j$, $z_j$ are the three warehouses under analysis regarding the supply chain under study, considering $m$ as the number of experts.

Consolidated fuzzy ratings and fuzzy weights were used to determine the fuzzy ASC index (FASCI), according to Equation (2.7).

$$FASCI \;= \frac{\sum_{j=1}^{n}(W_j \times R_j)}{\sum_{j=1}^{n}(W_j)} \tag{2.7}$$

Other researchers developed models to measure indexes based on fuzzy approach. For example Yang & Li. 2002) proposed a procedure for evaluating Agility with fuzzy logic approach for mass customized product manufacturing, identifying intervals on a scale of 2-10 to indicate whether the company are agile or not. Also, Yu *et al*., (2012) also stand out in this context since they used the fuzzy multi-objective vendor selection program for lean procurement, developing an algorithm solution using fuzzy Analytical Hierarchy Process (AHP).

## 2.4 Conclusions

In this chapter the literature review was presented in the context of Lean and Green paradigms, in particular its application in manufacturing companies. The literature review stands out some relevant practices associated with Lean and Green paradigms in manufacturing. These practices will support the creation of the indexes proposed in this dissertation. Allowing to proceed with the measurement of the performance of companies in the implementation of these practices, and consequently the application of the overall concept they represent, the Lean and Green paradigms.

Another important part of this chapter is the literature review on the creation of indexes. Thus, it was reviewed methods to creating indexes that can be used in the context of this dissertation. The index created by Lau (2011) use variables which are characterized as being practices or activities, indicates that may be used a similar approach to create the indexes proposed in this dissertation, the Lean Index and the Green Index.

# 3 Composite index construction methodology

## 3.1 Composite index

In this section the theoretical bases for composite indexes are presented and the numerous advantages in the use of composite indexes are identified. In addition, is their suitability to data from practices implementation level that in this work are the variables of the index.

In general, an indicator is a quantitative or quality evaluation from real observations. When the evaluation is performed at regular intervals, it is possible to observe the evolutionary trends of the indicator through time. Composite indexes can be obtained from indicators since indexes are characterized as being aggregated indicators that comprise individual indicators and their respective weights (Nardo *et al*., 2008). Composite indexes are weighted elements, generating a composite variable that does not suffer from disorders, which means that the composite variable is an exact linear combination of composite variables indicators. In the context of this dissertation, composite indexes are those that have relevance to the study and construction of the proposed index.

Composite indexes can be useful in politics and benchmarking or performance monitoring priorities. A composite indicator is formed by compiling individual indicators into a single index based on a mathematical model. The composite indicator shall measure multi-dimensional concepts, which is not possible with the simple indicators analysis Nardo *et al.* (2008). As examples of multi-dimensional concepts stand out competitiveness, industrialization, sustainability, etc. Due to the easy interpretation of composite indicators results, they have been used in comparative analyses of countries, classifying and evaluating their performance regarding a wide range of topics. Among the more recently studied themes, stand out those related to social, human, environmental and safety aspects, as well as those related to globalization theme. Several institutions and academics have been developing composite indexes. These indexes are based on various indicators and sub-indexes aggregated according to some analytical methodology that has the purpose to give a score to the organization involved. The scores obtained by companies resulting from the calculation of these indexes are used to create a classification that shows their progress (or reverse).

There are some advantages in the use of composite indexes (Nardo *et al*., 2008). When using composite indexes it is possible to summarize complex and multidimensional situations, helping and easing decision making. Another relevant positive aspect, as has been described above is the fact that such indexes are easy to interpret, especially when compared with a large number of other indicators that need to be analysed separately, also highlighting the fact that with its implementation, it is possible to reduce the size of the initial set of indicators without losing the basic underlying information. The possibility of measuring progress over time is another positive characteristic. However, it can be stated that one of the major advantages of using this type of indicators is the fact that it can provide users the ability to effectively compare complex dimensions. Saisana & Tarantola (2002) summarized the possible advantages and disadvantages of creating and using composite indexes for comparisons and country rank performance in areas such as industrial competitiveness, sustainable development, globalization and innovation. These advantages and disadvantages, adapted to the business context, can be found in Table 3.1.

Table 3.1 – Advantages and disadvantages of Composite Indicators

Adapted from Saisana & Tarantola (2002)

| **Composite Indicators** | |
|---|---|
| **Advantages** | **Disadvantages** |
| • Can summarize complex and multi-dimensional realities with a view to support decision makers.<br>• Easy to interpret than a battery of many separate indicators.<br>• Can assess the progress of companies over time.<br>• Reduce the size of a set of indicators without dropping the underlying information base.<br>• Make it possible to include more information within the existing size limit.<br>• Facilitate communication through companies' hierarchy and promote accountability.<br>• Enable users to compare complex dimensions effectively. | • Can lead to misleading messages about the results or position of the company, if misinterpreted.<br>• Can lead simplistic policies.<br>• May be misused, e.g. to support a desired policy, if the construction process is not transparent and/or lacks sound statistical or conceptual principles.<br>• May disguise serious failings in some dimensions and increase the difficulty of identifying proper remedial action, if the construction process is not transparent.<br>• Can lead to inadequate management policies if dimensions of performance that are difficult to measure are ignored. |

## 3.2 Indexes construction methodology

Composite indexes are similar to mathematical models. In other words, they are highly depend on the method used by its creator rather than by universal scientific guiding rules. Thus, existing models are justified by their ability to fulfill the intended purpose and for its accreditation by the scientific community through peer acceptance.  To start the construction of a composite index, it is necessary that the issues related to the methodology are clarified and well defined, to avoid data manipulation in analysis. Nardo *et al*. (2008) propose ten steps to construct a composite index, namely:

1. Theoretical framework - To provide the basis for the selection and combination of individual indicators into an expressive composite indicator, under a fitness for achieving the principal purpose. It is important to begin the process of index creation by this step to have a clear understanding and definition of the multidimensional phenomenon to be measured. If necessary, this step may be also important to structure the various sub-groups of the phenomenon.

2. Data selection - Factors such as analytical soundness, measurability, country coverage, relevance to the phenomenon being measured and its relation to one another should be the basis for the selection of indicators. The use of proxy variables should be considered when data are sparse, in other words, when the object of study is difficult to measure or observation of the indirect measurement of the variable that the researcher wants to study is performed.

3. Imputation of missing data - Should be considering different approaches to impute missing values. The extreme values must be considered as they can become unintended references.

4. Multivariate analysis - An exploratory analysis should be performed to investigate the general structure of the indicators, define and explain the methodological choices, evaluating the adequacy of the data, for example by weighting or aggregation.

5. Normalization - The indicators should be standardized to make them comparable. Attention should be paid to the extreme values or distorted data since they may influence the following stages of the construction of the index process.

6. Weighting and aggregation - Issues about correlation and compensation between indicators need to be corrected or treated as characteristics of the phenomenon that need to be retained in the analysis. There is a need to combine significantly different dimensions, which implies a decision about the weighting model and variables aggregation procedure. So the indicators should be aggregated and weighted in accordance with the underlying theoretical framework.

7. Robustness and sensitivity - Analysis should be undertaken to assess the robustness of the composite indicator, for instance, in terms of the imputation of missing data, the method for the inclusion or exclusion of individual indicators, standardization of data, the choice of weights and the aggregation method.

8. Back to the real data - Composite indicators should be transparent, being able to be broken down into their indicators or underlying values.

9. Links to other variables - It is important to try to relate the composite index with other indexes previously published in order to identify connections through regressions.

10. Presentation and visualization - There are several ways to display the index created. It should be noted that the presentation of the index may influence their interpretation.

The methodology of index construction and especially the quality of the structure and the data used, influence the quality and the robustness of the message to be transmitted with the construction and analysis of the index. A composite index based on a weak theoretical base or data that contain severe measurement errors may lead to results that transmit questionable messages, despite a good methodological basis.

In the context of this dissertation for the construction of the proposed indexes will be followed a similar methodology to that which was proposed by Nardo *et al* (2008). However, not all steps will be applied, since they may not be applicable or necessary in the particular context of this dissertation.

### *3.2.1 Using Factor Analysis to construct indexes*

In the next section a theoretical introduction to the Factor Analysis (FA) is made. This is a technique that will be used for the data treatment in order to build the Lean and Green indexes proposed in this dissertation.

FA is a multivariate technique in which the total number of variables in the model under study is reduced to a lower set of uncorrelated variables. The ability to act in the reduction of the dimensionality makes the FA one of the most popular techniques used in several scientific disciplines such as psychology and sociology, education or business studies, because of the multidimensionality and the need of using factor analysis in the study cases of these areas. FA is useful in indexes construction since it can be used to determine the weights for each indicator under study. According to Lau (2011) FA provides an approach for defining weights less biased than other subjective weighting methods, such as opinion polls. Moreover, the author states that the FA is also able to point the amount of variation in the data explained by the resulting composite index indicating how representative the index is. This method is also one of the oldest statistical techniques and its creation is due to Karl Pearson in 1901. However, the procedure as we know it nowadays is due to Harold Hotelling in his paper in 1933 (Jackson, 1991).

In general, it is possible to enumerate the four major goals of the FA application (Abdi & Williams, 2010):

1. Extract the most important information from the data table;
2. Compress the size of the data set by keeping only this important information;
3. Simplify the data set description;
4. Analyse the observations and the variables structure.

Principal Component Analysis (PCA) is one method used in the FA to extract the factors (called components). In many texts PCA is reported as a special case of (FA). As such, this practice is performed by some computer programs, presenting the PCA as an option in the factor analysis programs since they are similar techniques.

Table 3.2 shows some of the assumptions made in the applications of FA. For some issues such as determining the sufficient number of cases needed to perform FA, there are no scientific answers, there is only methodologist opinions. Thus, for this purpose, some arbitrarily enforced rules that have been popularized.

These rules are not mutually exclusive, for example, it is possible to certify both the cases-to-variables ratio and the Rule of 100.

Table 3.2 - Assumptions in Factor Analysis

Adapted from Nardo et al (2008)

| Assumptions | Alternative arbitrary rules of FA application in descending order of popularity |
|---|---|
| Sufficient number of cases | Rule of 10: There should be at least 10 cases for each variable. |
| | 3:1 ratio: The cases-to-variables ratio should be no lower than 3. |
| | 5:1 ratio: The cases-to-variables ratio should be no lower than 5 |
| | Rule of 100: The number of cases should be the larger of “5 × number of variables” and 100 |

#### *3.2.1.1 Application of Principal Component Analysis*

The data are observations described by multiple dependent variables, which are generally correlated. These observed variables can be measured directly and are called measured variable or indicators. To apply the PCA, the data are disposed in a table. The purpose of the application of PCA is to extract the important information from the data table. To express this information is generated a set of new orthogonal and uncorrelated variables called principal components.

The first step in FA is to test if the variables show a reasonable degree of correlation. To this end, the correlation matrix from the initial data table is calculated (Petroni & Braglia, 2000). The Bartlett's sphericity test and Kaiser - Meyer - Olkin measure of sampling adequacy (KMO) calculation are the next steps. Bartlett's sphericity test and KMO are two statistical procedures for assessing the quality of the correlations between variables in order to be able to proceed with the FA (Pestana & Gageiro, 2005).

The Bartlett's sphericity test is one way to determine if the factor analysis is appropriate for the data sets that are under analysis. This is a statistical test to test if the correlation matrix is significant correlation between at least some of the variables. This test is meant to test the null hypothesis that the correlation matrix is an identity matrix, i.e. all the diagonal elements are all 1 and the off-diagonal elements are 0, which means that all variables are uncorrelated. In some software such as Statistical Package for the Social Sciences (SPSS), the Bartlett's test of sphericity can be interpreted by the Significance value (Sig). If the Sig value of this test is less than the alpha level required, which normally follows the statement to be 0,001 (Petroni & Braglia, 2000), the null hypothesis that the population matrix is an identity matrix is rejected, which leads us to conclude that there are correlations in the dataset that are suitable for FA. Thus, the results of the Bartlett's sphericity test are significant when the Significance value (Sig) is less than 0.001, suggesting that there are relationships between variables.

The Kaiser - Meyer - Olkin Measure is a measure of sampling adequacy and is used to confirm that the sample data is suitable to be analyzed by Factor analysis. This metric is also considered in the analysis using SPSS software. KMO is a statistic that varies between zero and one (Pestana & Gageiro, 2005). When the value of KMO is located close to 1, indicates that the partial correlation coefficients are small. Otherwise, it indicates that the use of factor analysis is not indicated because there are weak correlations between variables. According Pestana & Gageiro (2005), the values of KMO can be appointed by categories. Table 3.3 summarizes this classification and its associated values to a better visualization. This classification will be used in the conduct of the present dissertation study.

Table 3.3 - Classification for Kaiser - Meyer – Olkin Measure values

Adapted from Pestana & Gageiro (2005) and Field (2009)

| Values around | Classification |
|---|---|
| >0,9 | Very Good |
| 0,8-0,9 | Good |
| 0,7-0,8 | Median |
| 0,6-0,7 | Reasonable |
| 0,5-0,6 | Bad |
| <0,5 | Unacceptable |

After performing the tests of the adequacy of the data to the FA, it is then possible to proceed with the calculation of the principal components. The first principal component identified is required to have the largest possible variance, i.e. it will explain the most of the variance in the data. The first principal component represents the maximum possible proportion of the variance. The second principal component represents the maximum possible variation of the remaining, and so on, until the last of the principal components absorb all the remaining variance (Nardo *et al.*, 2008). The components that represent the maximum variation are retained while the other components, which are responsible for a negligible amount of variance is discarded.

However, a pertinent question arises when the PCA technique is applied, which relates to the determination of the number of components to extract from the data. When the method is applied to the set of variables, it extracts combinations of variables that account for the largest amount of variance and then provide combinations that correspond to increasingly smaller amounts of variance.

The latent root criterion is one of the most widely used criteria. It is a technique with a very simple application that is based on the principle that any individual factor should account for the variance of at least a single variable if it is maintained for interpretation. Each variable contributes a value of 1 to the total eigenvalue. So it should be selected the significant components, that is those having latent roots or eigenvalues greater than 1, noting that eigenvalues represent the amount of variance accounted by the component (Hair *et al.*, 1990). Jolliffe (2002) also described this technique in his book, naming it the Size of variances of Principal Components rule. However, this criterion is commonly denoted Kaiser's Rule. In addition to this criterion, several authors refer to other methods to determine the number of Principal Components to maintain. Among others, Hair *et al.* (1990) describes the percentage of variance criterion and the Scree test criterion. This is one of the most intuitive criteria on which the decision maker establishes the necessary number of principal components through the selection of which will result together a certain amount of percentage of total variation (Jolliffe, 2002). The Scree test applies by plotting the eigenvalues as a function of the number of components in their order of extraction. By observing the shape of the curve in the graph is check what values lie to the left of the first "elbow". This "elbow" is approximately the cutoff point. Typically, the curve of the graph has a strong down inclination initially and then slowly becomes an approximately horizontal line (Jolliffe, 2002). The point at which the curve begins to straighten out is regarded as the last of the principal components extracted and it represents the cutoff point described above.

There is no consensus about this limit value assigned to the percentage of total variation of the principal components to retain. Thus, there is no recommended absolute value to apply. However, in the natural sciences, the procedure usually is performed until the value of at least 95% of variation being achieved. On the other hand, in the social sciences, are usually very satisfactory results, those that have solutions that account for at least 60% of total variance or sometimes less (Hair *et al*., 1990).

#### *3.2.1.2 Factors Rotation*

In order to facilitate interpretation of the components after its determination, the PCA often involves a rotation of the components that were retained. There are two types of rotations used in this type of analysis, the orthogonal when the new axes are also orthogonal and oblique rotation when there is no need for orthogonality (Abdi & Williams, 2010).

The orthogonal rotation originates factors do not correlate with each other, each of them being interpreted from their loadings which take values between -1 and +1. One of its objectives is to increase the higher loadings lower and lower, yielding components that can be named and are more clearly interpreted. The Varimax, Quartimax and Equamax methods are examples of orthogonal rotation. In oblique rotation the factors are correlated. So to be able to interpret, it is necessary to consider simultaneously the matrix of correlations and loadings, making more difficult to implementation of this type of rotation compared to the orthogonal rotation. Orthogonal Varimax Rotation is the most popular, being described by some authors as the most common method for the implementation of the rotation of the factors (Nardo *et al*., 2008). The Varimax criterion is based on simplifying the columns of the matrix of factors. With this approach, the maximum simplification of the array is reached when there are only 1 or 0 values in a column. This method aims to maximize the sum of variances of required loadings of the factor matrix. With this method it is possible to get some high loadings (close to -1 or +1), which indicates positive or negative associations between variables and factors, but also allows you to find loadings with values near 0 indicating clearly that there is no association. Thus, the solution allows for a Varimax clear distinction between the factors which led to consider that this technique as highly successful in obtaining orthogonal rotation of factors.

#### *3.2.1.3 Factor Loadings matrix*

After the factors rotation, the next step of the PCA method is related to the construction of the factor loadings matrix. This is the matrix of weighting factors and is used to calculate the factor scores after rotation. It should be considered the highest loadings of each variable for each principal component, thus obtaining weights for each variable that will be used in the construction of composite index.

## 3.3 Conclusions

This chapter explained what composite indexes are, how these have been used, as well as the advantages and disadvantages of their application. Its construction follows a methodology based on proposed models that are justified not so much on scientific rules but with their ability to achieve the intended goals. This chapter also highlighted the FA as a statistical method capable of assist the indexes construction by calculating the weightings assigned to each variable.

# 4 Development of a Lean and Green index

## 4.1 The EMS survey

To construct the Green and Lean indexes will be used data obtained with the implementation of the European Manufacturing Survey 2012 (EMS 2012) in Portugal. In 2001, researchers at the Fraunhofer Institute for Systems and Innovation (ISI) had created the survey Modernization of Production. To complement it in some areas that previously were not considered in the innovation surveys, they gave it a higher level of detail, by internationalizing the investigation through the creation of the European Manufacturing Survey (EMS). The EMS is managed by a consortium of research institutes and universities in countries across Europe and also China and Brazil. The Competence Center Industry and service innovations at the Fraunhofer coordinates this group (EMS | Fraunhofer ISI, 2014).

The purpose of the EMS is to obtain internationally comparable data through a questionnaire, translated into the official language of each of the participating countries, and with a standardized method of information processing. The EMS survey focuses on a wide range of indicators, such as new products, services, processes and technical concepts and organizational processes. The questions about these indicators are measured and standardized in all participating countries. It aims to contribute to the standardization of the use of information on organizational and technological subjects. However, issues such as energy and materials consumption efficiency technologies have been gaining importance nowadays, is also expected increased interest in this subject for the times ahead. EMS offers some advantages over other methodologies used in existing surveys. This allows obtaining a global view of the technologies adoption in the European manufacturing sector, being possible to obtain continuously reliable, comprehensive and compatible data, maintaining a common set of questionnaire for all participating countries (Zimper, 2013).

Since 2012, Portugal became a member of the EMS multinational consortium country by joining the UNIDEMI - Unit for Research and Development in Mechanical and Industrial Engineering, Faculty of Science and Technology, New University of Lisbon.

## 4.2 Sample characterization

The data used in the preparation of this study come from the EMS 2012, applied for the first time to manufacturing companies in Portugal. The application of EMS 2012 was conducted by the Research Unit of Mechanical and Industrial Engineering (UNIDEMI), Faculty of Science and Technology, New University of Lisbon. The data collected from the EMS 2012 in Portugal are related to the implementation of innovative technologies in production, organizational concepts and services related to the products with impact on the modernization of Portuguese manufacturing companies.

The survey was sent to 2370 Portuguese companies with 20 or more employees and it was delivered via the Internet. Of these 2370 companies, were only obtained 62 valid responses, leading to a response rate of 2,6%. Approximately 60% of survey respondents have the post of General Director or Production Manager. On the other hand, the survey also found that about 16% of the companies produce products for both industrial and business customers.

The participants companies have between 20 and 1448 employees. During the previous year of the implementation of this survey (2011), the inquired companies had a turnover between 0,7 and 3500 million euros, with an average of 83,7 and a standard deviation of 445,5 million euros.

In Table 4.1 and Table 4.2 are presented the percentage distribution of respondent companies regarding to each class considered in relation to number of employees, and their amounts of business

Table 4.1- Percentage of companies by number of employees

| **Number of employees** | **Number of companies (%)** |
|---|---|
| [20-50] | 40% |
| ]50 -250] | 48% |
| > 250 | 11% |

Table 4.2 - Percentage of companies by 2011 turnover.

| **2011 Turnover ($10^6$ €)** | **Number of companies (%)** |
|---|---|
| ≤10 | 60% |
| ]10 - 50] | 24% |
| > 50 | 16% |

## 4.3 Selection of the Lean and Green practices under analysis

The EMS is a very extensive questionnaire. However, for the construction of Lean and Green Indexes were considered only the issues that were relevant to these two paradigms. So, in Appendix B is an excerpt from the EMS 2012 distributed to the participating companies. Included in this appendix are the questions that have been selected as Lean and Green practices, thus assuming the role of variables in the study of this dissertation.

The practices selected for the characterization of Lean Manufacturing are defined in the Table 4.3, while the practices related to Green Manufacturing are presented in Table 4.4. In table it is indicated the number of the survey questions considered to build each practice.

Table 4.3 - Lean Practices

| Practices related to the implementation of Lean concept | Scale used | EMS question number |
|---|---|---|
| 1 - Methods of Value Stream mapping/Design | 0;1:2;3 | 174 and 177 |
| 2 - Production controlling by pull principles | 0;1:2;3 | 182 and 185 |
| 3 - Methods for optimizing of changeover time | 0;1:2;3 | 186 and 189 |
| 4 - TPM (Total Preventive Maintenance) | 0;1:2;3 | 190 and 193 |
| 5 - TQM (Total Quality Management) | 0;2;3 | 194 and 197 |
| 6 - Method of 5S | 0;1:2;3 | 198 and 201 |
| 7 - Standardized and detailed work instruction | 0;2;3 | 202 and 205 |
| 8 - Methods for continuous process improvement | 0;1:2;3 | 210 and 213 |
| 9 - Six Sigma | 0;1:2;3 | 226 and 229 |

Table 4.4 - Green Practices

| Practices related to the implementation of Green concept | Scale used for each variable | EMS question number. |
|---|---|---|
| 1 - Control system for shutdown of machines in off-peak periods | 0;1:2;3 | 155 and 159 |
| 2 - Recuperation of kinetic and process energy | 0;1:2;3 | 160 and 164 |
| 3 - Combined cold, heat and power (Bi-/Trigeneration) | 0;3 | 165 and 169 |
| 4 - ISO 14031 certification | 0;1:2;3 | 230 and 233 |
| 5 - ISO 50001:2011 certification | 0;1:2;3 | 234 and 237 |

Taking into account the 62 responses and considering the Lean and Green variables under analysis presented in tables 4.3 and 4.4, can be noted that data meets some of the proposed rules in section 3.2.1.1, thus ensuring conditions for the application of the FA method, regarding to the number of cases under study. Table 4.5 summarizes the application of the proposed rules (Table 3.2) to the data.

Table 4.5- Verification of the existence of a sufficient number of cases using the assumptions in Factor Analysis

| **Rule/ Assumption** | **Lean**<br>No. of variables: 9<br>No. of cases: 62 | **Result** | **Green**<br>No. of variables: 5<br>No. of cases: 62 | **Result** |
|---|---|---|---|---|
| **<u>Rule of 10</u>**<br>$\boldsymbol{No. of\ cases\ should\ be \geq 10 cases/variable}$ | $62 \leq 90$ | Does not fulfill | $62 \geq 50$ | Fulfills |
| **<u>3:1 ratio</u>**<br>$\boldsymbol{\frac{No. of\ cases}{No. of\ variables} \geq \frac{3}{1}}$ | $\frac{62}{9} \geq \frac{3}{1}$ | Fulfills | $\frac{62}{5} \geq \frac{3}{1}$ | Fulfills |
| **<u>5:1 ratio</u>**<br>$\boldsymbol{\frac{No. of\ cases}{No. of\ variables} \geq \frac{5}{1}}$ | $\frac{62}{9} \geq \frac{5}{1}$ | Fulfills | $\frac{62}{5} \geq \frac{5}{1}$ | Fulfills |
| **<u>Rule of 100</u>**<br>$\boldsymbol{No. of\ cases \geq 5 \times No. of\ variables}$; **and** $\boldsymbol{No. of\ cases \geq 100}$ | $62 \geq 5 \times 9 = 45$<br>but<br>$62 \leq 100$ | Does not fulfill | $62 \geq 5 \times 5 = 25$<br>but<br>$62 \leq 100$ | Does not fulfill |

It is quite perceptible through the analysis of Table 4.5, that the data satisfies at least one of the rules, which allows to conclude that there is a sufficient number of cases to proceed with the FA.

In this work, the data analysis was conducted using Statistical Package for the Social Sciences 20 (SPSS) software. SPSS is a powerful computer program supporting the statistical analysis. In Appendix A, the procedure within SPSS is described.

## 4.4 Output - Lean Data Analysis

After the introduction of Lean data variables in the program, the first matrix, generated in the output is the correlation matrix. The correlation matrix for the Lean variables can be seen in Table 4.6.

As discussed in Section 3.2.1.1, Bartlett sphericity test and KMO are applied to verify if the data analysis can be done through the FA. To this end, were obtained the results that can be observed in

Table 4.7, emphasizing that for Significance (Sig) level (Bartlett's test) was determined the value of 0,000. For KMO were obtained the value of 0,832 indicating good adequacy of the sample for FA application. The lack of correlation between the variables is a limitative factor for the application of the FA. With a KMO of 0,832 can be said that there is a good correlation between the variables (regarding the information presented in Table 3.3). In addition, from the Bartlett's sphericity test results a value of 0,000 leading to rejection of the hypodissertation that the correlation matrix could be an identity matrix, showing the existence of correlations between some variables. It is noteworthy that if both of these conditions were not obvious, the use of this type of analysis would have to be reexamined.

Through data analysis by SPSS, concerning to Total Variance Explained presented in Table 4.8, as well as analyzing the Scree plot (Figure 4.1), it is possible to justify the choice of the components number to retain using the criteria listed in Section 3.2.1.1. Based on the criterion Latent Roots or Kaiser criterion can be observed two significant components since only these two present eigenvalues higher than 1. Using a criterion that selects the components, based on the cumulative percentage of the variance, the choice of these two factors also appear to be satisfactory since it accounts for around 60% of the variability. On the other hand, and meeting the other criterion described in section 3.2.1.1 (the Scree Test), the analysis of the Scree plot (Figure 4.1) is much more intuitive, clearly demonstrating that from the point representing the component 2, the curve begins its straightening, indicating that this will be the maximum number of components to retain. SPSS itself uses the Kaiser criterion for determining the number of components by default.

Table 4.6- Lean Correlation Matrix

| | Value stream Mapping | Pull Principles | Changeover time | TPM | TQM | 5S | Work instruction | Continuous improvement | Six Sigma |
|---|---|---|---|---|---|---|---|---|---|
| **Value Stream Mapping** | 1,000 | 0,270 | 0,312 | 0,225 | 0,349 | 0,129 | 0,127 | 0,238 | 0,352 |
| **Pull Principles** | 0,270 | 1,000 | 0,430 | 0,439 | 0,511 | 0,285 | 0,363 | 0,259 | 0,332 |
| **Changeover time** | 0,312 | 0,430 | 1,000 | 0,594 | 0,567 | 0,542 | 0,336 | 0,415 | 0,415 |
| **TPM** | 0,225 | 0,439 | 0,594 | 1,000 | 0,559 | 0,354 | 0,498 | 0,380 | 0,303 |
| **TQM** | 0,349 | 0,511 | 0,567 | 0,559 | 1,000 | 0,348 | 0,319 | 0,389 | 0,533 |
| **5S** | 0,129 | 0,285 | 0,542 | 0,354 | 0,348 | 1,000 | 0,468 | 0,445 | 0,465 |
| **Work instruction** | 0,127 | 0,363 | 0,336 | 0,498 | 0,319 | 0,468 | 1,000 | 0,358 | 0,353 |
| **Continuous improvement** | 0,238 | 0,259 | 0,415 | 0,380 | 0,389 | 0,445 | 0,358 | 1,000 | 0,419 |
| **Six Sigma** | 0,352 | 0,332 | 0,415 | 0,303 | 0,533 | 0,465 | 0,353 | 0,419 | 1,000 |

**Value Stream Mapping** :Methods of Value Stream mapping/Design; **Pull Principles:** Production controlling by pull principles; **Changeover time**: Methods for optimizing of changeover time; **TPM**: TPM (Total Preventive Maintenance); **TQM:** TQM (Total Quality Management); **5S:** Method of 5S; **Work instruction**: Standardized and detailed work instruction; **Continuous improvement:** Methods for continuous process improvement; **Six Sigma**: Six Sigma

Table 4.7 - Kaiser - Meyer – Olkin and Bartlett's tests results for Lean data

| **Kaiser-Meyer-Olkin Measure of Sampling Adequacy.** | | 0,832 |
|---|---|---|
| **Bartlett's Test of Sphericity** | Approx. Chi-Square | 183,669 |
| | df | 36 |
| | Sig. | 0,000 |

Table 4.8 - Total Variance Explained. Lean variables

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| **1** | ***4,103*** | 45,588 | ***45,588*** | 4,103 | 45,588 | 45,588 |
| **2** | ***1,030*** | 11,447 | ***57,035*** | 1,030 | 11,447 | 57,035 |
| 3 | 0,890 | 9,886 | 66,921 | — | — | — |
| 4 | 0,666 | 7,399 | 74,320 | — | — | — |
| 5 | 0,631 | 7,016 | 81,336 | — | — | — |
| 6 | 0,574 | 6,374 | 87,710 | — | — | — |
| 7 | 0,522 | 5,798 | 93,508 | — | — | — |
| 8 | 0,311 | 3,450 | 96,958 | — | — | — |
| 9 | 0,274 | 3,042 | 100,000 | — | — | — |

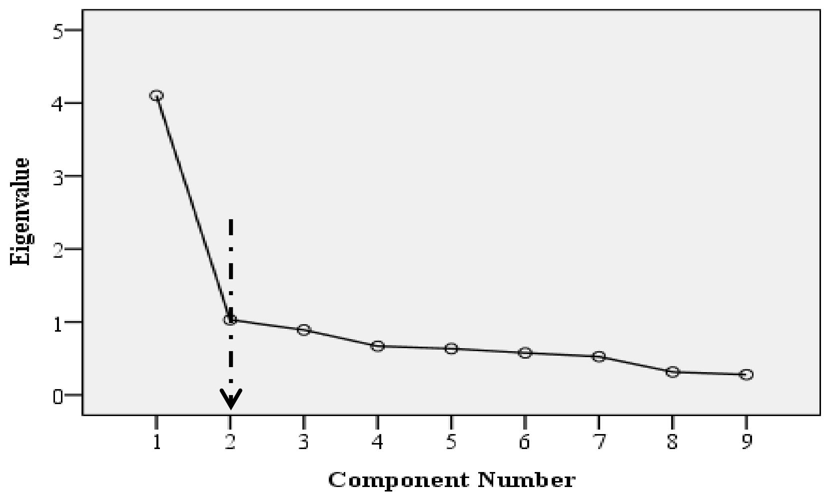



Figure 4.1 - Scree plot. Lean variables

The matrix of the components can be seen in Table 4.9. This matrix shows the loadings of the variables that are correlated to factors before rotation. But not always this step prior to the rotation provides interpretable extracted components. Thus, it becomes useful to examine the components of the matrix after rotation. From the analysis of Rotated Components Matrix (Table 4.10) is possible to make the association of each variable with a single factor. The analysis of this matrix suggests that the variables are associated with the corresponding component where values are highlighted. This assignment of the variable to a factor over another is chosen by the highest value obtained for each variable. As mentioned in the definition of assumptions for analysis by SPSS, the method of rotation of the selected components was Varimax.

Table 4.9 - Component Matrix. Lean variables

| Lean Practices | Component | |
|---|---|---|
| | 1 | 2 |
| Methods of Value Stream mapping/Design | 0,456 | 0,696 |
| Production controlling by pull principles | 0,642 | __ |
| Methods for optimizing of changeover time | 0,780 | __ |
| TPM (Total Preventive Maintenance) | 0,736 | __ |
| TQM (Total Quality Management) | 0,771 | __ |
| Method of 5S | 0,675 | -0,430 |
| Standardized and detailed work instruction | 0,630 | -0,445 |
| Methods for continuous process improvement | 0,642 | __ |
| Six Sigma | 0,689 | __ |

The graphic representing the components after rotation (Figure 4.2) can also be an intuitive support for the allocation of variables to factors, which is the representation of the values of the rotated matrix components. Its interpretation is simple in this case where only 2 components are being analyzed. For interpretation, only is necessary to consider those variables that are near the extremes of the horizontal line (0,0) to find the variables that belong to the component 1 (represented by the symbol "o"). On the other hand, those who are near the extremes of the vertical axis (0,0) match component 2 (symbolically represented by stars). Therefore, through Figure 4.2 can be identified five variables for the first component (Methods for optimizing of changeover time, TPM, Method of 5S, Standardized and detailed work instruction, Methods for continuous process improvement) and four variables for the second component (Methods of Value Stream mapping/Design, Production controlling by pull principles, TQM, Six Sigma).

Table 4.10 - Rotated Component Matrix. Lean variables

| Lean Practices | Component | |
|---|---|---|
| | 1 | 2 |
| Methods of Value Stream mapping/Design | __ | ***0,826*** |
| Production controlling by pull principles | 0,365 | ***0,562*** |
| Methods for optimizing of changeover time | ***0,588*** | 0,513 |
| TPM (Total Preventive Maintenance) | ***0,616*** | 0,411 |
| TQM (Total Quality Management) | 0,414 | ***0,705*** |
| Method of 5S | ***0,793*** | __ |
| Standardized and detailed work instruction | ***0,768*** | __ |
| Methods for continuous process improvement | ***0,603*** | __ |
| Six Sigma | 0,447 | ***0,538*** |

The component score is a composite measure created for each observable variable for each extracted component. The weights of components are used in combination with the values assigned to variables (observations) in order to calculate the score of each variable, or in this case, a group of variables that construct the Lean Index. For each case and each component, the component score is calculated by multiplying the values of the standardized coefficients scoring of the component variables. The values of the standardized variables are calculated using the observed responses in each respective variable by subtracting the mean and then dividing the total by the respective standard deviation (this procedure is automatically calculated by SPSS based on listwise exclusion procedure which was taken in the initial assumptions to run the analysis). Table 4.11 presents the results of Component Scores Coefficients. It can be observed, in agreement with the conclusion drawn from Table 4.10 and Figure 4.2, when selecting for each variable the highest value score which variables are related to each component.

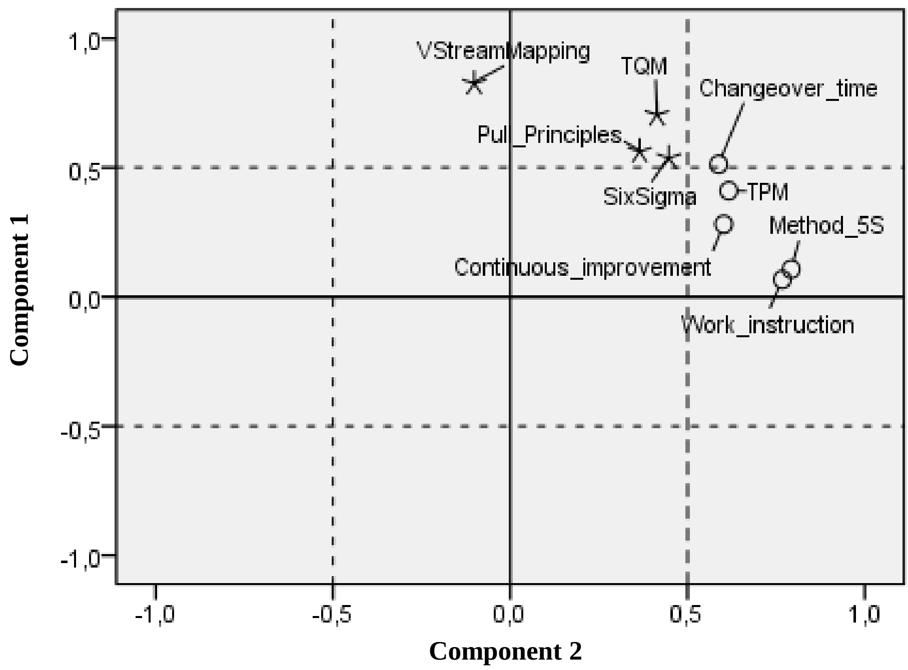
With component 1 are related four variables, are they:

- Methods for optimizing of changeover time
- TPM
- Method of 5S
- Standardized and detailed work instruction

Regarding the component 2 are listed the following variables that are related to them:

- Methods for continuous process improvement
- Methods of Value Stream mapping/Design
- Production controlling by pull principles
- TQM
- Six Sigma

Through the individual scores of each variable then is possible to obtain the total score performance. In the case of Lean variables, the total score will be denoted by $S_L$. Using the highlighted values in Table 4.11 and the nomenclature assigned to the variables represented in Table 4.12, the construction of SL is given in Equation ( 4.1).




**Legend:**

**Value Stream Mapping:** Methods of Value Stream mapping/Design; **Pull Principles**: Production controlling by pull principles; **Changeover time:** Methods for optimizing of changeover time; **TPM:** TPM (Total Preventive Maintenance); **TQM:** TQM (Total Quality Management); **5S:** Method of 5S; **Work instruction:** Standardized and detailed work instruction; **Continuous improvement:** Methods for continuous process improvement; **Six Sigma:** Six Sigma

Figure 4.2- Rotated component plot. Lean Variables

Table 4.11 – Components Score Coefficients. Lean variables

| **Lean Practices** | **Component** | |
|---|---|---|
| | 1 | 2 |
| Methods of Value Stream mapping/Design | -0,352 | ***0,588*** |
| Production controlling by pull principles | -0,002 | ***0,245*** |
| Methods for optimizing of changeover time | ***0,138*** | 0,132 |
| TPM (Total Preventive Maintenance) | ***0,190*** | 0,053 |
| TQM (Total Quality Management) | -0,026 | ***0,322*** |
| Method of 5S | ***0,395*** | -0,212 |
| Standardized and detailed work instruction | ***0,396*** | -0,230 |
| Methods for continuous process improvement | ***0,229*** | -0,028 |
| Six Sigma | 0,052 | ***0,198*** |

Table 4.12 – Lean variable score designation

| Variable Name | Variable total score name |
|---|---|
| Methods of Value Stream mapping/Design | $S_{L1}$ |
| Production controlling by pull principles | $S_{L2}$ |
| Methods for optimizing of changeover time | $S_{L3}$ |
| TPM (Total Preventive Maintenance) | $S_{L4}$ |
| TQM (Total Quality Management) | $S_{L5}$ |
| Method of 5S | $S_{L6}$ |
| Standardized and detailed work instruction | $S_{L7}$ |
| Methods for continuous process improvement | $S_{L8}$ |
| Six Sigma | $S_{L9}$ |

$$S_L = 0{,}588\, S_{L1} + 0{,}245\, S_{L2} + 0{,}138\, S_{L3} + 0{,}190\, S_{L4} + 0{,}322\, S_{L5} + 0{,}395\, S_{L6} + 0{,}396\, S_{L7} + 0{,}229\, S_{L8} + 0{,}198\, S_{L9} \quad (4.1)$$

## 4.5 Output - Green Data Analysis

To analyze the variables related to Green, it was used the same procedure taken in the case of the Lean variables analysis described in previous section (section 4.4). Then, similarly to the procedure taken in section 4.4, can then be initiated the analyze of the generated output by presenting the matrix of correlations (Table 4.13), as well as the metrics that validate the application of FA to data, or the results of the KMO test and Bartlett's Test.

Table 4.13 - Green Correlation Matrix

| | **Control_system** | **Recuperation** | **Bi_Trigeneration** | **ISO14031** | **ISO50001** |
|---|---|---|---|---|---|
| **Control_system** | 1,000 | 0,086 | 0,288 | 0,367 | 0,265 |
| **Recuperation** | 0,086 | 1,000 | 0,175 | 0,021 | 0,023 |
| **Bi_Trigeneration** | 0,288 | 0,175 | 1,000 | -0,077 | -0,062 |
| **ISO14031** | 0,367 | 0,021 | -0,077 | 1,000 | 0,472 |
| **ISO50001** | 0,265 | 0,023 | -0,062 | 0,472 | 1,000 |

**Control_system:** Control system for shutdown of machines in off-peak periods; **Recuperation**: Recuperation of kinetic and process energy; **Bi_Trigeneration**: Combined cold, heat and power (Bi-/Trigeneration); **ISO14031:** ISO 14031 certification; **ISO50001:** ISO 50001:2011 certification.

Table 4.14 - Kaiser - Meyer – Olkin and Bartlett's tests results for Green data

| **Kaiser-Meyer-Olkin Measure of Sampling Adequacy** | | **0,555** |
|---|---|---|
| **Bartlett's Test of Sphericity** | Approx. Chi-Square | 33,758 |
| | Df | 10 |
| | Sig. | **0,000** |

It is observable that the value obtained for KMO is not comparable with the one that was obtained from Lean variables analysis and that was classified with good suitability of the sample for FA analysis. Although this value falls below 0,6, it is not less than 0,5. Even it is not a criterion that indicates that the suitability of this type of analysis is exceptional (or close to), it is not so low to exclude the performance of this type of analysis. This happens because the application of PCA is only considered as unacceptable when the KMO values are below 0,5. Taking this assumption, the FA method was considered applicable. Possibly this KMO value has become so low due to the small number of variables analyzed in the construction of the Green metric, however, since the KMO value is above the minimum recommended value is given to evidence that the sample size fits (even in the limit) to the FA. The Bartlett's sphericity test presents a similar level of significance to that obtained in the analysis of the Lean variables, being made the same analysis, thus providing no evidence for this indicator become a pretext for refusal the FA technique to achieve this analysis.

So, continuing with the analysis of the obtained output, and similarly to what was done for Lean variables, observing the data matrix of Total Variance Explained (Table 4.15), well as analyzing the Scree plot of Green Variables (Figure 4.3), it is possible to perform a critical analysis of the number of extracted components.

Table 4.15 - Total Variance Explained. Green variables

| **Component** | **Initial Eigenvalues** | | | **Extraction Sums of Squared Loadings** | | |
|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | ***1,760*** | 35,197 | ***35,197*** | 1,760 | 35,197 | 35,197 |
| 2 | ***1,284*** | 25,675 | ***60,872*** | 1,284 | 25,675 | 60,872 |
| 3 | 0,898 | 17,958 | 78,830 | __ | __ | __ |
| 4 | 0,587 | 11,732 | 90,562 | __ | __ | __ |
| 5 | 0,472 | 9,438 | 100,000 | __ | __ | __ |

Based on the Kaiser criterion can be observed two significant components since only these two present eigenvalues higher than 1. Using a criterion that selects the factors, based on the cumulative percentage of the variance, two factors also appear to be a satisfactory choice since it accounts, like in Lean variables analysis case, for around 60% of the variability. On the other hand, and meeting the other two criteria, the analysis of the Scree plot (Figure 4.3), can also check the indication for extracting two components. After a preview of this image, it can be appreciated that this graph does not allow such an intuitive analysis as the Scree plot of Lean variables, not showing the typical "elbow" that represents the number of components to extract from. However, another graphical criterion indicated by Pestana & Gageiro (2005) can be used to determine the number of components to retain. The authors consider the slopes of the straights sections, this is a criterion that works quite well in this particular case, since this graph is not noticeable a point where the curve begins a horizontal stabilization. Thus, viewing the Scree plot it is possible to identify the section that ends at the point that represents the component 2 as the line with greater slope, suggesting that should be extracted at most 2 components.

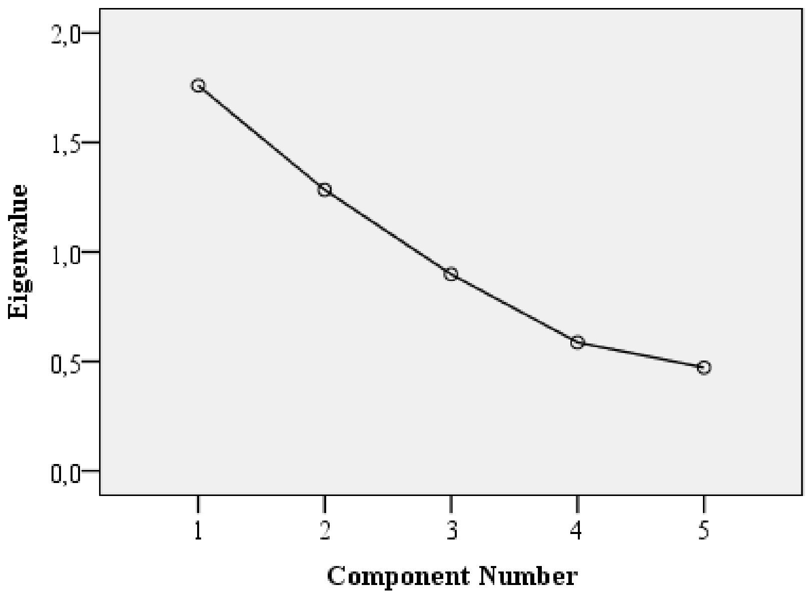



Figure 4.3 – Scree plot. Green variables

Table 4.16 shows the components matrix while the Rotated Components Matrix are represented in Table 4.17. From them can be drawn initial conclusions about what variables are associated with each extracted component being these values highlighted in Table 4.17.

Analyzing these indicators, it is hardly perceptible that there is a strong relationship between the *Control system for shutdown of machines in off-peak periods* variable and some of the obtained components, however the higher value for this variable is related to the component 1.

Table 4.16 - Component Matrix. Green variables

| Green Practices | Component | |
|---|---|---|
| | 1 | 2 |
| Control system for shutdown of machines in off-peak periods | 0,725 | 0,325 |
| Recuperation of kinetic and process energy | — | 0,557 |
| Combined cold, heat and power (Bi-/Trigeneration) | — | 0,823 |
| ISO 14031 certification | 0,796 | — |
| ISO 50001:2011 certification | 0,737 | -0,321 |

Table 4.17 - Rotated Component Matrix. Green variables

| Green Practices | Component | |
|---|---|---|
| | 1 | 2 |
| Control system for shutdown of machines in off-peak periods | ***0,596*** | 0,525 |
| Recuperation of kinetic and process energy | — | **0,582** |
| Combined cold, heat and power (Bi-/Trigeneration) | — | **0,837** |
| ISO 14031 certification | ***0,847*** | — |
| ISO 50001:2011 certification | ***0,799*** | — |

This part of the analysis is not very relevant for the final result, since later it will be calculated the score matrix, which has an effective effect on the final result. Nevertheless this part of the analysis allows us to understand the meaning of each extracted component.

The analysis of Table 4.17 suggests that Control variables for system shutdown of machines in off-peak periods, ISO 14031 certification and ISO 50001: 2011 certification are related to the factor 1 while Recuperation of kinetic energy and process and Combined cold, heat and power (Bi / trigeneration) are related to the factor 2. Once this is undertaking a subjective review, the investigator makes his own conclusions and decisions concerning the outputs he has. For this purpose, it is always necessary to have a critical analysis of the results obtained, because the generation of output is strongly correlated with the choices and assumptions made by the performer at an early stage of the process. Thus, by observing the matrix Components of Scores, and following the criterion that has been applied considering the highest values for each variable, we notice a slightly difference in the distribution of the variables over the components in relation to the previous matrix.

The *Control system for shutdown of machines in off-peak periods* variable, despite having similar values for both components will be weighted by the relative value corresponding to component 2 because this is the greatest value. Moreover, since the purpose of this analysis is to find the weights for each variable, is not so much to highlight issues relating to mathematics underlying this phenomenon. It is noteworthy that the association of this variable to the second component makes sense, since it relates variables that concern energy saving practices, while the first component includes variables concerning to certification according to the ISO standards.

Table 4.18 - Component Score Coefficient Matrix. Green variables

| Green practices | Component | |
|---|---|---|
| | 1 | 2 |
| Control system for shutdown of machines in off-peak periods | 0,319 | ***0,364*** |
| Recuperation of kinetic and process energy | -0,038 | ***0,443*** |
| Combined cold, heat and power (Bi-/Trigeneration) | -0,096 | ***0,642*** |
| ISO 14031 certification | ***0,500*** | -0,085 |
| ISO 50001:2011 certification | ***0,474*** | -0,115 |

Since from the beginning of the analysis, the reduced number of variables proved to be an issue to take into consideration (low KMO), in this context it may be a factor that has also led to this change during the course of analysis. However, it is noteworthy that it was possible to obtain a model for assigning weights to the variables, being those values highlighted in the previous table (Table 4.18).

As has been prepared for the construction of Lean index in section 4.4, the construction of the total score relating to the Green variables are essential for the construction of the Green Index. Applying the nomenclature shown in Table 4.19, as the coefficient of each variable obtained in Table 4.18, can be obtained the expression for Green variables total score ($S_G$) (Equation 4.2).

Table 4.19 - Green variable score designation

| Variable Name | Variable total score name |
|---|---|
| Control system for shutdown of machines in off-peak periods | $S_{G1}$ |
| Recuperation of kinetic and process energy | $S_{G2}$ |
| Combined cold, heat and power (Bi-/Trigeneration) | $S_{G3}$ |
| ISO 14031 certification | $S_{G4}$ |
| ISO 50001:2011 certification | $S_{G5}$ |

$$S_G = 0{,}364\, S_{G1} + 0{,}443\, S_{G2} + 0{,}642\, S_{G3} + 0{,}500\, S_{G4} + 0{,}474\, S_{G5} \qquad (4.2)$$

## 4.6 Indexes development

In this section the Lean and Green indexes will be developed using a methodology similar to Lau (2011). This methodology can be applied on this dissertation context, because Lean and Green practices will be used for the construction of the Lean and Green indexes and also because the data for each of them are derived from questionnaires. The methodology proposed by Lau (2011) is based on the following steps:

1. Selection of the practices that will be the model variables;
2. Application of PCA for assignment the weights to each variable;
3. Creation of the expression of Total Score Performance ($S$);
4. Calculations of the maximum and minimum value that $S$ can take ($S_{max}$ and $S_{min}$);
5. Creation of the index expression using the values of $S_{max}$ and $S_{min}$.

The base available for the creation of the indexes, take into account the practices previously proposed and the weights associated to these, which were estimated in previous section.

### *4.6.1 Lean Index*

Adapting the approach taken by Lau (2011) it is important to take into account the extreme values that $S_L$ can take. Once all Lean variables can be classified using scales that have a minimum value of 0 and a maximum value of 3, the minimum value that can be attributed to the overall score applying Equation ( 4.1 is $S_{Lmin}$ = 0 and the maximum is $S_{Lmax}$ = 8,103, as can be seen in Table 4.20. Note that $S_{Lmax}$ = 8,103 is the sum of all $S_{Lx}$ *(Max)*, where each $S_{Lx}$ value is calculate through the product between the variable score and the Maximum value of the variable scale. As an example consider $S_{L1}$ *(Max)* = 0,588 × 3 = 1,764.

Since this approach is adapted to this particular case, the expression which leads to the final index has a slight difference as to the expression described by Lau (2011). The author used a minimum scale value of 1, which leads to a minimum $S_L$ value different from zero. Thus, applying the value of $S_{Lmin}$ and $S_{Lmax}$ obtained by assigning values between 0 and 3 to Lean variables in the Lean total score expression (Equation 4.1) it can be obtained the parcels members of the Lean Index (*LI*) expression. The Lean Index proposed in this research presents a result which classifies the user on a scale of 10 points.

Table 4.20 - Maximum value for Lean Score

| **Variable total score name** | **Score** | **$S_{Lx}$(Max) (x=1,…,9)** |
|---|---|---|
| $S_{L1}$ | 0,588 | 1,764 |
| $S_{L2}$ | 0,245 | 0,735 |
| $S_{L3}$ | 0,138 | 0,414 |
| $S_{L4}$ | 0,190 | 0,570 |
| $S_{L5}$ | 0,322 | 0,966 |
| $S_{L6}$ | 0,395 | 1,185 |
| $S_{L7}$ | 0,396 | 1,188 |
| $S_{L8}$ | 0,229 | 0,687 |
| $S_{L9}$ | 0,198 | 0,594 |
| | $S_{Lmax}$ | 8,103 |

Variable total score name: $S_{L1}$: Methods of Value Stream mapping/Design; $S_{L2}$: Production controlling by pull principles; $S_{L3}$: Methods for optimizing of changeover time; $S_{L4}$: TPM (Total Preventive Maintenance); $S_{L5}$: TQM (Total Quality Management); $S_{L6}$: Method of 5S; $S_{L7}$: Standardized and detailed work instruction; $S_{L8}$: Methods for continuous process improvement; $S_{L9}$: Six Sigma

The expression leading to *LI* is described in Equation 4.3. The greater the *LI* value, the better the performance across all measures. Note that, similarly to what was proposed by Lau (2011), the value of $S_L$ is the global score obtained for the company whose performance on the Lean practices are being measured.

$$LI = \frac{(S_L - S_{Lmin}) \times 10}{S_{Lmax} - S_{Lmin}} \Leftrightarrow LI = S_L \times \frac{10}{8{,}103} \Leftrightarrow LI = S_L \times 1{,}234 \qquad (4.3)$$

The *LI* provides the company under assessment the value corresponding to its performance relative to the implementation of the Lean practices within the organization. The value obtained ranks the company on a scale from 0 to 10 points, where the value 0 means that the company does not implement at all, the Lean practices and the value 10 corresponds to the highest level of implementation of the underlying practices.

### *4.6.2 Green Index*

As can be seen in section 4.6.1, and making an analogy to the method used for the construction of *LI*, the construction of the Green Index is based on a similar approach. It is important to calculate the extreme values that $S_G$ can take. Again, like the procedure taken to build the Lean index, variables can be graded by the minimum and maximum values of 0 and 3, respectively. Applying Equation ( 4.2 and using the minimum and maximum values of the mentioned range, the $S_{Gmin}$ and $S_{Gmax}$ parameters ($S_{Gmin}$ = 0 and $S_{Gmax}$ = 7,269) are then obtained as presented in Table 4.21

Table 4.21 – Maximum value for Green Score

| Variable total score name | Score | $S_{Gx}$(Max) x = (1,…,5) |
|---|---|---|
| $\boldsymbol{S_{G1}}$ | 0,364 | 1,092 |
| $\boldsymbol{S_{G2}}$ | 0,443 | 1,329 |
| $\boldsymbol{S_{G3}}$ | 0,642 | 1,926 |
| $\boldsymbol{S_{G4}}$ | 0,500 | 1,500 |
| $\boldsymbol{S_{G5}}$ | 0,474 | 1,422 |
| | $S_{Gmax}$ | 7,269 |
| Variable total score name: $\boldsymbol{S_{G1}}$: Control system for shutdown of machines in off-peak periods; $\boldsymbol{S_{G2}}$: Recuperation of kinetic and process energy; $\boldsymbol{S_{G3}}$: Combined cold, heat and power (Bi-/Trigeneration); $\boldsymbol{S_{G4}}$: ISO 14031 certification; $\boldsymbol{S_{G5}}$: ISO 50001:2011 certification | | |

Applying the value of $S_{Gmin}$ and $S_{Gmax}$ obtained by assigning values between 0 and 3 (the minimum and maximum values of the scale) to Green variables in the index expression proposed by Lau (2011), also considering the proposed changes in the previous section, it is possible to achieve the Green Index (*GI*) by Equation
( 4.4).

$$GI = \frac{(S_G - S_{Gmin}) \times 10}{S_{Gmax} - S_{Gmin}} \Leftrightarrow GI = S_G \times \frac{10}{7{,}269} \Leftrightarrow GI = S_G \times 1{,}376 \qquad (4.4)$$

Similarly to *LI*, the application of *GI* provides a result that translates into a numbers, the companies' performance in implementing Green practices. It is intended that the results are the highest possible, i.e. achieving a result close to 10 shows a high degree of implementation of Green practices.

## 4.7 Application of the Lean and Green indexes to the inquired companies

It is interesting to apply the indexes created to real cases. As is described in section 4.2, the data used to Lean and Green indexes construction were retrieved from 62 valid responses from

Portuguese manufacturing companies to the EMS. Data from these companies' responses will be used to obtain the values for the Lean and Green Index to each one of them.

In Appendix C it is possible to find the overall results for each 62 company regarding to the Lean and Green Indexes. With the results obtained for each company, it is possible to group companies in five classes as shown in the Table 4.22.

Table 4.22 - Number of companies distributed by score classes

| Number of companies | | | | |
|---|---|---|---|---|
| **Score** | **Lean Index (*LI*)** | | **Green Index (*GI*)** | |
| [0;2[ | 23 | 37% | 49 | 79% |
| [2;4[ | 20 | 32% | 9 | 14% |
| [4;5[ | 8 | 13% | 1 | 2% |
| [5;6[ | 3 | 5% | 2 | 3% |
| [6;8[ | 5 | 8% | 1 | 2% |
| [8;10[ | 3 | 5% | 0 | 0% |
| **Total** | 62 | 100% | 62 | 100% |

For a better interpretation of the results distribution in Figure 4.4 and Figure 4.5 can be observed, the percentage of companies that are positioned in each class, respectively for the *LI* and *GI*.

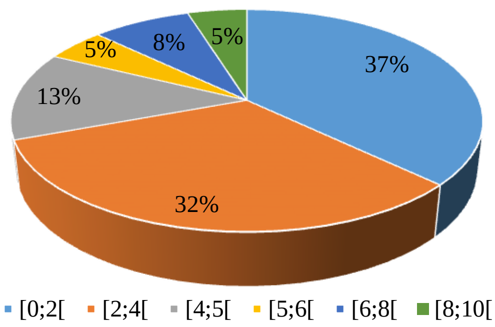



Figure 4.4 – Lean Index application. Distribution of companies by class

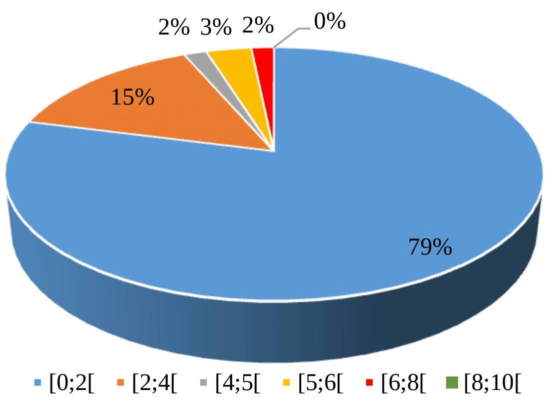



Figure 4.5 - Green Index application. Distribution of companies by class

The Lean and Green Indexes intend to achieve results as high as possible thereby translating a high level of performance in the application of paradigms in analysis. It becomes interesting to analyze the results in order to understand whether most of the participating companies were able to get positive results. Regarding the implementation of Lean practices, it is observable that only about 18% of the evaluated companies achieved a score between 5 and 10 points, where 10 would be the best possible outcome, and of those only slightly more than half, qualified with 8 or more points. It is not observable a large number of companies with high results concerning Lean practices.

In the same way companies were assessed for their level of implementation of practice concerning the Green paradigm. Regarding the implementation of the Green practices, the status does not appear to be better since only about 21% of companies achieved results above 2 points. Also noteworthy is that only three companies have achieved results above 5 points, without any of them has been able to obtain results with values above 8 points .

## 4.8 Conclusions

In this chapter using data obtained by the implementation of the EMS 2012 in Portuguese manufacturing companies, it was possible to obtain on the one hand, data about the implementation level of a number of significant practices of the Lean and Green paradigms and, moreover, to obtain weights for each one of those practices. Following an adaptation of the approach proposed by Lau (2011) and using the weights obtained for each of the practices, the expressions for Lean and Green indexes are proposed. The application of these indexes provides a value representative of the company performance regarding to the implementation level of the Lean and Green paradigms practices. The value obtained, ranks the company on a scale from zero to ten points.

# 5 Conclusions

## 5.1 Overview and discussion

With this study it is possible to highlight the importance and the impact that the application of Lean and Green practices can have on the companies' development, especially those that develop manufacturing activities. The adoption of Lean and Green practices have come over the years to play a key role in the growth of companies, assisting them in establishing a leading position in increasingly competitive markets.

The measurement of performance in the implementation of Lean and Green practices provides to managers the ability to understand if their policies are being effective so that the results correspond to expectations that they have about the company performance. It is vital for the successful implementation of Lean and Green practices in companies, that they have sense of their performance, since with this type of information companies have the opportunity to make reasoned decisions about changes in their management strategies, in order to the opportunity to improve their performance.

A comprehensive literature review was conducted (chapter 2) in order to understand which practices characterize the two paradigms, Lean and Green, and based on these practices to understand how this measurement can be performed. The composite indexes are useful tools in developing metrics being fairly simple to develop and implement. This type of index was chosen for the construction of expressions concerning Lean and Green Indexes proposed in this dissertation, in order to assess the degree of implementation of practices relating to these paradigms in Portuguese manufacturing companies.

To achieve the goal of constructing composite indexes it was followed a methodology based on the steps proposed by Nardo *et al* (2008), where the theoretical background played an important role as a starting point for the construction of Lean Index and the Green Index. After developing the theoretical basis that sustains the study, the data selection was a very simplified step because it was possible, through the data resulting from the implementation of the European Manufacturing Survey in 2012 in Portuguese manufacturing companies, get all the variables needed to start the process of indexes construction. Having all necessary data, following the methodology proposed by Nardo *et al.* (2008), it was performed an analysis phase, in which it was defined what kind of statistical methodology that could be used for the construction of the indexes expressions. Through the application of FA, the weights for each variable were obtained having been reached conditions to proceed with the aggregation of the variables. It was followed a methodology similar to the one adopted by Lau (2011) for variables aggregation. Two expressions for the proposed indexes were obtained being suitable for the available kind of data.

Since the expressions of the obtained indices reflect the context in which the data were obtained, therefore, it should be noted that since the data used for the indexes construction was obtained for the context of manufacturing Portuguese, a major limitation of this work is the fact that it is not possible to state that created indexes can be used in other contexts. In other words, it is not possible to say that the Lean Index and the Green Index are suitable for measuring the performance of the implementation of Lean and Green practices in companies that do not operate in the manufacturing sector or that are to the foreign companies.

The use of the EMS 2012 data supports the individual analysis of companies Lean and Green indexes. Few companies obtained high results, i.e. close to the maximum score (10 points) regarding to the Lean Index or the Green Index. However, the results were much more negative regarding to the calculation of the performance of companies in the implementation of Green paradigm. Concerning the implementation of Lean paradigm, it is observable that only about 5% of the evaluated companies were qualified with 8 or more points. In the context of the implementation of the Green practices, no company has achieved such a high result.

These results despite seemingly being so discouraging for Portuguese manufacturing companies, may indicate that the Lean and Green practices, despite already applied in business, can still be in a very early stage of development. This may be a positive indicator that the companies in Portugal still have a very large margin for progression showing great potential for development of these practices over the next years and the consequent development of the entire business context of the country.

Since it were obtained low results for the Lean Index and Green Index considering the companies surveyed, it would be interesting to continue this work through a study of Benchmarking. Since Benchmarking requires careful analysis and planning, it can be quite extensive so it is suggested its development in future work since there was no chance of its development during this dissertation. Benchmarking may come to be useful for companies, by conducting systematic and continuous surveys, comparisons and analyzes of practices, either processes, products and services, aimed at improving the management of the company, having as major goal the improvement of global company performance, particularly in the context of Lean and Green practices.

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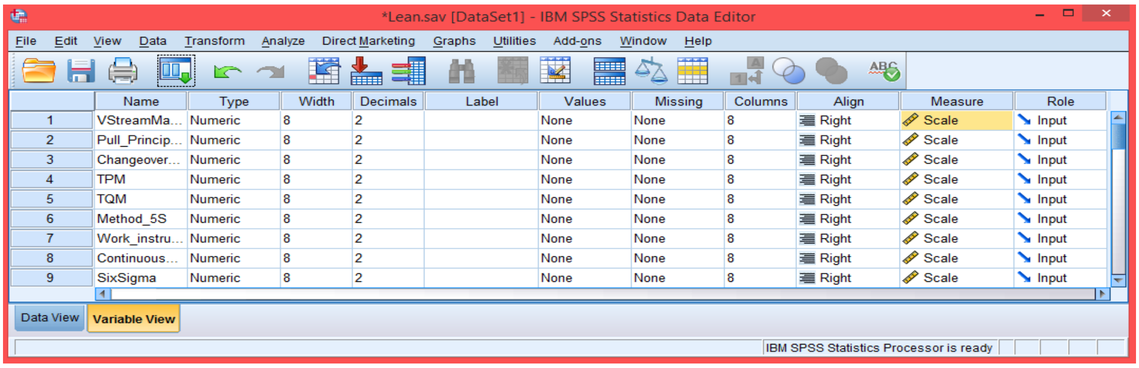
# Appendix A - Data analysis through Statistical Package for the Social Sciences

In this appendix, will be described, the procedure adopted for data analysis through the Statistical Package for the Social Sciences 20 software (SPSS 20):

As mentioned previously, PCA method is conceptually different from the FA, although often be used as alternatives to the FA. However, as also are methods for reducing the dimensionality, in SPSS, PCA can be found in Factor Procedure inside the package Dimension Reduction.

To be able to start the analysis with SPSS first it is need to perform data input correctly. The file containing the data is displayed in the data editor which in turn is constituted by the *Data View* and *Variable View*. In the *Data View* is where data is entered, and every column corresponds to a variable. In this case, each column will be where the data corresponding to each practice will be entered. Note that each line corresponds to all the answers given by a company (line 1 to 62). On the other hand, in the Variable View tab is where you can define the variables. This tab has columns designed to define or modify the characteristics of each variable, including information about each variable such as the name or type (numeric, string, money, ...), or information about the number of decimal places to display so as the definition of measurement (scale, ordinal or nominal) (Figure A. 1).




| | Name | Type | Width | Decimals | Label | Values | Missing | Columns | Align | Measure | Role |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | VStreamMa... | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |
| 2 | Pull_Princip... | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |
| 3 | Changeover... | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |
| 4 | TPM | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |
| 5 | TQM | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |
| 6 | Method_5S | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |
| 7 | Work_instru... | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |
| 8 | Continuous... | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |
| 9 | SixSigma | Numeric | 8 | 2 | | None | None | 8 | Right | Scale | Input |

Figure A. 1- SPSS Data Editor

After the characterization of the variables, the procedure to achieve the goal of PCA using SPSS is quite simple, being only necessary to introduce the assumptions considered for the analysis, by executing *Analyze* > *Dimension Reduction* > *Factor* (Figure A. 2).

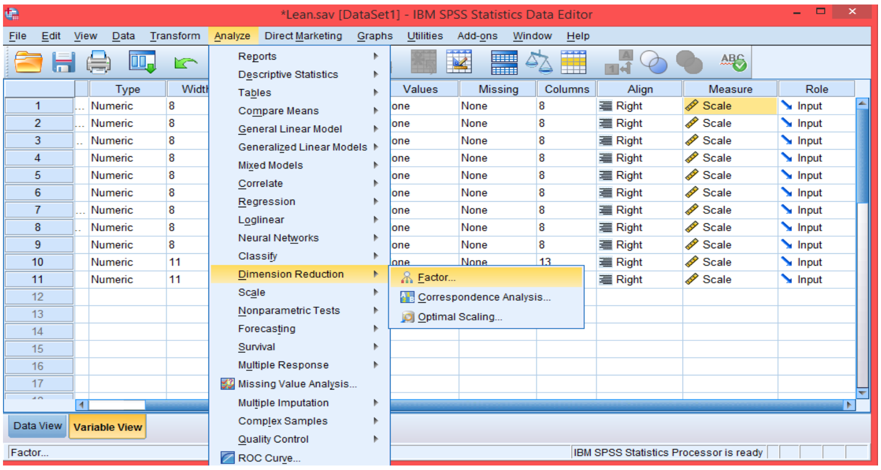



Figure A. 2 -Selecting PCA on SPSS

On factor analysis box, select all variables, can then establish the criteria of descriptive analysis, the method of extraction and rotation of factors, the method of allocation of scores as well as other options for viewing the data obtained by analysis (Figure A. 2).

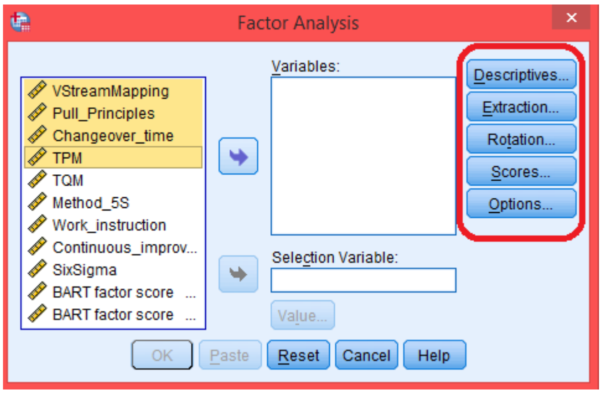



Figure A. 3 - Factor Analisys window

To be able to perform data analysis using SPSS, should be indicated in the program requirements in order to conform to the assumptions presented in Section 3.2.1.1. To this end, the program must be given the necessary information for it to be able to consider these and properly run the PCA analysis. However, note that the SPSS procedure for PCA is not linear (i.e., always to go through the steps it may be impossible to accept the result as the final results). Often it is necessary to rerun the steps, for example selecting different or additional procedure of SPSS to achieve the best possible solution.

In this study, PCA was performed using SPSS taking into account the assumptions set out below, selecting them through the choices shown in Figure A. 3.

In *Descriprive* option (Figure A. 4) was maintained the criterion Initial Solution in the options box of statistics, and in the *Correlation Matrix* options box were selected the items *Coeficients*, *KMO* and *Bartlett's test of sphericity*. In accordance with what was stated in Section 3.2.1.2, was chosen through the analysis of the correlation matrix instead of the covariance matrix. So, beyond indicating the choice of the method of principal components, in *Extraction* option (Figure A. 4), should be kept default options (*Correlation Matrix* and *Unrotated Factor Solution*) and chosen the scree plot option, to be possible to generate the scree plot in output. Was also selected in the *Extract* area, based on *Eigenvalues* option, indicating the choice of extracting *Eigenvalues greater than* 1.

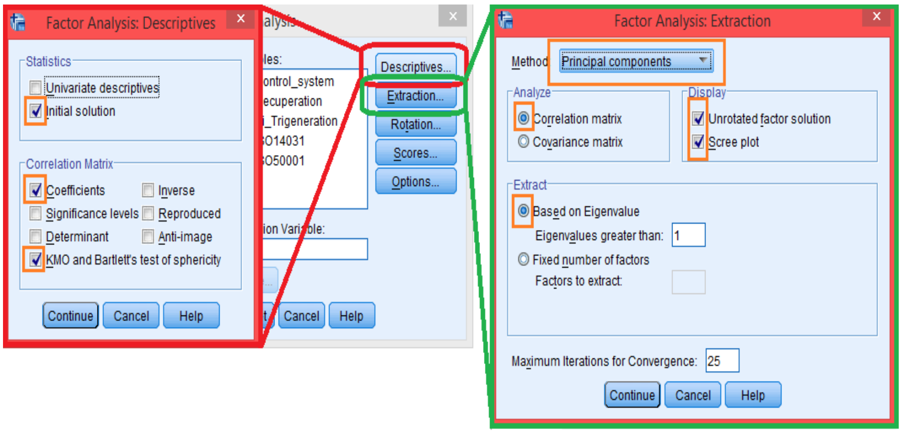



Figure A. 4 - Selecting the Descriptives and Extraction assumptions

In the *Rotation* dialog box (Figure A. 5) the method chosen is the *Varimax* rotation and should be selected in the *Display box* the *Rotated Solution* and *Loading Plot* options. In *Factor Score option*, for the present analysis was chosen *Barlett´s* method, moreover indicating the option Display factor score coefficient. In the last possible dialog-box , *Options*, the existing option was maintained (*Exclude cases listwises*) and was selected at *Coefficient Display Format* area, the option *Sorted by size*, so that the variables are ordered by score descending order, and also was selected the option S*uppress Small Coefficients*, indicating 0.3 in *Absolute value below* field. After these assumptions, it was then possible to generate the output for both Lean and Green variables.

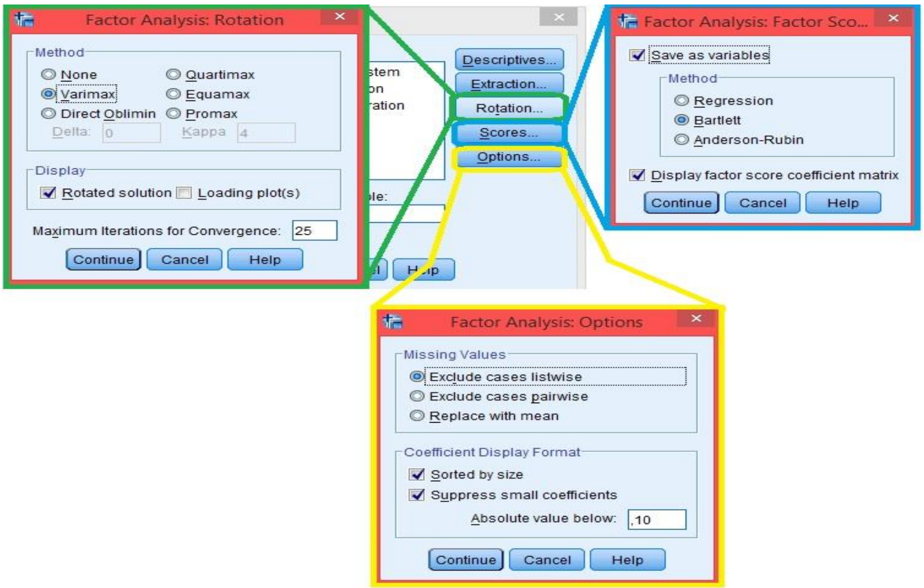



Figure A. 5 - Selecting the Rotation, Scores and Options assumptions

The output generated by SPSS is quite extensive and provides a lot of information about the examination. Below we briefly explain the seven steps you need to follow to interpret their results the PCA. Initially it is necessary to interpret the results in order to make sure that the data in the study are suitable for the use of the PCA. This includes the analysis of sampling adequacy, based on Measure Kaiser-Meyer-Olkin (KMO) and the adequacy analysis for dimensionality reduction with the Bartlett's sphericity test. The initial extraction of components is required. At this point, there will be as many components as variables. The focus should be on Eigenvalues early to get a general overview of the main components that should be extracted and the amount of the total variance each component explains. However, at this stage, it is important to be aware that there are not yet enough information to select the components, but also that the prod output produced is based on default options in SPSS that the user selects as described previously. Then there is the need to determine the number of 'significant' components that you want to keep in order to get a more simple structure, which means a structure where it is possible to have an easily observable variables distribution by components obtained. To be able to interpret the final solution should make the rotation of the factors. For such there is the need to interpret the final Total Variance Explained output from SPSS and Rotated Components Matrix. After these steps, it is possible to report the results. This should include all "relevant" decisions that were taken to perform the analysis (for example, the criteria used to extract components, what kind of rotation used, etc.). This is particularly important in the PCA because many subjective judgments are made along the way, which could have led to different results from the same data.

After completion of this analysis, the last step is assigning weights to each variable, taking into account the results obtained from the PCA.

# Appendix B – Excerpt from the European Manufacturing survey applied to Portuguese manufacturing companies

**155 [3.15]O) Sistema de controlo para desligar máquinas em períodos vazios ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**159 [3.15.4] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((**3.15.NAOK** == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**160 [3.16]P) Recuperação de energia cinética e de processo. Por exemplo, recuperação de calor ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**164 [3.16.4] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((**3.16.NAOK** == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**169 [3.17.4] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((**3.17.NAOK** == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**174 [8.1] A) <u>Métodos de mapeamento do fluxo de valor (VSM) / "Design"</u> ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**177 [8.1.3] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.1.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**182 [8.3] C) <u>Controlo da produção baseado em princípios "pull"</u>. Por exemplo, "stock" zero, Kanban ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**185 [8.3.3] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.3.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**186 [8.4] D) <u>Métodos de otimização de tempo de mudança de ferramenta</u>. Por exemplo, SMED ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**189 [8.4.3] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.4.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**190 [8.5] E) <u>Sistema de Manutenção Produtiva Total (TPM)</u>. Por exemplo, manutenção preventiva, manutenção pelos trabalhadores, planos de manutenção ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**193 [8.5.3] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.5.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**194 [8.6] F) <u>Sistema de Gestão pela Qualidade Total (TQM).</u> Por exemplo, zero defeitos, EFQM ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**197 [8.6.3] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.6.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**198 [8.7] G) <u>Metodologia 5S</u> ("Organização e limpeza do local de trabalho") ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**201 [8.7.3] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.7.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**202 [8.8] H) Instrução de trabalho detalhada e normalizada ("Trabalho standard") ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**205 [8.8.3] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.8.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**210 [8.10] J) Métodos para a melhoria contínua de processos. Por exemplo, Kaizen, círculos da qualidade ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

**213 [8.10.3] Estimativa do nível de utilização ***

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.10.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: "**Baixo**" para o nível correspondente à utilização inicial, "**Médio**" para uma utilização parcial e "**Elevado**" para um nível de utilização elevado.

**230 [8.15] O) Certificação ISO 14031. Auditoria ambiental ***

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

### 233 [8.15.3] Estimativa do nível de utilização *

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.15.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: “**Baixo**” para o nível correspondente à utilização inicial, “**Médio**” para uma utilização parcial e “**Elevado**” para um nível de utilização elevado.

### 234 [8.16] P) Certificação ISO 50001:2011. Auditoria energética *

Por favor, seleccione **apenas uma** das seguintes opções:

- É utilizada
- Não é utilizada

### 237 [8.16.3] Estimativa do nível de utilização *

**Responda a esta pergunta apenas se as seguintes condições são verdadeiras:**
° ((8.16.NAOK == "A1"))

Por favor, seleccione **apenas uma** das seguintes opções:

- Baixo
- Médio
- Elevado

Comparação do nível atual de utilização com o nível de utilização mais desejável: “**Baixo**” para o nível correspondente à utilização inicial, “**Médio**” para uma utilização parcial e “**Elevado**” para um nível de utilização elevado.

# Appendix C – Obtained results from Lean Index and Green Index applied to each company

| Company no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lean Index result | 2 | 2 | 2 | 7 | 6 | 3 | 2 | 5 | 4 | 5 | 3 | 3 | 4 | 4 | 0 | 0 |
| Green Index result | 1 | 0 | 0 | 1 | 0 | 1 | 2 | 4 | 4 | 0 | 2 | 0 | 2 | 0 | 0 | 1 |
| | | | | | | | | | | | | | | | | |
| Company no. | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| Lean Index result | 4 | 9 | 2 | 9 | 0 | 3 | 5 | 2 | 5 | 5 | 0 | 7 | 0 | 0 | 4 | 7 |
| Green Index result | 2 | 6 | 0 | 6 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 2 | 2 |
| | | | | | | | | | | | | | | | | |
| Company no. | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 |
| Lean Index result | 0 | 2 | 2 | 5 | 5 | 1 | 1 | 1 | 3 | 2 | 0 | 2 | 0 | 0 | 4 | 3 |
| Green Index result | 0 | 2 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 2 |
| | | | | | | | | | | | | | | | | |
| Company no. | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | | |
| Lean Index result | 1 | 3 | 3 | 7 | 0 | 2 | 0 | 0 | 0 | 3 | 3 | 1 | 2 | 9 | | |
| Green Index result | 1 | 6 | 3 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 4 | 0 | 0 | 4 | | |

Table C. 1 - Lean and Green indexes results for each respondent company