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Licenciado em Engenharia e Gestão Industrial

A Systematic Review Approach of Continuous Improvement Pillar Management Framework's

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

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Creativity, Challenge and Courage: the Three C's

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Abstract

Today's market is constantly changing, so companies are required to continuously evolve their processes so that they can meet the increasingly complex requirements of stakeholders, from customer needs to sustainable policies. The application of Business Process Management improves its processes, bringing together all the activities carried out by the company that aim to generate value for the client. As a consequence, one of the biggest problems for companies is the absence of information management and communication with internal and external stakeholders. Duplication and deprivation are very common in these companies and generate a huge amount of waste.

To solve this problem the developments done in this research work aims to generate a new way of looking to Business Management, focusing on companies that adopt Continuous Improvement, using a structured flow of tools and techniques. In structured approaches to Continuous Improvement management frameworks recurrently uses modelling support pillars. This study is based on a company that has implemented eight-pillar Total Productive Maintenance (TPM) and uses performance indicators to monitor the state of systems and processes. The first step involved the application of the Cluster, Discriminant and Principal Component Analysis, so that it was possible to aggregate the indicators of each pillar. The processes of strategic management of the company and management of the pillars have been taken into account.

Through the proposed approach a reduction of around 86% in the total number of pillar of the company was obtained, avoiding diverse informational wastes through redundancies of information, increased reliability, coherence and ease of access to it as well as greater visibilities of their interactions and information responsibilities necessary to the management of systems management of continuous improvement, based on pillars of action.

Keywords: Performance Indicators, Business Process Management, Cluster and Discriminant Analysis, Principal Component Analysis.

Resumo

O Mercado atual está em constante mudança, de modo que é exigido às empresas que evoluam continuamente os seus processos para que estes possam atender aos cada vez mais complexos requisitos das partes interessadas, desde as necessidades do cliente até às políticas sustentáveis. A aplicação da Gestão de Processos de Negócio melhora os seus processos, congregando todas as atividades realizadas pela empresa que têm por objetivo gerar valor para o cliente. Em consequência disso surge um dos maiores problemas das empresas, a ausência de gestão da informação e comunicação com as partes interessadas internas e externas. A duplicação e privação são muito comuns nestas empresas e geram uma enorme quantidade de desperdícios.

Para resolver este problema o desenvolvimento feito neste trabalho tem por objetivo gerar uma nova forma de olhar para a Gestão de Negócio, com foco em empresas que adotam a Melhoria Contínua, utilizando um fluxo estruturado de ferramentas e técnicas. Em abordagens estruturadas de gestão da melhoria contínua, são recorrentemente utilizados pilares de apoio estruturais. Este estudo é baseado numa empresa que implementou a Manutenção Produtiva Total (TPM- *Total Productive Maintenance*), com oito pilares, e utiliza indicadores de performance para monitorizar o estado dos sistemas e processos. A primeira etapa envolveu a aplicação das Análise de Clusters, Discriminante e de Componentes Principais, para que fosse possível agregar os indicadores de cada pilar. Os processos de gestão estratégica da empresa e gestão dos pilares foram tidos em consideração.

Através da abordagem proposta foi obtida uma redução de cerca de 86% no número total de pilares da empresa, evitando-se assim diversos desperdícios informacionais através de redundâncias de informação, aumento da fiabilidade, coerência e facilidade de acesso à mesma bem como uma maior visibilidades das suas interações e responsabilidades de informação necessária à gestão de sistemas de gestão de melhoria contínua baseados em pilares de atuação.

Palavras-chave: Indicadores de Performance, Gestão de Processos de Negócio, Análise de Clusters e Discriminante, Análise de Componentes Principais.

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List of Abbreviations, Acronyms and Symbols

AHP – Analytic Hierarchy Process

BD – Breakdowns

BMA – Business Management Assessment

BPI – Business Process Integration

BPM – Business Process Management

BPMS – Business Process Management Software

BPR – Business Process Reengineering

CAD – Computer-Aided Design

CAM – Computer-Assisted Manufacturing

CASE – Computer-Aided Software Engineering

CI – Consistency Index

CIL – Cleaning, Inspection and Lubrication.

CIP – Continuous Improvement Process

CSF – Critical Success Factors

DRE – Detail Reference Expression

FEO – For Exposition Only Diagram

ICAM – Integrated Computer-Aided Manufacturing

IT – Information Technology

KAI – Key Activity Indicator

KMI – Key Management Indicator

KMO – Kaiser-Meyer-Olkin statistic

KPI – Key Process Indicator

MDT – Mean Down Time

MTBF – Mean Time Between Failures

MTTR – Mean Time To Repair

PCA – Principal Component Analysis

PI – Performance Indicators

RI – Random Index

SADT – Structured Analysis and Design Technique

SE – Software Engineering

SDF – Structure Data Flow

SDM – Sequential Design Method

SBM – Simultaneous Business Method

SMT – Senior Management Team

SSCP – Pure Sums of Squares and Cross Products Matrix

TOC – Theory of Constraints

TP – Thinking Process

TPM – Total Productive Maintenance

TQM – Total Quality Management

VSM – Value Stream Mapping

WIP – Work in Process

1 Chapter – Introduction

1.1 Content & Scope Research

Since we are living in a market of continuous change, with the introduction of new productive processes, technologic innovations and with less than two years product life cycle, companies are demanded to constantly adapt so they can meet their client's needs.

Also the degree of competitiveness is increasing and there is an increasing competition even in sectors and areas of business where before there was only a small number of Leading Companies, which aligned with the change of client needs, who want customized products, demanded companies to be more flexible so it is possible to produce a large number of "versions" of the final product, with features that go towards getting the greatest possible satisfaction of the customers.

With this in mind it is increasingly vital that companies have a management of all systems that not only meet customer requirements, but also the entire universe of stakeholders. Those management systems are needed in order to carry company's business management policies, objectives and methodologies that allow the improvement of the organization's performance, setting goals, making the verification, monitoring and implementing corrective and preventive actions that aim the premise of Continuous Improvement.

"Value and Risk management enables organizations to succeed in the delivery of ambitious projects by defining their desired outcomes and then exercising processes that maximise value and minimise uncertainty.

A successful outcome requires that the value to the business is maximized through the delivery of a facility that gives them the benefits they need at a price they can afford at the time when they need it at a quality that fulfils their expectations" (Dallas, 2006, p. 1).

This work aims to elaborate a systematic analysis of performance indicators adopted in infrastructural pillar management continuous improvement system, congregating different types of decision and management tools, in order to stimulate new ways of looking to Process Management.

1.2 Objectives

This proposal was based on the premise that it is possible to implement pillar structures on process management that can facilitate the information and communication between stakeholders, intern or extern to the company, by eliminating excess of information, duplication of procedures/information and redundancy.

A Proposed Business Model will than flow after this process is accomplished and it will be based on a company that applies one Continuous Improvement Process approach, for this case TPM (Total Productive Maintenance). The pillar revision will generate a new pragmatic and focalized vision of companies' information, so it will be possible to filter the information across all the distinctive areas of business.

To provide a more accurate entrepreneurial modelling the research will focused on the companies' Performance Indicators in used, specially having in mind if it is possible to cluster them in larger groups so the information can be rapidly acknowledge by all interested parts. By doing this it will generate a more effective and efficient Managing System for each company.

1.3 Research Study Approach

The applied research approach to develop this work is shown in Figure 1.1, where a flowchart is presented to more easily depict the structure of this research.

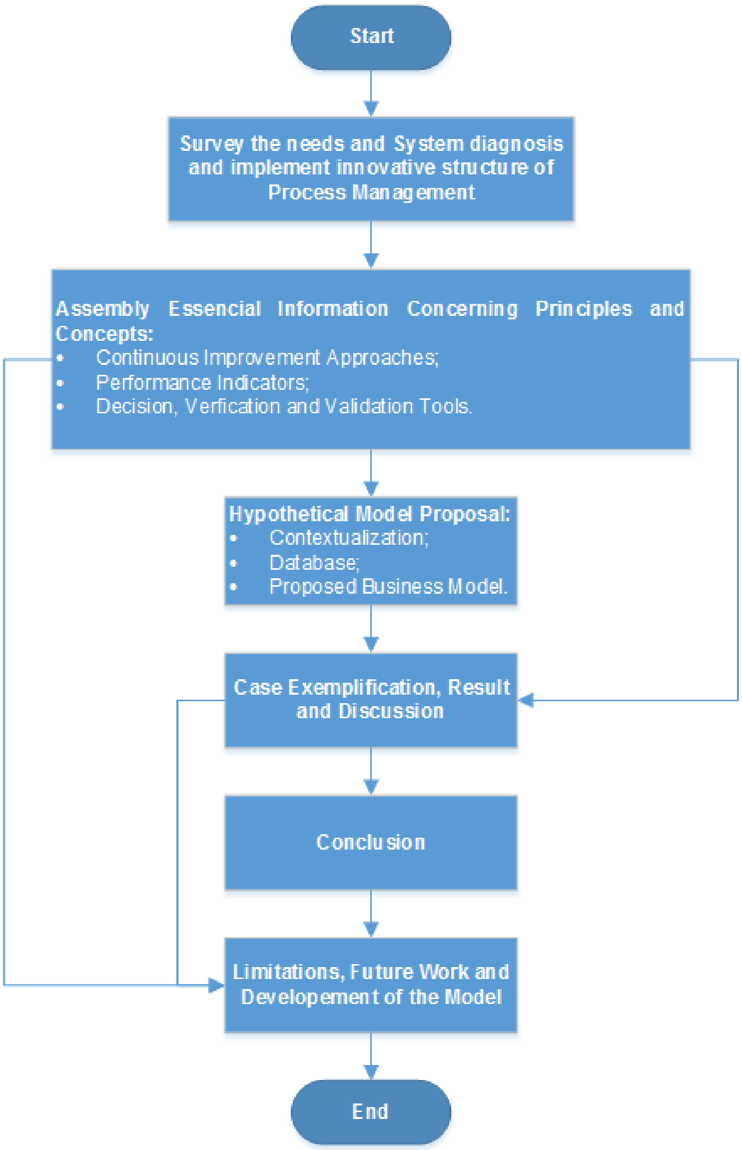

Figure 1.1 - Research Methodology Flowchart

Having set forth the objective of this thesis, this work advances with the Research Study Approach that will be utilized to allow the completion of the Proposed Model described and consequent result obtained from the Business Process Management (BPM) Case Exemplification.

The first stage of this process is the assembly of essential information related to the principles and concepts being revised and the identification of all available techniques that are helpful when managing business.

The first step of this stage begins by collecting information about Managing Business, regarding the existing proposals to manage them, and also information that concerns the different approaches of Continuous Improvement of Processes (CIP). The tools from the CIP are then compared and discussed so it can be possible to acknowledge the existing needs.

Next, the Performance Indicators (PI) are identified and characterized to recognize the importance of this measures when diagnosing the system and the processes that need to be improved.

To help the decision, verification and validation when addressing PI's and Systems Management certification, information about Decision tools for business modelling was then gathered and depicted in the final step of this stage.

After this stage a Proposed Model is presented with the implemented Methodology and designed structure of Process Management. The contextualization and the collected dataset are defined. This stage is necessary to know the company status, concerning the different Managing Systems, in order to be able to make a diagnosis and to survey the needs that are essential to the development of this work.

Subsequently, to the Proposed Model depiction, a BPM Case exemplification is addressed so it is possible to validate the former stage of this work and also to create a new characterization of the process with an innovative technique that allows the optimization of the system.

Finally, bearing in mind the previous step, result analysis and discussion are done. Conclusions, advantages and future work will be address and verified about the implementation of this new Model.

1.4 Thesis Structure

The purpose of this chapter is to describe how the dissertation was structured. Having this in mind the current work was divided in five distinctive Chapters.

The first Chapter objective is to give a prime description of what is the study undertaken in this work. It starts with an introduction of the content and scope research, depicting the characteristics of this work. The next step describes the considerations about what are the truly significant objectives and acknowledges the main focus of this paper. The third step is the research study approach applied, that originated this dissertation, and the last step is the chosen structure of chapters for the present work.

On the second Chapter is presented a succinct description of the Business Process Management and the Continuous improvement approaches, with reference to the respective characteristics, tools and techniques. Also in this chapter there is a depiction of Performance Indicators, System Certification and Decision tools, all of these correlated with Business Modelling.

The third Chapter features the full structure of the proposed Business Model Assessment. This chapter begins with the proposed contextualization followed by a diagram representing the flow of the implemented methodology. Then all the dataset is described and commented with the help of figures and tables. The chapter concludes with the development of the proposed Model, always considering the information obtained in the second Chapter.

On the fourth Chapter is depicted the BPM Case exemplification with the application test of the Model presented in the previous one. In this Chapter terminus the obtain results are shown, compared and discussed.

The fifth Chapter presents the main Conclusions of the study that can demonstrate the validation of the Model proposed. The Model Limitations are described and the Future Work and Developments for this project are suggested, followed by the research reference list and supporting appendixes.

2 Chapter – Continuous Business Management

Nowadays, the basic element that defines a company's' business strategy is market competitiveness. Companies aim to be more competitive regarding prices, quality of the product/service, productivity, location, time-to-market, customer and supplier portfolios, due to the importance that these factors have in differentiating them from their peers.

"*Organizations are looking out for inspired leadership and people with far-away vision to bring about fundamental changes both within and outside the firm in order to grow, build and excel in the twenty first century"* (Rao & Srinivasulu, 2013, p. 74).

Organizations also depend upon teamwork efforts. This requires understanding the interdependencies among team members and using them effectively in order to achieve the common goal (Mission) (Cardona & Wilkinson, 2006).

Other relevant area in an organization is the process management. A process can be defined as a sequence of interrelated events or activities that are carried out by the company's various areas of activity, consuming various resources to convert one or more raw materials into one final element with added value. It involves the transformation of inputs in outputs (Mallar, 2010).

There are two different types of processes (Mallar, 2010):

1. **Business Processes** are the ones that directly serve the mission of the business and satisfy the customer's specific needs and can be classified as:
    - **Strategic management processes** – those that through which a firm or a joint direction of a network, plan organize, direct and control resources.
    - **Operative or Key Processes** – those that impact directly on the customer's satisfaction and on any other aspect of the mission of the organization.
2. **Strategic Processes** are the internal services necessary for business process, also called secondary processes.

A Business Process can be considered as a complete, dynamical and coordinated set of collaborative and transactional activities that deliver value to the customer (Smith & Fingar, 2007).

A business process starts with an event in which the plan to achieve the main goal is launched. It continues until every demand of the stakeholder, which initiated the first event, is fulfilled and the outcome of the process satisfies all parts involved. Activity is the major unit of work to be completed in achieving the objectives and performing actions specific to a process. Every activity has a supplier and a customer, whom can be internal or external. Internal processes are part of the organization and their activities take an input from a previous stage of the process or internal supplier which adds value to it and provides an output to the following work step or internal customer.

Business processes require the consumption of resources that can be inputs, such as raw materials and information about the requirements demanded by the customer, or equipment and people needed to transform the inputs. Also all processes must meet customer, organizational and applicable regulatory requirements. Their performance can be monitored and measured using controls and check points and the gathered data can be analysed to conclude whether any corrective action or improvement will be needed. This is shown in Figure 2.1.

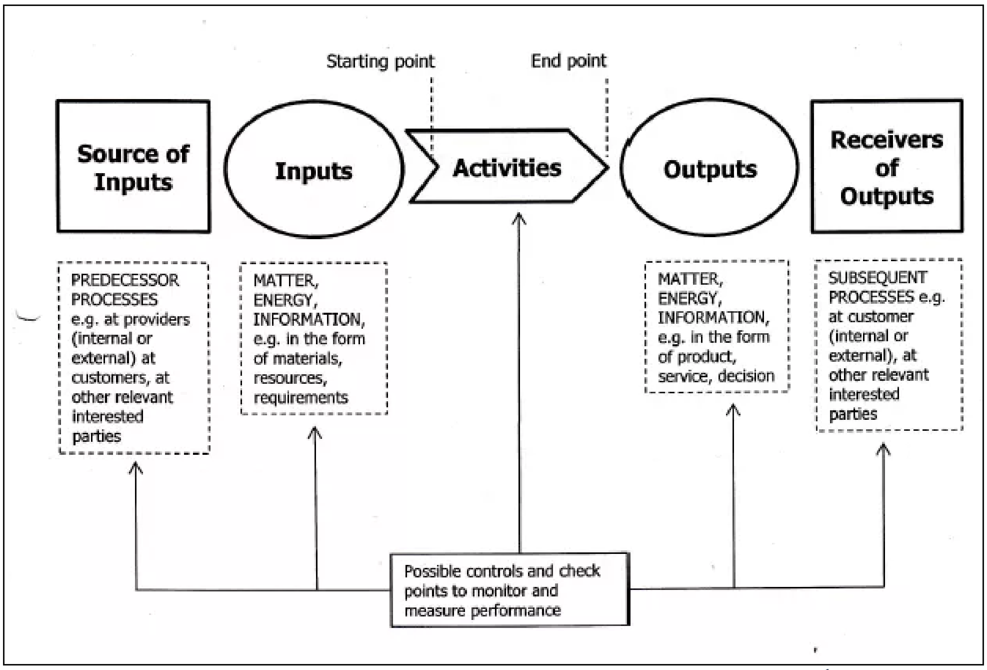

Figure 2.1 - Organizational Process Schematic Representation[1]

A true process comprises all the things that the company does to provide stakeholders with what they are expecting to receive. The process also contains all the actions that the company has to undertake when it fails to meet those expectations.

The processes are defined and managed in a structured way, and an improvement of each one is based on the improvement across the whole organization. Considering processes provides an integral vision that allows the understanding of the global activities (Mallar, 2010).

Management of Processes is to execute transformation projects that improve the products or services delivered to the customers. It is also the methodology that improves the company's day-by-day in and sorted and systematic way, with an approach that focuses the attention in optimizing every aspect of the various activities.

The main goal with this kind of management is to improve the processes efficiency, by maximizing the results interposing them with the resources consumed during the activities, and effectiveness, which relates the efficiency with the customer's satisfaction, and compares the outcomes obtained with the expected ones. It's also important to have in mind the satisfaction, *"which is the*

[1] Source: http://www.icrqa.net/icr/en/_system/system01.asp (Accessed 19/12/2017)

user's comfort with and positive attitudes towards the use of the system" (Frøkjær, Hertzum & Hornbæk, 2000, p. 345).

Efficiency and effectiveness are mutually reinforcing and their analysis relates the link between inputs, outputs and outcomes (Mandl, Dierx & Ilzkovitz, 2008).

Figure 2.2 shows a conceptual framework of efficiency and effectiveness.

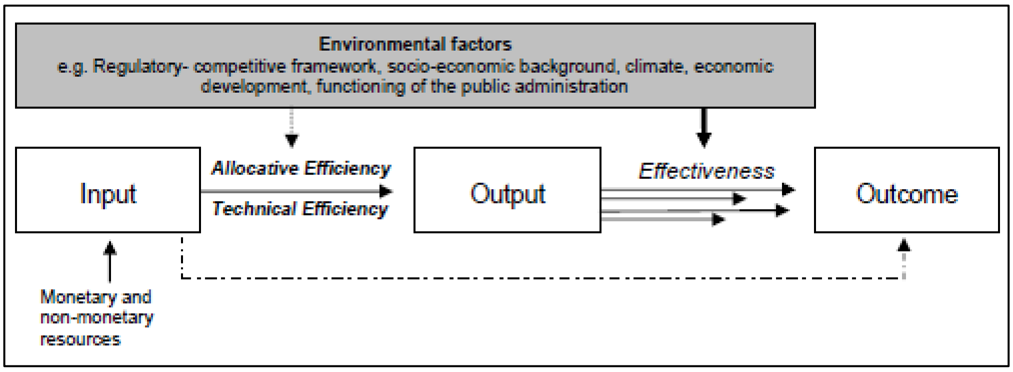

Figure 2.2 - Conceptual framework of efficiency and effectiveness

(Source: Mandl, Dierx & Ilzkovitz, 2008, p. 3)

Thus, the advantages in adopting Process Management are (Barros, 2003; Laurindo & Rotondaro, 2006):

- **Improve the Product or Service value that is delivered to the customer** – The Company is organized through a vision that favours the performance of its activities always based on the satisfaction of the customer, and all the functional areas are committed to this objective through the involvement in the processes.
- **Increase overall Efficiency** – Performance improvement is no longer only reflected by the automation levels of specific areas or sectors, but through processes that cross all functional areas, making the outcomes that each service must guarantee less abstract. Due to greater clarity of the outcomes obtained, there is an increase in the overall efficiency of the organization;
- **Increase Competitiveness –** Acting on competitive strategies that are considered relevant, such as costs, quality, flexibility and all the activities that add value to the product or service.
- **Costs Reduction** – Activities that do not generate valuable results in the framework of a lean process should be extinguished or considered secondary. The chain of activities has a tendency to narrow by nullifying information-generating intermediary activities that previously only ensured the transition of results. The objectives of each functional area are determined by the customer or product requirements and the outcomes from the processes are required to add value, thus eradicating secondary activities and reducing the costs.
- **Increase of the Communication and Information Sharing** – With process management the organization has its information align and consequently there is a

dynamically exchange of communication between all the functional areas, assuring that this information is accessible and comprehensible for downstream operations.

- **Continuous Improvement Enhancing** – An organization with process management has the possibility of aligning what actually is done in the company through a more intuitive way, which facilitates its comprehension and adhesion by all workers. Then again, working with various processes brings objective and visible results to the company which makes it possible to solve problems and create alternatives.

As a final point, Process Management modifies the structure of the company placing processes in the centre of the organization and aligns the organization's objectives. There are several essential elements that relate to Process Management that must be identified and considered. In general they are current processes, strategy, critical success factors, project team and control that are all linked as essential elements (Louzada & Duarte, 2013).

2.1 Continuous Improvement Process (CIP) Approaches

To achieve customers' requirements and strategy goals, for instance higher quality products, production flexibility and shorter delivery times, companies rely on Continuous Improvement Process (CIP).

CIP purpose is to optimize information, physical flows and products in order to control cost and quality, in order to improve companies' performance. This is accomplished with the involvement of all stakeholders, form suppliers to team managers and factory workers.

"Continuous Improvement is a systematic process of continuous and incremental improvements, supported in various tools previously established" (Mora, 2014, p. 121).

With the objective of being more and more competitive companies are always targeting reduced costs. Poor quality, downtime, low efficiency, scrap, overtime are also called Wastes, and the Continuous Improvement Process is focused on eliminating them.

CIP includes a number of principals, practices, techniques, and tools that have proven effective in fostering change for continuous improvement. The potential benefits of employing CIP are extremely vast, but require a long-term commitment, deliberate and thorough planning, coordination and cooperation (Mansir & Schacht, 1989).

As stated before, there are several approaches and techniques that support CIP individually or integrated, but for the purpose of this work the following ones will be depicted in the next chapters:

1. Total Quality Management (TQM);
2. Six Sigma;
3. Lean Thinking;
4. Total Productive Maintenance (TPM);

5. Theory of Constraints.

2.1.1 Total Quality Management (TQM)

Quality has been an important issue for organizations for many years. The early focus on quality evolved from inspection to quality control and later to quality assurance (Dale, 1999).

Quality management evolved through different stages in the last several decades such as inspection, control, assurance and TQM (Basu, 2004).

Total Quality Management (TQM) can be defined as a continuously evolving management system consisting of values, methodologies and tools, the aim of which is to increase external and internal customer satisfaction with a reduce amount of resources (Hellsten & Klefsjö, 2000).

TQM has been a dominant management concept for continuous improvement utilising Deming's basic concepts of PDCA. TQM can be define as a quality management system or a corporate culture continuously evolving and consisting of values and tools focusing on customer satisfaction and the use of fewer resources (Salah, Carretero & Rahim, 2009).

TQM is regarded as an integration of various processes characterizing the behavioural dynamics of an organization. For this, an organization is referred to as a total system, where all activities carried out are geared towards meeting the requirements of customers with efficiency and effectiveness (Lakhe & Mohanty, 1994)

The TQM approach differs from traditional management in the following ways (Lakhe & Mohanty, 1994):

- TQM focuses on customers absolutely. The firm customer focus brings competitive edge to the organization;
- "Products conquer markets" is the basic edifice of TQM;
- TQM takes the view that profits follow quality, not the other way around;
- TQM views total quality as having multi-dimensional attributes;
- TQM creates goal-directed connections between customers, managers and workers. Everyone is motivated to contribute towards quality. TQM empowers each and every employee, regardless of the level, to find better ways to work. Traditional management, in contrast , is monolithic: workers work and managers manage the workers;
- TQM is process-oriented, as against the traditional result-oriented approach;
- TQM favours a long span of control, with authority pushed down almost to the lowest level, as against short spans and many layers of authority in the traditional management cultures. Accountability for quality is embedded at every level;
- TQM requires a multi-skilled workforce with job rotation, in contrast to division of labour.

There are seven quality tools frequently mentioned in the TQM literature. The seven quality tools are depicted as follows (Salah, Carretero & Rahim, 2009):

1. Control charts;
2. Histograms;
3. Check sheets;
4. Scatter plots;
5. Cause and effect diagrams;
6. Flowcharts;
7. Pareto charts.

TQM is viewed as a philosophy used by organization to drive Continuous Improvement Process (CIP) across its business activities (Short & Rahim, 1995).

2.1.2 Six Sigma

Six Sigma is a methodology for pursuing continuous improvement in customer satisfaction and profit. It is a management philosophy attempting to improve effectiveness and efficiency and it was created at Motorola, by Bill Smith, at 1986.

Six Sigma aims to eliminate waste and inefficiency, thereby increasing customer satisfaction by delivering what the customer is expecting. This methodology strive for improving processes, lower defect levels, reduce process variability, reduce costs, and increase customer satisfaction and increase profits, as TQM.

The central idea behind Six Sigma is that if it is possible for a company to know how many defects it has in its process, the company can systematically figure out how to eliminate them and get as close to “zero defects” as possible and specifically it means a failure rate of 3,4 parts per million, or 99,9997% perfect (Gupta, 2015).

The immediate goal of Six Sigma defect reduction and by consequence this leads to yield improvement, and higher yields greatly improve customer satisfaction.

Six Sigma defect reduction is intended to lead to cost reduction. It has a process focus and aims to highlight projects improvement opportunities through systematic measurement, usually supported by Sigma Projects implementations (Raisinghani, Ette, Pierce, Cannon & Daripaly, 2005).

Six Sigma represents a new wave of the quality management evolution towards operational excellence. The definition of TQM is different from that of the Six Sigma but it has a similar aim. Six Sigma has additional data analysis tools and more financial focus than what is found in TQM. TQM has a comprehensive approach that involves and commits everyone in a company while Six Sigma has a project management approach that is associated with a team (Salah, Carretero & Rahim, 2009).

Six Sigma and TQM show many similarities, however the package of quality tools, the attention to financial result, the sustaining of the gains, and the focus of the problem solving methods of projects are new approaches in Six Sigma, compared to other concepts in quality management (Andersson, Enriksson & Tortensson, 2006).

"TQM can be the holistic and comprehensive umbrella that reaches to all stakeholders and Six Sigma can be the extension that provides a strong structure for achieving process improvements" (Salah, Carretero & Rahim, 2009, p. 245).

2.1.3 Theory of Constraints (TOC)

Nowadays, companies struggle to survive in a global market, with global competitors. In order to gain advantage among their peers it is important that the company finds the best suitable philosophy that can accomplish their strategy.

Companies, whether in production or service areas, should be more focused on understanding their own structure in terms of the processes. Having that in mind Theory of Constraints (TOC), first pull forth by Eliyahu M. Goldratt in 1984, becomes an important methodology. This methodology is focused on the weakest link in the chain to improve the performance of the systems. According to Tenera (2006), four key dimensions can be identified for structuring TOC as a management philosophy. This is shown in Figure 2.3.

	Prescriptive Component	**Thinking Component**
	1. Concepts and Principles	**2. Logical Thinking Tools**
Strategic Component	- Main Concepts - General Principles (Fundamental questions and focusing steps) - Layers of Resistance to change	- Thinking Tools (CRT, CRD, FRT, NBR, PRT, TT) - Categories of Legitimate Reservation (CLR)
	3. Specfic Solutions	**4. Performance Measurements**
Operational Component	- Drum-Buffer-Rope (DBR) - Critical Chain (CC) - Buffer Management (BM) - V-A-T Analysis	- Throughput, T - Inventory, I - Operating expense, OE

Figure 2.3 - TOC Schematic Summary

(Source: Tenera & Abreu, p. 169)

As identified on the Figure 2.3 the TOC thinking process (TP) is becoming an important problem solving approach which is changing the way of thinking of managers (Simsit, Gunayn & Vayvay, 2014). In the context of the Thinking Process, Kendall (1998) highlights three pillars for thinking process success, namely:

1. **Policies;**
2. **Performance Measures;**
3. **Training.**

A constraint is defined as anything that can impose a limit to a system so that it can't achieve higher performance verses its goal. It is a process step that limits throughput.

The Theory of Constraints states that every system must have at least one constraint that limits the output of the process, by doing this it enables people to invent simple solutions to high complexity problems.

Goldrrat (1984) suggests two pre-steps before the Five Steps described in Table 2.1:

1. Definition of the system Goal;
2. Proper, global and simple Measures of performance;

After the Goal is identified it is important to identify which measurement will be used to judge progress. The measurement are, in terms of money are:

- **Throughput - T**. The rate which the system generates incomes through:
  $$T = \ Sales - Raw\ Materials - Purchased\ Parts$$
- **Inventory - I**. All the money the system has invested in purchasing materials with the intend to sell (i.e., raw materials, finished goods);
- **Operating Expense - OE**. All the money the system needs to spend in order to turn inventory into throughput (i.e., employee time, machine depreciation, scrap material, operating and maintenance expenses)

There are Five Steps in the Process On-going Improvement, called focusing steps for addressing system problems on a continuous improvement basis (Goldratt & Cox, 1984).

These steps are depicted in Table 2.1.

Table 2.1 - Goldratt's Five Steps

(Adapted from Mabin, 1999)

Steps	Description of the Steps
1 - Identify the Constraint	Identify the operation that is limiting the productivity of the system. This may be a physical or policy constraint.
2 - Exploit the Constraint	Focus on how to get more production within the existing capacity limitations. Achieve the best possible output from the constraint. Remove limitations that constrain the flow, and reduce non-productive time so that the constraint is used in the most efficient way possible.
3 - Subordinate other activities to the constraint	Link the output of other operations to suit the constraint. Smooth workflow and avoid build-up of WIP inventory. Avoid making the constraint wait for work form other machines or processes.
4 - Elevate the constraint	In situations where the system constraint still does not have sufficient output, invest in new equipment or increase staff numbers to increase output.

5 - If anything has changed, go back to step one	Assess to see if another operation or policy has become the system constraint. If the constraint has changed then go back to step one.

TOC provides approaches to operation decisions that avoid pitfalls of local optimization by reaching across functional boundaries in organizations (Gupta & Boyd, 2008).

In the context of Theory of constraints, the existence of four pillars has recently been discussed, namely[2]:

1. **Inherent simplicity** – Reliability Simple and Harmonious;
2. **Every conflict can be removed** – Don't accept conflict as given;
3. **People are good** – Win-Win is always possible;
4. **Never say I know** – The bigger the base the bigger the jump.

2.1.4 Lean Thinking

In the aftermath of World War II, Toyota faced a really daunting challenge as they had many problems related with the fact that Japan was a small and fragmented market, had worn-out workforce, scarce of natural resources and little capital. To change their fate Toyota's leaders had to come with a revolutionary paradigm of manufacturing excellence.

The result was the Toyota Production System (TPS). TPS is a consistent way of thinking and management philosophy that focus on (Liker, 2004):

- Total customer satisfaction;
- An environment of teamwork and improvement;
- A never-ending search for a better way;
- Quality built in process;
- Organized, disciplined Workplace;

Lean Thinking is based on the Toyota Lean model, which combines operational excellence with value-based strategies to produce steady growth through a wide range of economic conditions (Womack & Jones, 1996).

The central philosophy behind Lean Manufacturing is to provide superior quality products for more customers, at a significantly lower price, and to contribute to a more prosperous society. Lean is a philosophy, or way of thinking, with commitment to achieve a totally waste-free operation that is focused on customer success. It is achieved by simplifying and continuously improving all

[2] Source: https://elischragenheim.com/2015/12/11/is-toc-an-ideology-or-a-pragmatic-approach-discussing-the-pillars-of-toc/ (Accessed 05/03/2018)

processes and relationships in an environment of trust, respect and full employee involvement. It is all about people, simplicity, flow visibility, partnerships and true value as perceived by the customer.

Toyota created a structured system, a house, so it could be possible to see the fundamentals of the TPS. This is shown in Figure 2.4:

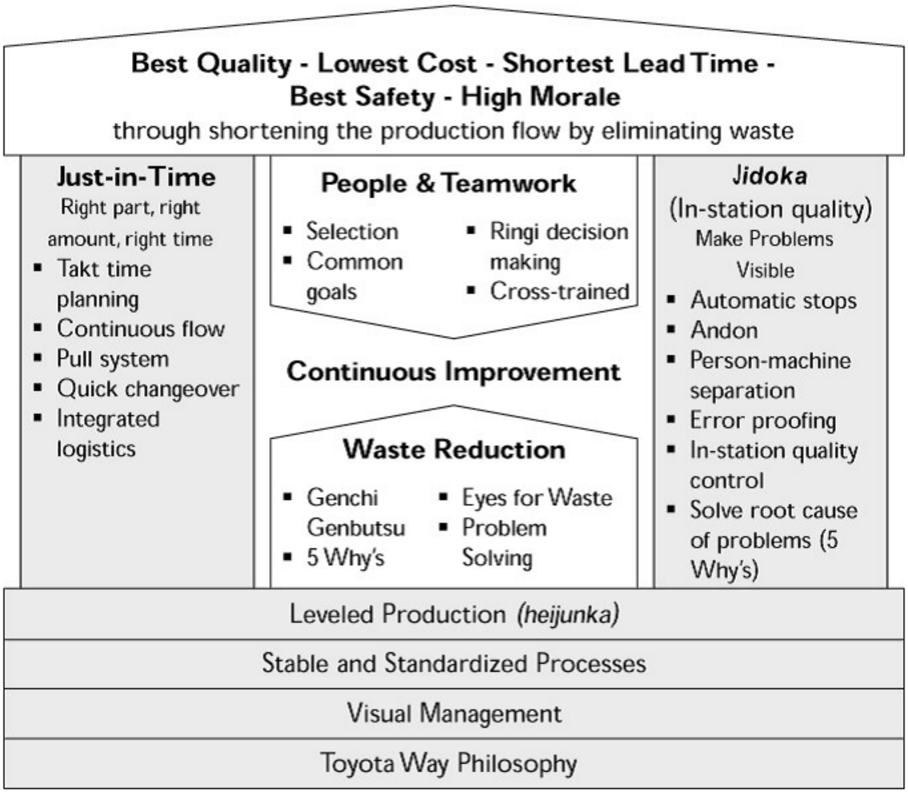

Figure 2.4 - The Toyota Production System House

(Source: Liker, 2004, p. 33)

There are five Lean fundamental principles (Womack & Jones, 1996):

1. **Value Specification**. Value is defined by customer in terms of specific products and services;
2. **Value Stream Identification**. Map out all end-to-end linked actions, processes and functions necessary for transforming inputs into outputs to identify and eliminate waste;
3. **Continuously Value Flow**. Having eliminated waste, make remaining value-creating steps flow;
4. ***Pull* System**. Customer's pull cascades all the way back to the lowest level supplier, enabling Just-in-Time (JIT) production;
5. **Pursue Perfection.** Pursue continuous process of improvement striving for perfection.

Value Added Activity is any activity, or action, that transforms or shapes raw material or information into a capability for the ultimate customer requirements at the right time and with the right quality (Nightingale, 2005).

Non-Value Added Activity is any activity that takes time, resources, or space but does not add value to the product, or service itself.

Waste is any activity that is time and money consuming but does not add value from the customer's perspective.

There are eight types of non-value-adding activities or wastes (Liker, 2004):

1. **Over production (without demand)**. Producing items from which there are no orders, which generates such wastes as overstaffing and storage and transportation costs because of excess inventory;
2. **Waiting (for next step of production)**. Workers merely serving to watch an automated machine or having to stand around waiting for the next processing step, tool, supply, part or just plain having no work because of stock outs, lots of processing delays, equipment downtime, and capacity bottlenecks;
3. **Unnecessary transportation (un-required movement of products)**. Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts, or finished goods into or out of storage or between processes;
4. **Over Processing (creates extra activity as result of poor design)**. Taking unneeded steps to process the parts. Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. Waste is generated when providing higher-quality products than is necessary;
5. **Excess of Inventory (components, WIP, finished product not being processed)**. Excess of raw material, WIP, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also, extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long setup times.
6. **Unnecessary Movement (un-required movement of people/equipment)**. Any wasted motion employees have to perform during the course of their work, such as looking for, reaching for, or stacking parts or tools;
7. **Rework/Defects (inspecting, repairing, redesigning)**. Production of defective parts or correction. Repair or rework, scrap, replacement production, and inspection mean wasteful handling, time, and effort;
8. **Unused Employee Creativity**. Losing time, ideas, skills, improvements, and learning opportunities by not engaging or listening to the company's employees.

A Lean tool that is going to be utilized in this work is the Value Stream Mapping (VSM). VSM is a very important tool when implementing Lean as it is a visual representation of every process in the products or services path, form the moment an order is made to the moment the product, or service is delivered.

Value Stream Mapping is a very useful tool especially because (Rother & Shook, 1998):

- It helps to visualize interactions and flows;

- It helps to identify wastes and their sources;
- It provides common language for business talking and makes decision flows apparent;
- Shows the linkage between information and material flows;
- Identifies the constraints of the process, any resource whose capacity is less than customer demand.

In the following chapter Total Productive Maintenance (TPM) will be depicted. TPM is mostly regarded as an integral part of Lean Manufacturing.

TPM as well as Lean requires employee’s involvement in all levels throughout the organization. Lean goals are not achievable without reliable machinery and processes, on the other hand, TPM is more effective in Lean driven enterprises (McCarthy & Rich, 2004).

2.1.5 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is defined as a company-wide, team-based effort to build quality into equipment and to improve productivity by reducing the time lost due to breakdowns.

In 1971, Nippon Denson Co., Ltd., a supplier of Toyota Motor Company, first introduced and successfully implemented TPM in Japan, by Seiichi Nakajima, that brings maintenance into focus as a necessary and vitally important part of business (Venkatesh, 2007).

Total Productive Maintenance has been developed from the original Preventive Maintenance concept and methodology introduced in the USA. It has been further developed and implemented in many Japanese companies, and is now rapidly becoming a method applied worldwide.

Total Productive Maintenance aims to increase productivity by reducing lost production time, increasing both available time for production and products quality, therefore increasing outputs from the process.

Also TPM seeks to maximize equipment effectiveness throughout the life of the machine. It strives to maintain the equipment in optimum condition in order to prevent breakdowns, speed losses, quality defects and accidents.

The Overall Equipment Effectiveness (OEE) is one of the key measures of TPM which indicates how efficiently the machinery and equipment is being run. OEE is a performance metric compiled from three data sources of the machine, or process, being measured. It compiles:

- Availability. Compares the actual time that a piece of equipment is available to produce parts in comparison to the planned available time;
- Performance. Compares the actual amount a product processed relative to the maximum amount that could be processed within the available production time.
- Quality. The proportion of the product from a process that is right the first time, that mean with no rework, scrap or non-conformities with tolerances;

TPM is based on eight key highly important strategies, also referred to as pillars, which include improved planning of maintenance activities, measurement of machine performance, continuous improvement and enhancement of safety. This pillars are represented in Figure 2.5.

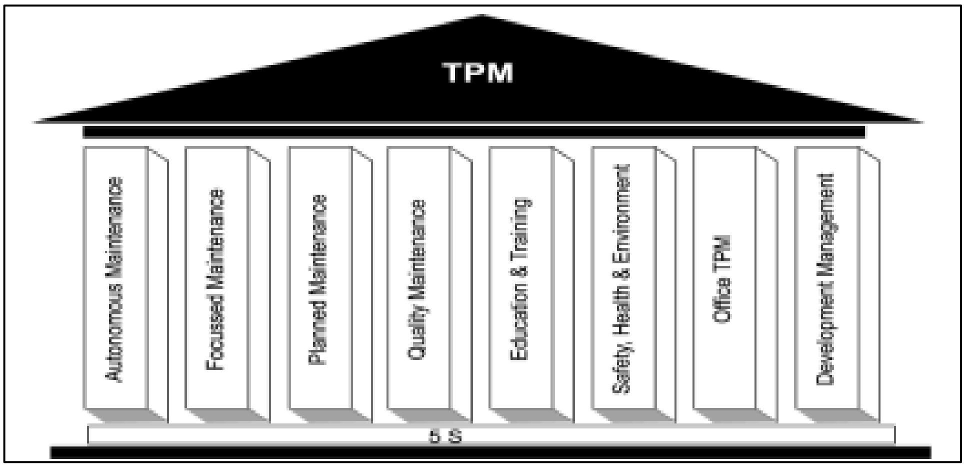

Figure 2.5 - TPM pillars

(Source: Rahman & Hoque, 2014, p. 20)

The ultimate aim of each of the pillars is the elimination of all losses. The pillar approach is a way to manage change and a rigorous methodology to ensure that the company can sustain results to the future. The depiction of the pillars is shown in Table 2.2.

Table 2.2 - The 8 pillars of TPM

(Adapted from Venkatesh, 2007).

Pillars	Description
Autonomous Maintenance (AM)	It follows a structured approach to increase the skill levels of personnel so that it is possible to understand, manage and improve their equipment and processes.
Focussed Maintenance or Improvement (FI)	It provides a structured, team-based approach to drive elimination of specifically identified losses.
Planned Maintenance (PM)	Objective of achieving zero breakdowns. It follows an approach to establish management system that extends the equipment reliability at optimum cost.
Quality Maintenance (QM)	Zero defect conditions. It aims to prevent defects from being produced, rather than installing inspections systems that detect the defects after the manufacturing process.
Education & Training (ET)	It ensures that the workers are trained in the skills identified as essential, both for their personal development and successful deployment of TPM.

Safety, Health & Environment (SHE)	Zero Accidents. It aims to eliminate the problem root causes, prevent reoccurrence, and reduce the risk of potential incidents, targeting near misses and potential hazards
Office TPM	It applies eliminating waste and losses to administrative and support functions departments.
Development Management or Early Management (EM)	It aims to implement and develop new products and process with vertical ram up and minimised development lead times.

A variety of tools are often utilized through TPM programs based on these eight pillars. Some of the tools use by Total Productive Maintenance and Lean Thinking are 5S, Pareto's Diagram, Statistical Process Control, Brainstorming, Ishikawa's Diagram, 4M approach, One-Point-Lesson (OPL), Standard Operation Procedure (SOP).

Problems cannot clearly be see when the workplace is unorganized. Cleaning and organizing the workplace helps workers to uncover problems. Making problems visible is the first step for improvement. TPM starts with 5S tool that is often used during the plant cleaning activities and is a systematic method to organize, order, clean and standardize a workplace. 5S like other improvement techniques requires both employee's involvement and management commitment. The features of 5S are depicted in Table 2.3.

Table 2.3 - 5S Depiction

5S Japanese	5S English Translation	Description
Seir	Sort	It means sorting and organizing the items from the workplace is crucial.
Seiton	Set in order (Organize)	It means that the items should be arranged in order and placed back after usage at the same place they were taken from.
Seiso	Shine	It means cleaning the workplace of all dirty particles (i.e. grease, oil, dirt, scrap). Also no loose wires or oil leakage.
Seiketsu	Standardize	It means that workers must decide on standards for workplace organization and housekeeping. This is implemented in the whole company and randomly inspections are taken.
Shitsuke	Sustain (Self Discipline)	It means employees should be trained for accomplishing good workplace organization autonomously

2.2 Performance and Assessment Systems Indicators

When a strategy is being defined in a company, one of the most difficult tasks this organization as to face is the development of significant objectives and their associated KPIs (Key Performance Indicators). Without the implementation of a good methodology, creating company's objectives and KPIs, an organization's strategy will never be effectively executed.

The selection and monitoring of the KPIs has become an important part of company's business as it is critical to the continuous improving strategy and increasing organization's competitiveness.

Key Performance Indicators (KPIs) help organizations understand how well they are performing in relation to their strategic goals and objectives. In a largest sense, a KPI provides the most important performance information that enables organizations or their stakeholders to understand whether the organization is on track or not (Marr, 2010).

KPI represents a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization.

David Parmenter (2007) states that there can be defined seven KPI characteristics:

1. Nonfinancial measures;
2. Measured frequently;
3. Acted on by the CEO and Senior Management Team (SMT);
4. Understanding of the measure and the corrective action required by all staff;
5. Ties responsibility to the individual or team;
6. Significant impact (e.g., affects most of the critical success factors [CSFs] and more than one BSC perspective);
7. Positive impact (e.g., affects all other performance measures in a positive way).

The Key Performance Indicator demonstrates how effectively a company is capable of achieving significant business objectives. Organizations use KPIs at multiple levels to evaluate their success at reaching targets. High-level KPIs may focus on the overall performance of the enterprise, while low-level KPIs may focus on processes in departments such as sales, marketing or a call centre.

A KPI is only as valuable as the action it inspires. Too often, organizations blindly adopt industry recognized KPIs and then wonder why that KPI doesn´t reflect their own business and fails to affect any positive change. One of the most important, but often overlooked, aspects of KPIs is that they are a form of communication. As such, they abide by the same rules and best-practices as any other form of communication. Therefore, succinct, clear and relevant information is much more likely to be absorbed and acted upon.

In terms of developing a strategy for formulating KPIs, a team should start with the basics and understand what its organizational objectives are, how to plan on achieving them and who can act on this information. This should be an interactive process that involves feedback from analysts, department heads and managers. As this fact finding mission unfolds, the company will gain a better understanding of which business processes need to be measured with KPIs and with whom that information should be shared.

KPIs are only as valuable as someone can make them. KPIs require time, effort and employee buy-in to live up to their high expectations.

In simple terms KPI is a way of measuring how well a worker, as individual, or how well an entire companies or business units are performing. KPI is short for Key Performance Indicator. A KPI should help to understand how well a company, business unit or individual is performing compared to their strategic goals and objectives.

Together, these metrics (or KPIs) allow the team in charge to understand whether they are on track or deviating from the course route. This enables them to make decisions about where to steer next, selecting new objectives and addressing new goals.

The wrong KPIs bring the danger of pointing people into the wrong direction and even encouraging them to deliver the wrong things. So it's of major importance to select the correct KPIs which vary from case to case depending on the company's business. Managers have to have in mind the different requirements given by their stakeholders, when they are choosing the adequate KPIs for the company's areas (Parmenter, 2007).

Effective KPIs are closely tied to strategic objectives (be it for the entire company, a business unit, or an individual). Firstly, companies have to develop a performance management framework that articulates the strategic priorities. Then normally they create a single-page diagram of the key objectives and how they can support each other to deliver the ultimate goal (e.g. deliver value to shareholders).

Key Performance Indicators (KPIs) should be the vital navigation instruments used by managers and leaders to understand whether they are on course to success or not. The right set of KPIs will shine light on performance and highlight areas that need attention.

The problem is that most companies collect and report a vast amount of everything that is easy to measure and as a consequence their mangers end up drowning in data while thirsting for insights, this can cause a lot of lost time and money.

KPIs are important not only for performance measurement, but also for mapping organizational development. Best practice organizations clearly understand what is needed for their development. They separate external reporting indicators if they are not relevant for the measures that must be adopted internally, in order to avoid confusion and data overload. They create the proper culture for driving high performance (Popa, 2015).

In order to identify the right KPIs for any business it is important to be clear about the objectives and strategic directions.

The business world is saturated with KPIs. The corporate rivers are overflowing with them drenching everything in numbers and targets. KPIs stands for Key Performance Indictors and most companies and government organization are either drowning in metrics or are using them so badly that they are leading to unintended behaviours (Parmenter, 2007).

The selected KPIs should have the capability to measure and assist the current situation of the process (Sharifi, Ayat, Ibrahim & Sahibuddin, 2009).

There are three levels of metrics:

1. **Key Management Indicators (KMI).** KMIs are Lagging Indicators that are tracked at a senior management level;
2. **Key Performance Indicators (KPI).** KPIs are Leading Indicators which result in the success or failure of the KMIs. This are followed at the department level;
3. **Key Activity Indicators (KAI).** KAIs are given to operational levels. When KAIs succeeds, they affect positively the Key Performance Indicators.

These levels are shown in the following Figure 2.6.

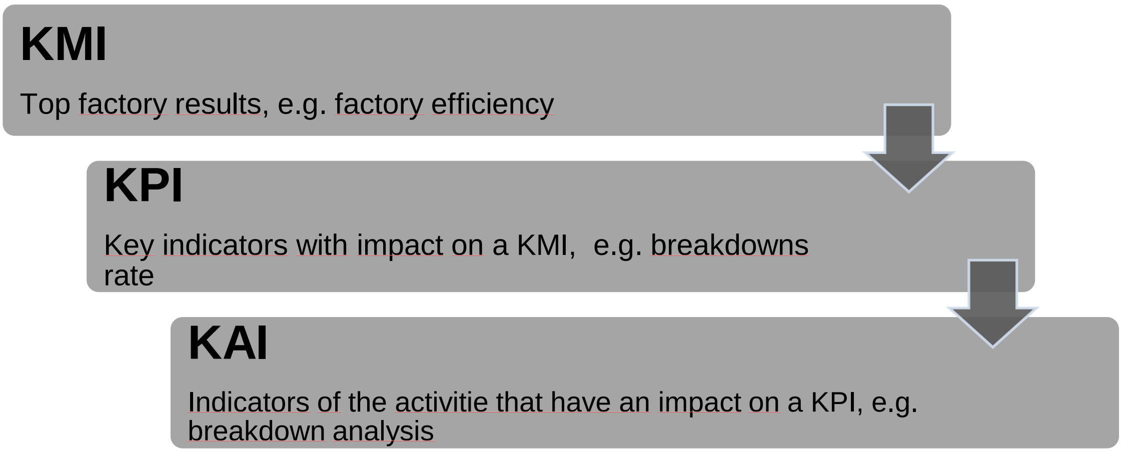

Figure 2.6 - Hierarchy of Performance Indicators

As a conclusion it is possible to say the relationship between organizational culture and performance management is very close. Measuring for discovering and improving is the most natural form of using KPIs, with a view to provide the managers and the employees with the information necessary for taking decision. In this context, KPIs are used inside the organization as support for managerial decisions and for learning and development (Popa, 2015).

2.3 Decision Tools for Business Modelling

This chapter focus on describing the Decision tools that are most adequate for the Chapter 3 of this work.

The field of decision analysis has had a crescent impact in the way organizations are making strategic decisions. Major advances in theory, modelling tools and computational techniques have turn decision analysis increasingly crucial in business decision making. This decision making tools helps the companies to accomplishing greater customer satisfaction by adding value to the products.

Decision analysis refers to the broad quantitative field, overlapping operations research and statistics that deals with modelling, optimizing and analysing decisions made by individuals, groups and organizations.

Since, the complexity of business environment makes the process of decision making difficult the decision maker cannot rely entirely upon the observation, experience or evaluation to make a decision. The field of statistics provides methods for collecting, presenting, analysing and interpreting data (Srivastava, Shenoy & Sharma, 1989).

The effectiveness of business modelling and the corresponding decision support tools is derived from the concept that the value of the collective knowledge is greater than the value of its constituted parts.

For the purpose of this work the Principal Component, the Cluster and the Discriminant Analysis will be considered also as decision tools since they are important for the selection of the aggregate components that will help the construction of the Proposed Model. Consequently this tools are going to be presented in the next sections:

- Cluster Analysis;
- Analytic Hierarchy Process (AHP);
- Discriminant Analysis;
- Principal Component Analysis (PCA).

In section 2.3.5 the computational software's for the previous analysis are going to be depicted, and compared, so one of them will be chosen for the Proposed Model Proposal.

2.3.1 Cluster Analysis

The objective of cluster analysis is to assign observations to groups so that, the observation within each group are similar to one another with respect to variables or attributes of interest, and the group themselves stand apart from one another. The objective is to divide the observations into homogeneous groups. Cluster Analysis is used also to group variables rather than observations, and this groupings are frequently based on the correlation coefficients of the variables (Tryfos, 1998).

Nowadays, the number of studies and publications that concern the Cluster Analysis have grown exponentially because of the great development on computer analysis and the fact that clustering has become a scientific method.

The method can be described as a given set of n individuals for which there is information on the form of p variables. The method proceeds by grouping individuals according to the existing information, such so individuals belonging to the same group are similar and always more similar to members of the same group than to members of the remaining groups (Reis, 2001).

The two cluster algorithm categories are the hierarchical, the most common and the non-hierarchical. The methods being depicted for the purpose of this work are:

- Hierarchical Cluster;
- K-Means Cluster;
- TwoStep Cluster.

The Cluster Analysis for the Hierarchical method comprises five different stages explain next (Reis, 2001):

1. **Selection of individuals or a sample of individuals to be grouped**. It is necessary to consider the type of variables (e.g. continuous, ratio, ordinal, nominal or binary) to choose the appropriate grouping algorithm;
2. **Definition of the variables from which the information for the clustering of the individuals is obtained**;
3. **Definition of a measure of similarity or distance between each individual**. The most commonly used indexes of similarity can be divided into four categories (Andenderfer & Blashfield, 1985):
    a. **Correlation coefficients.** The similarity is not evaluated by the magnitude of the correlation coefficients but by the generated pattern;
    b. **Distance measures**. Usually they represent the similarity as proximity between observations for a given group of variables. There are several possible measure for distance but for the purpose of this work the measure chosen is the square of Euclidean distance, of all the most usually utilized. The distance between two objects i and j, considering n variables is given by the next equation:

$$d_{ij}^{\ 2} = \left(\sqrt{\sum_{k=1}^{n} \left(x_{ik} - x_{jk} \right)^2} \right)^2 \qquad (1)$$

    c. **Association coefficients**. Used to compare objects whose characteristics are measured in non-metric, nominal or ordinal scales;

d. **Measures of probabilistic similarity**. In order to formulate the probabilistic gain of the information is evaluated, starting with the initial variables, and the individuals with less information gain are grouped together;

4. **Criteria choice for aggregation or disaggregation of individuals**. Defined the measure of similarity it's time to choose the aggregation criteria. There are many criteria and their objective is always to maximize the differences between the clusters, considering the variation inside these clusters.

   Agglomerative method, in which every object begins be being its own cluster and then the closest ones are combined, and divisive method that is the inverse of the previous one, are the two hierarchical methods. The most utilized aggregation criteria in the hierarchical methods are:

   i. **Single linkage or the nearest neighbour**. This criteria defines as similarity between two groups the maximum similarity between any two cases belonging to this groups, that is, given two groups (i, j) and k, the distance between the two is the smallest of the distances between the elements of the two groups.

   $$d_{(i,j),k} = \min\{d_{ik}; d_{jk}\} \tag{2}$$

   ii. **Complete linkage or the furthest neighbour**. This criteria uses the inverse procedure of the Single linkage, since the distance between the two groups is defined as the distance between the furthest elements, or less similar. Given two groups (i, j) and k, the distance between them is the largest distance between their elements.

   $$d_{(i,j),k} = \max\{d_{ik}; d_{jk}\} \tag{3}$$

   iii. **Centroid Criteria**. The centroid method calculates the distance between the two groups as the difference between their means, for all variables. A disadvantage of this method is the fact that if the dimensions inside the group are very different then the centroid cluster will be closest to the bigger group.

   iv. **Ward's Criteria**. It is based on the loss of information from the group of individuals. It is measured by summing the squares of deviations from the individual observations relative to the means of the groups in which they are classified.

5. **Validation of the Clustering**. Since the cluster analysis aims to create homogenous groups, a problem arises that is the choice of the appropriate number of clusters or groups. The application of hierarchical methods allows the presentation of the results on the form of a Dendogram. In this work the best method for each case will be characterized in the Proposed Model and Case Exemplification, Chapters 3 and 4.

In non-Hierarchical method during the calculation process, objects can be included and excluded in a given grouping. This class of methods has the great advantage of being able to treat millions of objects. The most recognized non-Hierarchical method is K-Means.

K-Means or nearest centroid sorting consists essentially in the transfer of an individual to the cluster whose centroid is at a shorter distance. This criteria may be combinatorial or not, inclusive or exclusive. This method includes each individual in the cluster that presents a smaller distance between the individual and the centroid of the cluster. It starts by portioning the input points into k initial sets, then calculates the mean point, or centroid, of each set, subsequently constructs a new partition by associating each point with the closest centroid and finally repeats the last two steps until the objects no longer switch clusters.

Finally the TwoStep analysis identifies groupings by running pre-clustering first and then by running hierarchical methods. TwoStep clustering can handle scale and ordinal data in the same model, and it automatically selects the number of clusters.

TwoStep Cluster analysis represents a method that requires only one step pass throughout the data. The process is consisted of two major steps, being the first where initial clustering of observation into small sub clusters is performed and then these sub clusters are treated as separate observations. The grouping of these new observation is done by hierarchical cluster method. The second step is where the sub clusters are grouped into the required number of clusters. Since the number of sub clusters is significantly smaller than the number of observation the traditional grouping methods are easy to be used (Trpkova & Tevdovski, 2009).

2.3.2 Verification/Validation (AHP)

For the purpose of this work Analytic Hierarchy Process (AHP) will be depicted with the objective of allowing to verify and validate, when implementing the Proposed Model, which one or two of the previous described Cluster Analysis methods will be the most adequate to the data.

Nowadays, decision-making is a very complex process, which has many factors that need to be weighted before a decision is made.

AHP was developed in 1977 by Thomas Saaty. It can assess, prioritize, rank and evaluate decision choices.

AHP is a method largely used for multi-criteria decisions and it was developed to optimize decision making when a decision maker is faced with a mix of qualitative, quantitative, and sometimes conflicting factors that are taken into consideration. AHP is considered to be a very effective decision method when making complicated, often irreversible decisions (Melvin, 2012).

Analytic Hierarchy Process uses decision judgement to form a decomposition of problems into hierarchies. The hierarchy is used to derive ratio-scaled measures for decision alternatives and the relative value that alternatives have against organizational goals. AHP uses matrix algebra to sort out factors to arrive at a mathematically optimal solution (Triantaphyllou & Mann, 1995).

The Analytic Hierarchy Process consists of four steps (Melvin, 2012):

1. Define the problem and state the goal or objective;
2. Define the criteria or factors that influence the goal, structuring this factors into levels and sublevels;
3. Use paired comparisons of each factor, with respect to each other, that forms a comparison matrix with calculated weights, ranked eigenvalues, and consistency measures;
4. Synthesize the ranks of alternatives until the final choice is made.

After setting the goal of the AHP, the next step is to compute the vector of criteria weights. In order to do this it starts creating a pairwise comparison matrix A. This matrix is a $m \times m$, where the m represents the number of the considered evaluation criteria. Each entry a_{jk} of this matrix represents the importance of the j criterion relative to the k criterion. If $a_{jk} > 1$, then the j criterion is more important than the k criterion, while if $a_{jk} < 1$ the opposite occurs. If both criteria have the same importance then $a_{jk} = 1$. This entries have to satisfy the following requirement:

$$a_{jk} \times a_{kj} = 1 \tag{4}$$

The relative importance between criteria is measured according to Table 2.4.

Table 2.4 - Scale of Criteria Relative Importance

(Adapted from Saaty, 1980)

Value of a_{jk}	**Interpretation**
1	j and k are equally important
3	j is slightly more important than k
5	j is more important than k
7	j is strongly more important than k
9	j is absolutely more important than k
2, 4, 6, 8	Intermediate values

Once the Matrix A is built, it is possible to derive from A the normalized pairwise comparison matrix A_{norm} by making the sum of the entries in each column equal to one. Each entry $\bar{a}_{jk}$ of this matrix is computed as:

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \tag{5}$$

The criteria weight vector w is built by averaging the entries on each row of A_{norm} as follows:

$$w_j = \frac{\sum_{l=1}^{m} \bar{a}_{jl}}{m} \tag{6}$$

The third step is to compute the matrix option scores. This matrix is a $n \times m$ matrix S. Each entry s_{ij} of S represents the score of the i option with respect to the j criterion. In order to derive such scores, a pairwise comparison matrix $B^{(j)}$ the first built for each of the m criteria, $j = 1, \dots, m$. This matrix is a $n \times n$, where n is the number of options evaluation. The matrixes $B^{(j)}$ have the same considerations as stated for matrix A.

The AHP the applies to each matrix $B^{(j)}$ the same two-step procedure described for the matrix A, dividing each entry by the sum of the entries in the same column, and then it averages the entries on each row, thus obtaining the score vectors s^j, $j = 1, \dots, m$. The vector s^j contains the scores of the evaluated options with respect to the each j criterion. The score matrix S is obtained as:

$$S = \left[s^{(1)} \dots s^{(m)}\right] \tag{7}$$

Once the weight vector w and the score Matrix S have been computed, the AHP obtains a vector v of global scores by:

$$v = S \times w \tag{8}$$

As the final step, the option ranking is accomplished by ordering the global scores in decreasing order, but when some pairwise comparisons are performed, some inconsistencies may typically arise. A consistent evaluation is then needed.

AHP technique for checking the consistency of the evaluations made relies on the computation of a suitable consistency index, and will be described only for matrix A. The Consistency Index (CI) is obtained by first computing the scalar x as the average of the elements of the vector whose j element is the ratio of the j element of the vector $A \times w$ to the corresponding element of the vector w. Then,

$$CI = \frac{x - m}{m - 1} \tag{9}$$

A perfectly consistent decision maker should always obtain $CI = 0$, but small values of inconsistency may be tolerated. In particular, if

$$\frac{CI}{RI} < 0.1 \tag{10}$$

The inconsistencies are tolerable, and a reliable result is expected from the AHP. RI is the Random Index, which is the consistency index when the entries of A are completely random. The number values of RI are shown in Table 2.5.

Table 2.5 - Values of Random Index

(Adapted from Melvin, 2012)

m	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

2.3.3 Discriminant Analysis

For the purpose of this work Discriminant Analysis will be depicted with the objective of allowing to validate, when implementing the Proposed Model, the chosen clusters.

Discriminant function Analysis is a parametric technique to determine which weightings of quantitative variables or predictors best discriminate two or more than two groups of cases. The analysis creates a discriminant function which is a linear combination of the weightings and scores on these variables (Ramayah, Ahmad, Halim, Zainal & Lo, 2010).

In many ways, discriminant analysis parallels multiple regression analysis. The main difference between these two techniques is that regression analysis deals with a continuous dependent variable, while discriminant analysis must have a discrete dependent variable. The methodology is to plot each variable versus the group variable. First is a selection phase to determine which independent variable are beneficial and after is conducted a residual analysis to determine the accuracy of the discriminant equations (Surhone, Timpledon & Marseken, 2010).

Discriminant analysis is a powerful tools for analysing and describing group differences and for classifying cases into groups formed on the basis of their similarities and differences on multiple variables.

The following step are performed in a descriptive discriminant analysis (Bown & Wicker, 2009):

1. Determine if the discriminant analysis will provide statistical results that answer the research questions;
2. Determine the appropriateness of the data set for discriminant analysis;
3. Define the groups that will be used in the analysis;
4. Select the variables that will be used in the analysis;
5. Test the data to assure that the assumptions of the discriminant analysis are met. If some assumptions are not met, determine whether discriminant analysis is robust for those assumptions;
6. Perform the analysis;
7. Interpret the results.

The first four steps are addressed when making the Cluster Analysis. Because the data used in discriminant analysis involves multiple variables, the assumptions required for this analysis are the same as those required for other multivariate analysis, like Cluster Analysis. The assumption of independent observations is critical.

To interpret the values of the results of the analysis that are going to be taken some tests are going to be performed:

- **Determination of the relative importance of discriminant functions**. Test used is the Eigenvalues, which values describe how much discriminating ability a function possesses. The magnitudes of the eigenvalues are indicative of the function's discriminating ability;

- **Global validation of the model**. In this case the test used is Wilk's Lambda, which test how well each level of independent variables contributes to the model;
- **Verification of relative importance of independent variables**. Structure Matrix, which is the canonical structure, also known as canonical loading or discriminant loading, of the discriminant functions. It represents the correlations between the observed variables and the dimensions created with the unobserved discriminant functions;
- **Checking the reliability of the Model**. Cross-validation, which verifies if the variables are correctly classified;

2.3.4 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is one of the most important and powerful methods of multivariate data analysis. It is a technique for identifying patterns in data and expressing the data in such a way as to highlight their similarities and differences.

Since patterns are very hard to find in high dimension data, where graphical representation is not available, PCA is a powerful tool for analysing this data. PCA is a multivariate technique that examines a data table in which observations are described by several inter-correlated quantitative dependent variables. Its goal is to extract the important information form the table, to represent it as a set of new orthogonal (non-correlated) variables called principal components, and display the pattern of similarity of the observations and of the variables (Abdi & Williams, 2010).

The application of PCA to business is divided in two categories (Reis, 2001):

- **Those that aim to reduce the size of the data**. Of the large number of descriptive variables becomes a smaller set, more easily analysed and still representative of the initial group of variables;
- **Those whose objective is to allow the understanding of the processes behaviour of the individuals, through identification and interpretation of the underlying factors**.

The first principal component components accounts for as much of the variability in the data as possible, and each of the succeeding component accounts for as much of the remaining variability as possible

Traditionally, principal component analysis is performed on a square symmetric matrix, which can be a SSCP (Pure Sums of Squares and Cross Products) Matrix, Covariance (Scaled Sums of Squares and Cross Products) Matrix or Correlation Matrix.

The correlation Matrix is used if the variances of individuals differ much, or if the units of measurement of the individual variates differ.

PCA is a dimensionality reduction or data compression method. The goal is dimension reduction. It helps to select a smaller set of variables from a larger group, based on which of the original variables have the highest correlations with the principal component.

Before performing a PCA there are some requisites:

- **The variables are metric**;
- **The sample dimension it adequate**. There is a minimum number of observations for variable, normally five times more cases that the number of variables;

When performing the Principal Component Analysis there are four steps that need to be followed and then presented for the full validation of the PCA, that are going to be depicted (Reis, 2001):

1. **Estimate the correlation Matrix between the initial variables**. If there are considered number of non-correlated variables after this Matrix is calculated, a validity test is going to be applied. Three tests are required for this validation test:
    a. **Bartlett's Sphericity Test**. Tests the hypothesis of the correlation Matrix being an Identity Matrix and if its determinant is equal to one, and by doing so verifies if the variables are non-correlated. If $p < 0.05$ than reject H_0.

    $$H_0: The\ Correlation\ Matrix\ is\ an\ Identity\ Matrix$$

    $$H_1: The\ Correlation\ Matrix\ is\ not\ an\ Identity\ Matrix$$

    b. **Kaiser-Meyer-Olkin (KMO) Statistic**. It is a statistic that provides the adequacy of the initial Matrix, by comparing the correlations between the variables. Higher the value of the KMO, greater the consistent of the components selected. The results of KMO should be interpreted as follows:

Table 2.6 - KMO Statistic values

(Adapted from Reis, 2001)

KMO	**Principal Component Analysis (PCA)**
<0.50	Unacceptable
]0.50 ; 0.60]	Bad
]0.60 ; 0.70]	Acceptable
]0.70 ; 0.80]	Medium
]0.80 ; 0.90]	Good
]0.90 ; 1]	Very Good

c. **Anti-Image Matrix**. Is composed by the symmetric of the coefficients of partial correlations. If there are low values in a significant number, it is valid the importance of applying the Principal Component Analysis to this case.

2. **Extraction of Principal Components and Estimation of number of components needed for representing properly the initial data;**
3. **Rotation of the Components**. This is done so the components can be easily interpreted. This interpretation is easier when the contribution of a variable is close to 100% in one factor and close to 0% in the others.
4. **Determine the value of the each factor for each individual.**

2.3.5 Tools Software

So it is possible to develop the Proposed Model the computational software's for the Cluster, Discriminant and Principal Component Analysis and for the Analytic Hierarchy Process are chosen in this Chapter.

Microsoft Excel was chosen for the Analytic Hierarchy Process because it has the necessary feature to calculate the method of AHP, which uses a matrix algebra to arrive at a mathematically optimal solution.

Cluster, Discriminant and Principal Component Analysis have a vast number of computational software that can be applied. For the purpose of this work the software tool chosen was IBM SPSS, which is a platform that offers advanced statistical analysis that is easy to use, flexible and scalable. This software is the leading statistical software used to solve such business and research problems.

Also, one of the main reasons for the selection of SPSS is the fact that the author of this work is well aware of the different features of this software.

2.4 Business Process Modelling

Since the 1980s there has been a tremendous evolution regarding Process Management, particularly because there was given greater attention to the management of business in the organizations which resulted in an increase of competitiveness between companies. In this decade it became clear that the processes had great importance and needed to be supported in a systematic manner, in opposition with the traditional information systems that used information modelling as a starting point. Focus shifted to Total Quality Management (TQM). This new way of doing business was called the First Wave of Process Orientation.

Total Quality Management describes a management approach to continuous and long-term success through customer satisfaction, capable of ensuring customer expectations and the performance of all adding value activities in the organization. TQM arose from the need of organizations to present competitive strategies in order to improve the results and to keep up with the consumers' demands and the increasingly greater technological innovation (Boiça, 2015).

In the nineties the Second Wave of Process Orientation came with the business process reengineering movement, which reshaped business practices with technology and automation. In 1993 "*Reengineering the Corporation"* was published by Hammer and Champy and it was at this time that the management of processes was seen by organization leaders as a crucial part of their business management. During this time processes were reengineered manually, one process at a time, and then the reengineered processes typically solidified into what was fairly rigid and overseen by software applications.

The method that resulted of this movement was the Business Process Reengineering (BPR). It was a faster method to improve processes, increasing processes identification and better perception, and so the TQM was in some way outdated. However, there were some problems concerning the lack of tools to model and associate the large amounts of information and also the fact that this method uses exclusively theoretical concepts without making their association so it could be applied in practice.

The result was the advent of CAD (Computer-Aided Design) and CAM (Computer-Assisted Manufacturing) that brought radical new efficiencies and efficacies to industrial engineering. With the help of this tools and taking into account the weaknesses of TQM and BPR, the Business Process Management (BPM) arises.

Technology was shifted from being a process driver to a process enabler during the Third Wave of Process Orientation, which began in the late 1990s and is still applied. This new wave brings much greater flexibility to the creation and change of the process definition, meaning that is a fundamentally new approach to business process innovation and management.

This third wave of BPM enables companies and workers to create and optimize new business process on the fly. Change is the primary design goal (Smith, 2007).

Table 2.7, on the next page, demonstrates the evolution of Process Management and the Three Waves of Process Orientation.

BPM is based on the observation that each and every product that a company provides to the market is the outcome of a number of activities performed. Business processes are all addressed in a logical and horizontal manner and are the key instrument to organize these activities and to improve the understanding of their interrelationships. Management of Information deserves an important role in business process management, because increasingly more activities that a company performs are sustained by information systems (Weske, 2007; Brocke, Mathiassen & Rosemann, 2004).

Business process management includes concepts, methods, and techniques to support the design, administration, configuration, enactment, and analysis of business processes. BPM is a method that involves any combination of modelling, automation, execution, control, measurement and optimization of business activity flows, in support of enterprise goals, spanning systems, employees, customers and partners and all stakeholders within and beyond the enterprise limits[3] (Juran, 2014).

Table 2.7 - The Three Waves of Process Orientation

(Adapted from Lusk, Paley & Spanyi, 2005)

Phase	Time	Focus	Business	Technology	Tools/Enablers
1st Wave : Process Improvement	1970/80s	• Quality Management • Continuous Flow • Task Efficiency	• Multi-Industry Enterprises • Line of Business Organization • Mergers & Acquisitions	• Computerized Automation • Management Information Systems • MRP	• TQM • Statistical Process Control • Process Improvement Methods
2nd Wave : Process Reengineering	1990s	• Process Innovation • "Best Practices" • Better, Faster, Cheaper • Business via the Internet	• Flat Organization • End-to-End Processes • Value Propositions (Speed to Market, Customer Intimacy, Op. Excellence)	• Enterprise Architecture • ERP • CRM • Supply Chain Management	• Activity Based Costing • Six Sigma • Buy vs Build • Process Redesign/ Reengineering Methods
0. 3rd Wave : Business Process Management	Since 2000s	• Assessment, Adaptability & Agility • 24/7 Global Business • Continual Transformation	• Networked Organization • Hyper Competition • Market Growth Driven • Process Effectiveness over Resource Efficiency • Organizational Effectiveness over Op. Efficiency	• Enterprise Application Integration • Service Oriented Architecture • Performance Management Software • BPM Systems	• Balanced Scorecard • Self Service & Personalization • Outsourcing, Co-Sourcing, In-Sourcing • BPM Methods

There are many arguments that can demonstrate how helpful the Business Process Management (BPM) is. Thus the advantages in using BPM are (Smith, 2007):

1. BPM provides enhanced business agility, control and accountability. It will streamline internal and external business processes, eliminate redundancies, and increase automation.

[3] Source: https://bpm.com/what-is-bpm; article by Nathaniel Palmer (Accessed at 30/11/2017)

2. BPM provides a direct path from process design to a system for implementing the process. It's not so much "rapid application development"; instead, it's removing application development from business cycle.
3. BPM supports top-down and bottom-up process modelling, right across the value chain, involving all business-process participants: systems, people, information, and machines.
4. BPM is a platform for sharing end-to-end business processes in a manner analogous to the use of a database management system as a platform for sharing business data, both between applications and among business partners. BPM is the platform upon which the next generation of business applications will be constructed.
5. BPM supports processes that inherently integrate, collaborate, combine and decompose, no matter where they were created and independent of the different technical infrastructures in which they exist. BPM creates reusable process patterns.
6. BPM is defined by the ability to change business process at a speed governed by the business cycle (day-to-day, week-to-week, quarter-to-quarter), radically reducing the friction arising from today's endemic business- IT divide.
7. BPM supports the derivation of key business metrics – for example, activity-based costs – directly from the execution of business processes. BPM processes are accountable, transparent and persistent, and include all the information passed among participants over process lifetime.
8. BPM radically simplifies the development of processes that spa the value chain, eradicating the point-to-point integration problem that still plagues on the value-chain execution today.
9. BPM supports the fluid movement, management and monitoring of work between companies. It is the operational environment that underpins value-chain integration and business process outsourcing.
10. BPM has the potential to automate the discovery of business processes arising naturally in the course of business operations, as readily as a database naturally fill with business data during use.
11. BPM will enable the industrial-scale collaborative design of business processes among partners, and will provide the tool for the value management analysis of processes supporting visual organizations.

As a conclusion, it is possible to define Business Process Management as a set of principles, methods and tools to design, analyse, execute and monitor business processes. Its greater purpose is to add value to the business in the long run, so that the company can grow and be more competitive in the future. It is important to have in mind that it's a longstanding implementation process as it requires a high level of specialization regarding all the activities and processes of the business.

3 Chapter – Business Model Assessment (BMA) Framework Proposal

In the previous Chapter is was possible to characterize the Business Modelling, with emphasis on the Business Process Modelling, Continuous Improvement Processes, Performance Indicators, and Decision tools for Business Modelling. By doing so it was possible to identify and verify some of needs of the current Business Modelling approaches.

Thus, in this Chapter a new and innovative methodology is presented based on the need to create new ways of managing the information and communication between different areas of the companies and between their stakeholders, which can be intern or extern.

The first part of this Chapter includes the contextualization of the company with the focus on the type of the company, its environment and the type of Continuous Improvement Process implemented. The second part of this Chapter is description of the features used for the Proposed Business Model Assessment and the last part is the consequent depiction of the proposed methodology to be implemented.

3.1 Model Contextualization

As an engineering student I had the opportunity of exploring the Management side of the Business by doing several internships from different sectors of Business, which granted me a diverse way of looking to Process Management, especially concerning the areas of information and communication management.

The sector of business and the work that I practice on these companies is characterized next:

- The first Company is part of the automotive sector and has TQM/Six Sigma methodology implemented. The work that was developed there concerned the implementation of new projects required in the areas of innovation and product management;
- The second Company is part of the retail market and has Lean Thinking methodology implemented. The developed work there was an implementation of a transformation process in the areas of supplier, procurement and product management;
- The third Company is part of the automotive sector and has Lean Six Sigma methodology implemented. The work that was developed there was an implementation of a Project that gathered and integrated common processes throughout all the areas of the company, such as Quality, Human Resources, Chemistry area, Production and Suppliers. The objective was to simplify the access to data and promote the communication between the different areas;

- The fourth company is part of the food processing and packaging sector and has Total Productive Maintenance implemented. The work that was developed there concerned the System Management and Certification and also Project management.

The knowledge acquired from this experiences was fundamental to the recognition of improvement opportunities. Thus, this was how the desire arose to create a methodology that would improve the management of information and communication within a company, especially related to performance indicator measures.

The application of this model was based on a company that has Total Productive Maintenance implemented. The strategy of this company relies on four main objectives:

- Grow in all markets;
- Accelerate value driven innovation;
- Improve environmental excellence;
- Strengthen operational performance.

The Factory Management indicators are:

- Number of Accidents;
- TEE- Total Equipment Effectiveness;
- EE – Equipment Effectiveness;
- Landed Cost;
- Total Waste;
- Perfect Delivery;
- Claims;
- IRP – Issue Resolution Performance Average;
- Energy Efficiency.

The House of TPM is composed by the following eight pillars:

1. **Focused Improvement and Cost (FIC)**. This pillar focus on achieving factory cost competitiveness through efficiency improvement and productivity and cost optimization;
2. **Autonomous Maintenance (AM)**. This pillar focus on providing all employees he knowledge of the equipment for proper identification of anomalies;
3. **Planned Maintenance (PM)**. This pillar focus on increasing availability of equipment, eliminating the number of faults and ensuring safety and quality at the minimum cost;
4. **Quality Maintenance (QM)**. This pillar focus on the premise of exciding customer satisfaction, reducing losses and non-quality costs and developing a systematic approach to reach the goal of zero defects;
5. **Early Management (EM)**. This pillar focus on reducing cost and time to market for new equipment and installation. It aims to implement and develop new products and process and minimised development lead times;

6. **Education and Training (ET)**. This pillar focus on optimizing skill and knowledge level of all employees, through TPM technology and tools integrated with management process;
7. **Supply Chain and Office (SCO)**. This pillar focus on delivering order with minimum possible cost, on time, and in a reliable way;
8. **Safety, Health and Environment (SHE)**. This pillar focus on identifying and eliminating all the risk activities and potential hazards, and reduce environment impact. It aims to monitor and eradicate problems in order to reach zero accidents.

Each of this pillars has Performance indicators that guarantee that the pillar's objective is being accomplished, and that helps the monitoring of their values. The next Table 3.1 shows the number of KMIs, KPIs and KAIs of the each pillar.

Table 3.1 - Company's PIs

Pillar	KMI	KPI	KAI	Pillar's PIs
FIC	6	7	4	17
AM	-	3	12	15
PM	-	11	3	14
QM	3	10	7	20
EM	-	8	3	11
ET	-	3	12	15
SCO	1	7	6	14
SHE	1	16	8	25
Total	**11**	**65**	**55**	**131**

3.2 Dataset Main Characteristics

To begin with this work it was important to collect all the dataset available. In order to create a Proposed Model the author had to resample all the data so it could be possible to manipulate this data.

The gathered data was the Performance Indicators of each of the eight pillars, from 2011 to 2016. This data was insufficient for the implementation of the Model, so a manipulation of the data was implemented. The strategies taken when manipulating the data to fit the Cluster, Discriminant and Principal Component Analysis as well as the data needed for applying an Analytic Hierarchy Process are going to be depicted next.

3.2.1 Data for the Cluster Analysis

For the Cluster Analysis a Table was produced that on each column has the KMI, KPIs and KAIs, their designation, the type of units and the code of the performance indicator, their Direction/Importance and the respective Category.

Concerning the Direction/Importance column the objective was to link the direction, crescent or decrescent, and the importance of each of the performance indicators. So levels of this column are shown in Table 3.2.

Table 3.2 - Direction/Importance levels

Level	Direction	Importance
-3	Decrescent	Very important
-2	Decrescent	Important
-1	Decrescent	Less Important
0	-	Irrelevant
1	Crescent	Less Important
2	Crescent	Important
3	Crescent	Very Important

For the Category column the objective was to divide the different performance indicators in smaller categories with differentiated characteristics. Each of this categories represent a different company's strategy goal. In the proposed model the company has six main strategic goals that translate in the following six categories:

- **Cost Category (*cat_cost*)**. This strategy goal aims to reduce cost by improving the production efficiency, reducing wastes and optimizing factory expenses;
- **Engagement Category (*cat_engagement*)**. The objective of this strategy goal is the engagement of all the stakeholders of the company by implementing a continuous and consistent relationship system between all stakeholders and, individual and team training development;
- **Safety Category (*cat_safety*)**. This strategy goal targets the safety of both people and environment by having the knowledge of all existing the risks and the way to resolve them and developing a certified safety system;
- **Quality Category (*cat_quality*)**. The objective of this strategy goal is to improve quality by improving the delivery status, reducing the number of claims, improving the process and the numbers of defects as well as the resolution of each client problem;
- **Service Category (*cat_service*)**. This strategy goal aims to improve the customer service deliverance by accelerating issue resolution and its root cause eradication, and optimizing the company's logistic solutions;

- **Innovation Category (*cat_innovation*)**. The objective of this strategy goal is to foment industrialized innovation by developing new products and new solutions to client's needs.

The values of this columns are Boolean numbers, because the objective was to turn possible the verification of the relationship between the strategic goals and each of the indicators, from the eight pillars. Hierarchical cluster and K-Means perform well with binary data and hierarchical clustering is capable of producing valid solutions with samples as small as *N = 20* (Henry, Dymnicki, Mohatt, Allen & Kelly, 2015; Dimitriadou, Dolnicar & Weingessel 2002). Having that in mind it was established that:

- Equal to 1 if true;
- Equal to 0 if false.

Eight tables were obtain, each for the respective pillar, and the resulted data was ready to be analysed. The next Table 3.3 is from the Focused and Improvement Cost Pillar, and serves as an example. The other seven Tables are in Appendix-A.

Table 3.3 - FIC Pillar Cluster Analysis Input

				Direc_import	**Category**					
					Cat_ cost	Cat_ engage ment	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innova tion
KMI	Landed Cost	index	**FIC1**	-3	1	0	0	0	0	0
KPI	Transformation Cost	index	**FIC2**	-2	1	0	0	0	0	0
KPI	Allocated Expenses	index	**FIC3**	-2	1	0	0	0	0	0
KPI	Logistic Cost	index	**FIC4**	-2	1	1	0	0	0	0
KMI	TEE	%	**FIC5**	3	1	1	0	0	1	0
KMI	OEE	%	**FIC6**	3	1	1	0	0	1	0
KMI	EE	%	**FIC7**	3	1	1	0	1	1	0
KMI	Total Waste	%	**FIC8**	-3	1	0	0	1	0	0
KPI	Process Waste	%	**FIC9**	-2	1	0	0	1	0	0
KPI	Productivity	kstraw s/h	**FIC10**	2	1	0	0	1	1	0
KAI	Loss cost tool updates	#	**FIC11**	-1	1	0	0	0	0	0
KAI	Standards identified and reviewed	#	**FIC12**	1	0	1	0	1	0	0
KMI	Energy efficiency	GJ/kto n	**FIC13**	-3	1	0	1	0	0	0

Table 3.3 – FIC Pillar Cluster Analysis Input (Cont.)

				Direc_import	Category					
					Cat_ cost	Cat_ engage ment	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innova tion
KAI	Pillar skill gaps reduction vs ideal	%	**FIC14**	1	0	1	0	0	0	0
KAI	Best Practice Sharing (Poke Yoke, X-ideas and standards)	#	**FIC15**	1	0	1	0	0	0	0
KPI	Pillar assessment score	%	**FIC16**	2	0	1	0	0	0	0
KPI	Pillar cost savings	kEUR	**FIC17**	2	0	1	0	0	0	0

The next step for the Cluster Analysis is to compute the values in the SPSS, which is described in Chapter 4.

3.2.2 Data for the Analytic Hierarchy Process

For the purpose of this work the Analytic Hierarchy Process (AHP) was chosen to help selecting the more adequate Cluster Analysis methods, comparing them with six criteria. The three methods from the cluster analysis, described in chapter 2.3.1, are:

- Hierarchical;
- TwoStep;
- K-Means.

AHP will allow, when implementing the Proposed Model, to choose which one or two of the previous described Cluster Analysis methods will be the most adequate to the data.

In this Analytic Hierarchy Process (AHP) six criteria were selected to differentiate the above mention methods. The six different criteria chosen were defined by the author of this work, concerning the study of the different Cluster methods and the relations between this methods and the data from the previous Cluster Analysis:

- **I - Suitability**. It is related to the ability of each of the methods being adequate for the data that is processed. Evaluates the capacity of each method to validate the propose clustering;
- **II - Cluster Structure (number of Clusters generated)**. How clusters are defined after using the method;
- **III - Output**. The output obtained from each of the methods differs, in terms of visualization of the clustering;
- **IV - Sample Size**. Each of the methods has a required sample size or size limitation;
- **V - Bootstrapping**. The ability of each method to bootstrap ;

- **VI - Automatic definition of the number of Clusters**. The capability of the methods to define automatically the output number of clusters;

Subsequently, the comparison of criteria is made with the help of the Relative Importance Matrix. This Matrix is depicted in Table 3.4.

Table 3.4 - Scale of Criteria Relative Importance II

Value of a_{jk}	Interpretation
1	j and k are equally important
3	j is slightly more important than k
5	j is more important than k
7	j is strongly more important than k
9	j is absolutely more important than k
2, 4, 6, 8	Intermediate values

The Criteria pair comparison table has four different columns. The first contains the pairs being compared. In the second column the most important criterion is selected. The qualification of how much more important is the selected criteria is described in the third column. Finally, in the last column is the numerical notation based on the Relative Importance Matrix. This comparison was also defined by the author having in mind the different features shown by each of the three methods when clustering the data. Table 3.5 shows the comparison between the six chosen criteria.

Table 3.5 - Criteria Pair Comparison

Compared pair	Most important Criteria	Qualification of how much more important	Numerical Notation
Suitability vs Cluster Structure	Suitability	More important to strongly more important	6
Suitability vs Output	Output	Slightly more important	3
Suitability vs Sample Size	Suitability	More important	5
Suitability vs Bootstrapping	Suitability	Slightly more important	3
Suitability vs Automatic Cluster definition	Suitability	More important to strongly more important	6
Cluster Structure vs Output	Output	Strongly more important	7
Cluster Structure vs Sample Size	Cluster Structure	Equally important to slightly more important	2
Cluster Structure vs Bootstrapping	Cluster Structure	Equally important to slightly more important	2

Table 3.5 – Criteria Pair Comparison (Cont.)

Compared pair	Most important Criteria	Qualification of how much more important	Numerical Notation
Cluster Structure vs Automatic Cluster definition	Cluster Structure	Slightly more important	3
Output vs Sample Size	Output	Strongly more important	7
Output vs Bootstrapping	Output	More important	5
Output vs Automatic Cluster Definition	Output	Strongly more important	7
Sample Size vs Bootstrapping	Bootstrapping	Slightly more important	3
Sample Size vs Automatic Cluster definition	Sample Size	Slightly more important	3
Bootstrapping vs Automatic Cluster Definition	Bootstrapping	Slightly important to more important	4

Also important for the implementation of AHP is the comparison table of the chosen methods. This table structure is the same as the Criteria Pair Comparison. Taking into account that there are six different criteria, the methods will be compared for each one in six different tables from Table 3.6 to 3.11.

I - Suitability

Table 3.6 - Method Pair Comparison (Suitability)

Compared pair	Most important Criteria	Qualification of how much more important	Numerical Notation
Hierarchical vs K-Means	K-Means	Equally important to slightly more important	2
Hierarchical vs TwoStep	TwoStep	Slightly more important	3
K-Means vs TwoStep	TwoStep	Equally important to slightly more important	2

II – Cluster Structure

Table 3.7 - Method Pair Comparison (Cluster Structure)

Compared pair	Most important Criteria	Qualification of how much more important	Numerical Notation
Hierarchical vs K-Means	K-Means	Equally important to slightly more important	2
Hierarchical vs TwoStep	TwoStep	Slightly important to more important	4
K-Means vs TwoStep	TwoStep	Slightly more important	3

III – Output

Table 3.8 - Method Pair Comparison (Output)

Compared pair	Most important Criteria	Qualification of how much more important	Numerical Notation
Hierarchical vs K-Means	Hierarchical	More important	5
Hierarchical vs TwoStep	Hierarchical	Slightly more important	3
K-Means vs TwoStep	TwoStep	Slightly important to more important	4

IV – Sample Size

Table 3.9 - Method Pair Comparison (Sample Size)

Compared pair	Most important Criteria	Qualification of how much more important	Numerical Notation
Hierarchical vs K-Means	K-Means	Slightly more important	3
Hierarchical vs TwoStep	TwoStep	Slightly more important	3
K-Means vs TwoStep	-	Equally important	1

V – Bootstrapping

Table 3.10 - Method Pair Comparison (Bootstrapping)

Compared pair	Most important Criteria	Qualification of how much more important	Numerical Notation
Hierarchical vs K-Means	Hierarchical	Slightly more important	3
Hierarchical vs TwoStep	Hierarchical	Slightly important to more important	4
K-Means vs TwoStep	K-Means	Slightly more important	3

VI – Automatic Cluster Definition

Table 3.11 - Method Pair Comparison (Automatic Cluster Definition)

Compared pair	Most important Criteria	Qualification of how much more important	Numerical Notation
Hierarchical vs K-Means	K-Means	Slightly important to more important	4
Hierarchical vs TwoStep	TwoStep	More important	5
K-Means vs TwoStep	TwoStep	Equally important to slightly more important	2

The next step for the Analytic Hierarchy Process is to compute the values in the Excel, which is described in Chapter 4 – BPM Case Exemplification.

3.2.3 Data for the Discriminant Analysis

For the purpose of this work the Discriminant Analysis is utilized after the Cluster Analysis and Analytic Hierarchy Process so it can validate the obtain clusters.

The values that are going to be computed in the Discriminant Analysis are:

- Each of the eight Pillar Cluster Analysis Output;
- Cluster Membership, obtain from the selected Cluster Analysis methods.

3.2.4 Data for the Principal Component Analysis

The last decision tool being depicted is the Principal Component Analysis (PCA). For the construction of the table of values for PCA it was necessary to resample the data that was available.

To show how this was conducted, an example of the Resampling data process for the Focused Improvement and Cost (FIC) is going to be depicted next. Performance Indicator designation and code are the same as in Table 3.3. The state of the data available in FIC pillar is shown in Table 3.12.

Table 3.12 - FIC Pillar previous state

			2011	2012	2013	2014	2015	2016
KMI	index	**FIC1**	-	107	111	107	96	87
KPI	index	**FIC2**	-	105	123	135	108	97
KPI	index	**FIC3**	-	79	71	68	65	65
KPI	index	**FIC4**	-	72	52	30	38	42
KMI	%	**FIC5**	-	0.450	0.360	0.380	0.488	0.547
KMI	%	**FIC6**	0.580	0.670	0.610	0.730	0.680	0.748
KMI	%	**FIC7**	0.590	0.820	0.890	0.900	0.900	0.889
KMI	%	**FIC8**	0.047	0.027	0.023	0.023	0.021	0.0232
KPI	%	**FIC9**	0.046	0.023	0.014	0.017	0.016	0.0165
KPI	kstraws/h	**FIC10**	-	35	34	27	46	41
KAI	#	**FIC11**	-	4	2	6	7	2
KAI	#	**FIC12**	-	10	12	12	14	20
KMI	GJ/kton	**FIC13**	4902	4587	4715	4413	4455	4347
KAI	%	**FIC14**	0.70	0.75	0.76	0.78	0.76	0.89
KAI	#	**FIC15**	-	6	1	2	8	16
KPI	%	**FIC16**	-	0.50	0.51	0.57	0.62	0.80
KPI	kEUR	**FIC17**	-	-	-	107.9	176.6	62.4

In order to show how the resample was done, an example is given for the Performance Indicator **FIC1 – Landed Cost.**

- **1st Step**. Verify the direction and the long term objective of the Performance Indicator values.

The direction is decrescent because it's a cost and the goal is to reduce it. However as time progresses it will stabilize. As it is an index it starts at 100.

- **2nd Step**. Calculate the Mean and the Standard Deviation (Figure 3.1).

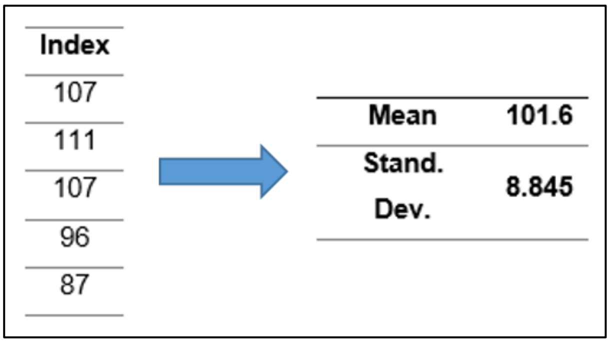

Figure 3.1 - FIC Mean and Std. Dev. (PCA)

- **3rd Step**. Generate the first column (*rand*) with one hundred random values using the Excel function $rand(\,)$.

- **4th Step**. For the purpose of this work it was defined that all the samples for the different indicators are defined by a Normal distribution with a mean and a standard deviation calculated on the second step. Considering this the fourth step consists on generating a second column (*dist*) with values calculated by the following function:

$$ROUND(NORMINV(Probability; Mean; Standard_{dev}); 0) \quad (11)$$

Where Probability is equal to the respective value of random in the first column. Table 3.13 shows an example of the first ten values for the resampling of *FIC1*.

Table 3.13 - Rand() and distribution Function (PCA)

	rand	dist
1	0,491143	101
2	0,197086	94
3	0,666151	105
4	0,99616	125
5	0,468194	101
6	0,263645	96
7	0,20528	94
8	0,829037	110
9	0,68041	106
10	0,685863	106

- **5th Step**. Generate a third column with the values sorted decreasing;

- **6th Step**. Select twenty random values of the third column and shuffle them. (To shuffle the values the *Resampling Stats for Excel* add-on was utilized). In Table 3.14 the coloured values are the ones shuffled.

Table 3.14 - FIC Pillar samples (PCA)

	Sample		Sample		Sample
1	100	**35**	106	**69**	97
2	123	**36**	106	**70**	97
3	122	**37**	106	**71**	97
4	122	**38**	106	**72**	97
5	89	**39**	113	**73**	104
6	118	**40**	105	**74**	96
7	118	**41**	105	**75**	96
8	118	**42**	105	**76**	96
9	117	**43**	105	**77**	97
10	116	**44**	88	**78**	95
11	104	**45**	104	**79**	95
12	115	**46**	104	**80**	95
13	114	**47**	104	**81**	96
14	114	**48**	106	**82**	94
15	113	**49**	104	**83**	94
16	110	**50**	103	**84**	94
17	112	**51**	103	**85**	94
18	112	**52**	103	**86**	93
19	112	**53**	103	**87**	107
20	111	**54**	102	**88**	93
21	99	**55**	92	**89**	118
22	110	**56**	102	**90**	91
23	110	**57**	102	**91**	89
24	110	**58**	101	**92**	89
25	109	**59**	116	**93**	94
26	109	**60**	101	**94**	89
27	109	**61**	100	**95**	89
28	109	**62**	99	**96**	102
29	108	**63**	101	**97**	88
30	108	**64**	99	**98**	86
31	107	**65**	99	**99**	86
32	93	**66**	99	**100**	84
33	107	**67**	98		
34	106	**68**	98		

- **7th Step**. Select the values obtained and place them in a new table with all the Performance Indicators with one hundred samples each.

3.3 Proposed Business Model Assessment

In this Chapter the methodology Proposed, which allowed the completion of the Proposed Business Model Assessment and consequently will permit the demonstration of the results success in the Case Exemplification, is depicted. The different stages of the methodology implementation are shown in Figure 3.2.

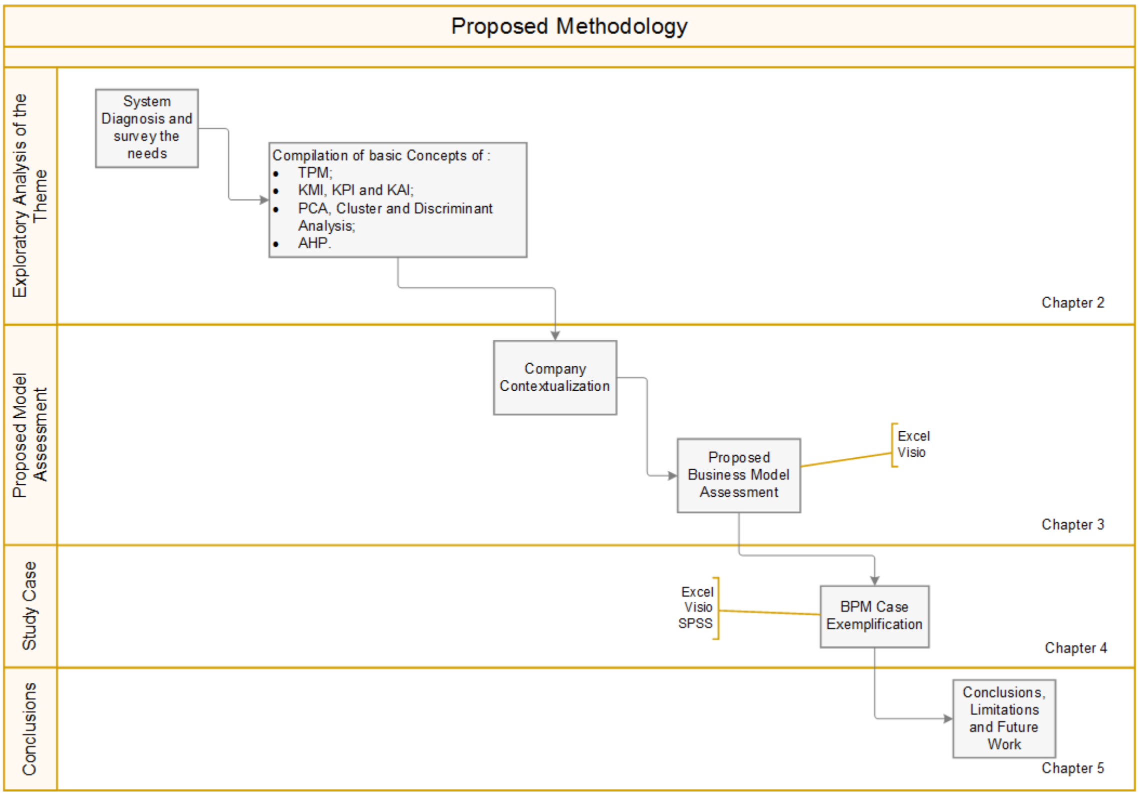

Figure 3.2 - Methodology Proposed Diagram

The first stage of this process is the Exploratory Analysis of the theme where the objective is to recognize the opportunity for the model being proposed. It is crucial to assembly all the essential information related to the principles and concepts being revised and the identification of all available techniques that are helpful when managing business.

This stage has already been addressed in Chapter 2, on which all the information regarding Managing Business. Also on this Chapter the information that concerns the different approaches of Continuous Improvement of Processes (CIP) is described and the tools from the CIP are compared and discussed so it can be possible to acknowledge the existing needs.

Next, the Key Management, Key Performance, and Key Activity Indicators were identified and characterized to recognize the importance of this measures when diagnosing the evolution of the system, the processes that need to be develop and the measures to improve them.

To help the decision, verification and validation when addressing PI's and Systems Management certification, information about Decision tools for business modelling was then gathered and depicted in the final step of this stage.

After this stage a Proposed Business Model is presented with the implemented Methodology and designed structure of Process Management.

The contextualization and the collected dataset are already defined. This stage was crucial to know the company status and the possibilities for improvement.

The collected data is an important foundation for the Proposed Model and its flow is defined in Figure 3.3.

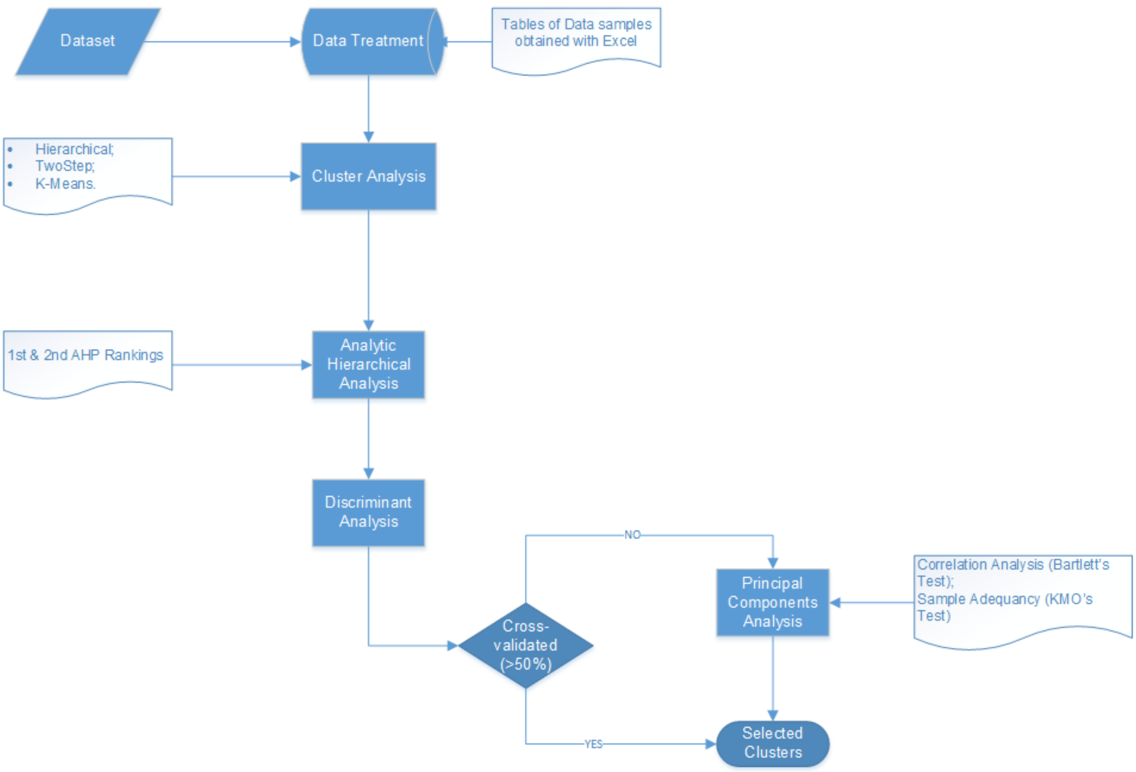

Figure 3.3 - Flowchart of the Selected Cluster

Subsequently, a Case exemplification is addressed so it is possible to validate the former stage of this work and also to create a new characterization of the process with an innovative technique that allows the optimization of the system.

Finally, bearing in mind the previous step, result analysis and discussion are done. Conclusions, advantages and future work will be address and verified about the implementation of this new Model.

4 Chapter – BMA Case Exemplification

This Chapter describes the Case exemplification for the Proposed Model. This exemplification is addressed so it is possible to validate this work and also to create a new characterization of the process with an innovative technique that allows the optimization of the system.

As described in the previous chapter the company has Total Productive Maintenance implemented and has eight pillars that characterize the different areas of the factory.

4.1 Cluster Analysis Results

The first stage of the Case Exemplification is the Cluster Analysis that will allow to aggregate the KMI, KPIs and KAIs of each of the eight pillars.

In order to begin the cluster analysis a treatment of the data was conducted, as described in Chapter 3.2.1. The first part was the construction of a Table, which has depicted all the performance indicators, their designation, the type of units and the attributed code, their Direction/Importance and the respective Category.

To help advancing in this stage a Table containing a Direction/Importance column, where the objective was to link the direction, crescent or decrescent, and the importance of each of the performance indicators was build. This is depicted in Table 3.2.

After establishing the data to be utilized in the Cluster Analysis the process of scrutinizing was made with the help of statistics software SPSS.

In this chapter only the FIC pillar is described in detail, to show an example of the progress of the methodology, but all the results obtain from the Cluster Analysis are going to be explained.

Focused Improvement Cost (FIC) Pillar

The data to be computed in SPSS is shown in *Table 3.3 - FIC Pillar Cluster Analysis Input*. After defining the variables the next step is to introduce them in the software. The methods that are going to be tested are:

1. **Hierarchical**;
2. **TwoStep**;
3. **K-Means**.

To access to the Hierarchical method, in SPSS, the first step was to paste the variables in the *Data Editor – Data View*.

Then the *Variable View* was selected and the name designation and the measure of each variable were changed to:

- direc_import (*Ordinal*);
- *cat_cost* (*Nominal*);
- *cat_engagement* (*Nominal*);
- *cat_safety* (*Nominal*);
- *cat_quality* (*Nominal*);
- *cat_service* (*Nominal*);
- *cat_innovation* (*Nominal*);

It was considered that for the variables that are binary the name designation is Nominal considering 0 (zero) false and 1 (one) true (Henry, Dymnicki, Mohatt, Allen & Kelly, 2015).

After this it was necessary to perform the following steps depicted in Figure 4.1:

- **Menu**: *Analyse*;
- **Submenu**: *Classify;*
- **Select the Method**: *Hierarchical Cluster;*
- **Select the variables to be computed.** Select *Cluster Cases* and *Display Satistics* and *Plots*;
- **Select Statistics.** Select the range of solutions;
- **Select Plots.** Select *Dendogram*;
- **Select Method.** Select the *Squared Euclidean distance*. This step was done four times, each time for the different Hierarchical Cluster method. The chosen were:
  i. **Nearest Neighbour;**
  ii. **Furthest Neighbour;**
  iii. **Centroid Clustering;**
  iv. **Ward method.**

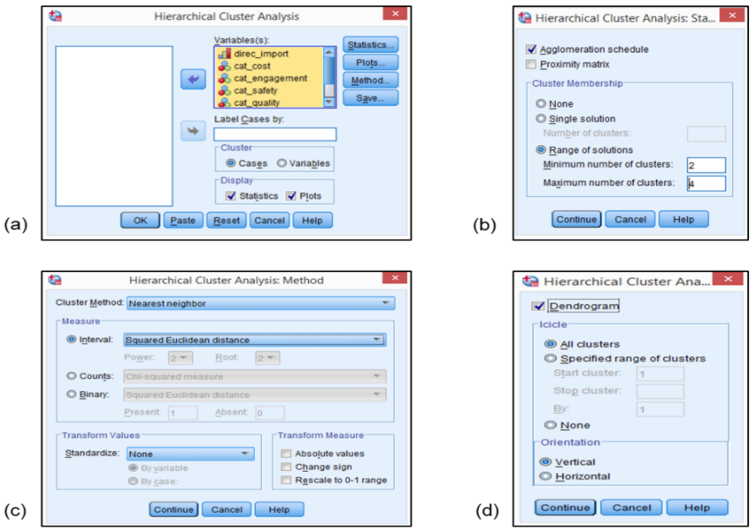

Figure 4.1 - Hierarchical Cluster Analysis (a) Variables; (b) Statistics; (c) Method; (d) Plots

For the purpose of this work the information collected from the SPSS when utilizing the Hierarchical methods was:

- **Cluster Membership**;
- **Dendogram**.

Throughout the Cluster analysis it was verified that for the four Hierarchical methods the Cluster Membership was the same. The Cluster Membership collected from the *FIC – Focused Improvement Cost Pillar*, in the case of the four Hierarchical methods, is described in Table 4.1.

Table 4.1 - FIC Hierarchical Cluster Membership

			Cluster 1	Cluster 2
KMI	Landed Cost	**FIC1**	x	
KPI	Transformation Cost	**FIC2**	x	
KPI	Allocated Expenses	**FIC3**	x	
KPI	Logistic Cost	**FIC4**	x	
KMI	TEE	**FIC5**		x
KMI	OEE	**FIC6**		x
KMI	EE	**FIC7**		x
KMI	Total Waste	**FIC8**	x	
KPI	Process Waste	**FIC9**	x	
KPI	Productivity	**FIC10**		x
KAI	Loss cost tool updates	**FIC11**	x	
KAI	Standards identified and reviewed	**FIC12**		x
KMI	Energy efficiency	**FIC13**	x	
KAI	Pillar skill gaps reduction vs ideal	**FIC14**		x
KAI	Best Practice Sharing (Poke Yoke, X-ideas and standards)	**FIC15**		x
KPI	Pillar assessment score	**FIC16**		x
KPI	Pillar cost savings	**FIC17**		x
		Total Indicators	**8**	**9**

The Dendograms of the four Hierarchical Methods, of FIC pillar, are depicted in Figure 4.2. The red line represents the distance between clusters.

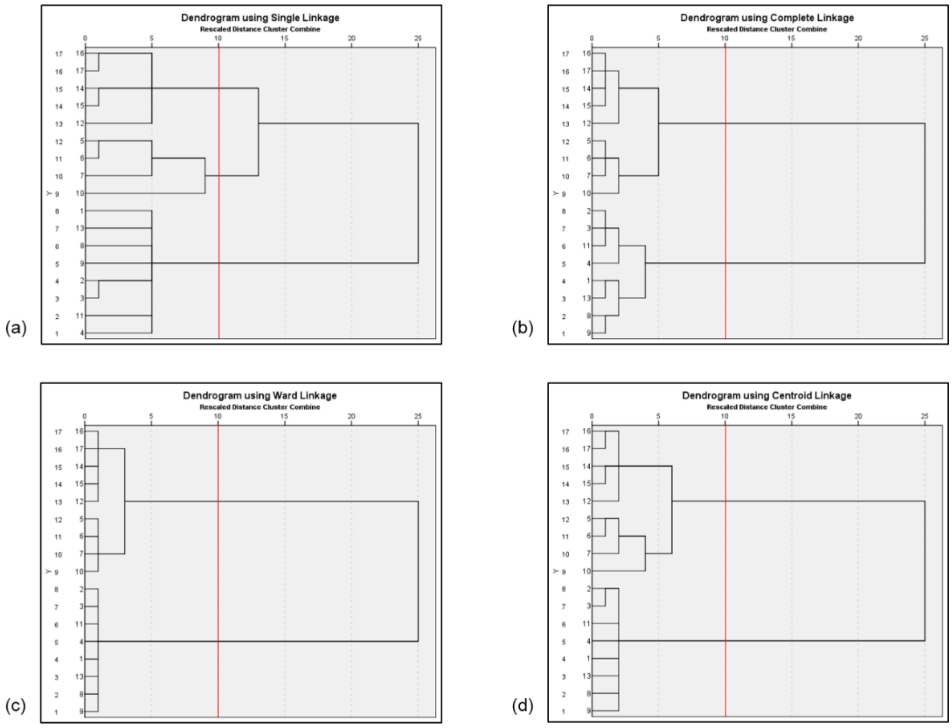

Figure 4.2 - FIC pillar Hierarchical (a) Nearest; (b) Furthest; (c) Ward; (d) Centroid Method Dendogram

In this case the Hierarchical Method selected was the Ward method, because it shows the smallest distance between the clusters selected. The number of Clusters of the FIC pillar using the Hierarchical method is two.

The next stage is to utilize the TwoStep method. To access to the TwoStep method, in SPSS, the first step is to paste the variables in the *Data Editor – Data View*. Then the *Variable View* was selected and the name designation and the measure of each variable were changed, as shown is the previous example of the Hierarchical Method.

After this it was necessary to perform the following steps depicted in Figure 4.3:

- **Menu**: *Analyse*;
- **Submenu**: *Classify;*
- **Select the Method**: *TwoStep Cluster;*
- **Select the variables to be computed.** Select *Number of Clusters - Determine Automatically* and *Schwarz's Bayesian Criterio (BIC)*;
- **Select Output**. Select *Create cluster membership variable.* This step was done so it is possible to obtain the cluster membership.

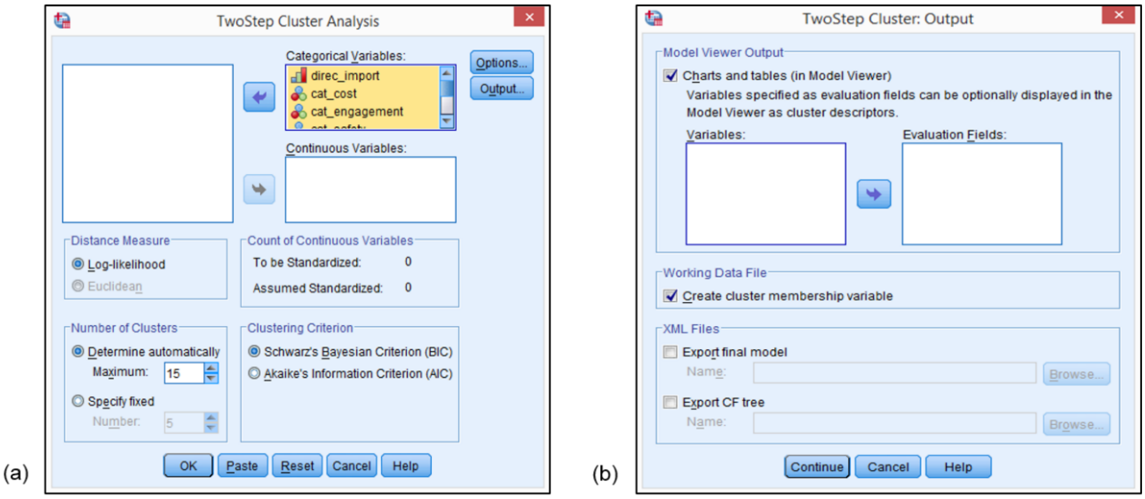

Figure 4.3 - TwoStep Cluster Analysis (a) Variables; (b) Output

For the purpose of this work the information collected from the SPSS when utilizing the TwoStep Method was:

- **Model Summary;**
- **Cluster Sizes;**
- **Cluster Membership**.

The Model Summary and the Cluster Sizes, of FIC pillar, are depicted in Figure 4.4.

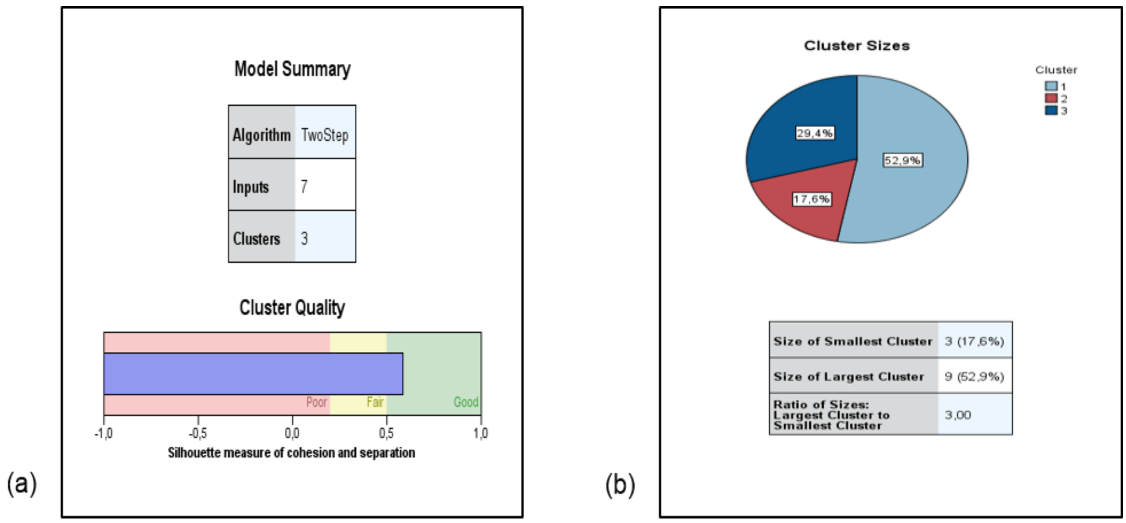

Figure 4.4 - TwoStep Cluster Analysis (a) Model Summary; (b) Cluster Sizes

The average Silhouette is good and the sizes of the Cluster are:

- Cluster 1 - Nine Indicators (52.9%);
- Cluster 2 – Three Indicators (17.6%);
- Cluster 3 – Five Indicators (29.4%).

The Cluster Membership of the TwoStep method, collected from the *FIC – Focused Improvement Cost Pillar*, is described in Table 4.2.

Table 4.2 - FIC TwoStep Cluster Membership

			Cluster 1	Cluster 2	Cluster 3
KMI	Landed Cost	**FIC1**	x		
KPI	Transformation Cost	**FIC2**	x		
KPI	Allocated Expenses	**FIC3**	x		
KPI	Logistic Cost	**FIC4**	x		
KMI	TEE	**FIC5**		x	
KMI	OEE	**FIC6**		x	
KMI	EE	**FIC7**		x	
KMI	Total Waste	**FIC8**	x		
KPI	Process Waste	**FIC9**	x		
KPI	Productivity	**FIC10**	x		
KAI	Loss cost tool updates	**FIC11**	x		
KAI	Standards identified and reviewed	**FIC12**			x
KMI	Energy efficiency	**FIC13**	x		
KAI	Pillar skill gaps reduction vs ideal	**FIC14**			x
KAI	Best Practice Sharing (Poke Yoke, X-ideas and standards)	**FIC15**			x
KPI	Pillar assessment score	**FIC16**			x
KPI	Pillar cost savings	**FIC17**			x
		Total Indicators	**9**	**3**	**5**

In the case of the TwoStep Method the number of Clusters of the FIC pillar is three.

The following stage is to utilize the K-Means method. To access to the K-Means method, in SPSS, the first step is to paste the variables in the *Data Editor – Data View*. Then the *Variable View* was selected and the name designation and the measure of each variable were changed, as shown is the previous methods.

After this it was necessary to perform the following steps depicted in Figure 4.5:

- **Menu**: *Analyse*;
- **Submenu**: *Classify;*
- **Select the Method**: *K-Means Cluster;*
- **Select the variables to be computed.** Select *Iterate and Classify* ;
- **Select Options.** Select *Initial Cluster centers*, *ANOVA table* and *Cluster information for each case;*
- **Save.** Select *Cluster Membership* and *Distance from Cluster center.*

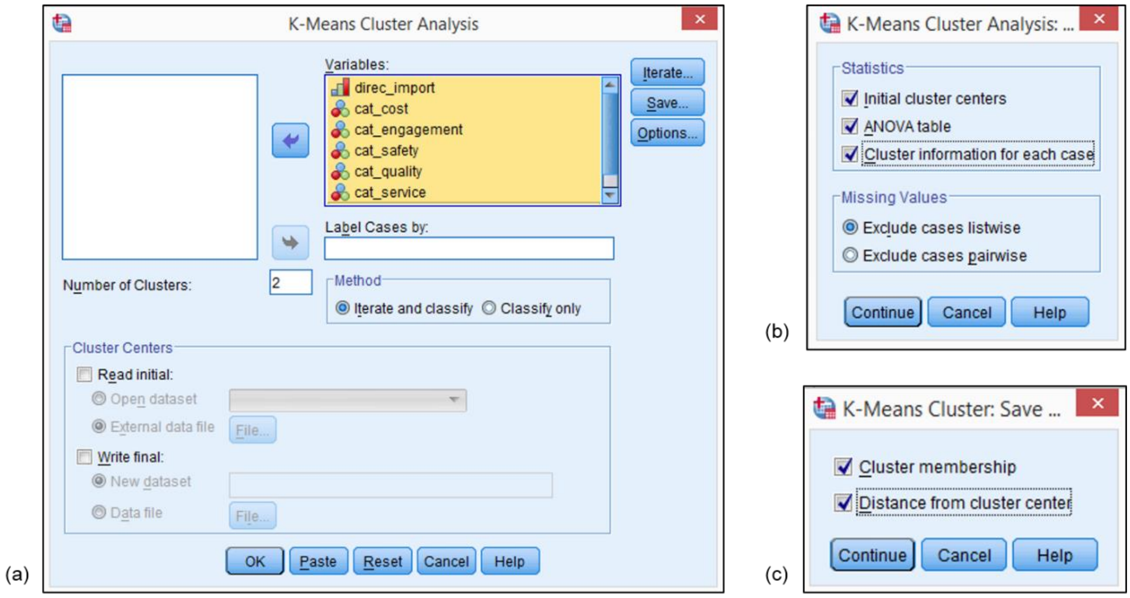

Figure 4.5 - K-Means Cluster Analysis (a) Variables; (b) Options; (c) Save

For the purpose of this work the information collected from the SPSS when utilizing the TwoStep Method was:

- **Distance between Final Cluster Centers;**
- **Cluster Membership**.

The Distance between Final Cluster Centers, of FIC pillar, are depicted in Table 4.3.

Table 4.3 - K-Means Cluster Distance between Cluster Centers

Cluster	1	2
1		4.379
2	4.379	

The centres of the two Cluster are separated from each other. The greater the distances, the greater the heterogeneity between objects of different clusters.

The Cluster Membership of the K-Means method, collected from the *FIC – Focused Improvement Cost Pillar*, is described in Table 4.4.

Table 4.4 - FIC K-Means Cluster Membership

			Cluster 1	Cluster 2
KMI	Landed Cost	**FIC1**	x	
KPI	Transformation Cost	**FIC2**	x	
KPI	Allocated Expenses	**FIC3**	x	
KPI	Logistic Cost	**FIC4**	x	
KMI	TEE	**FIC5**		x
KMI	OEE	**FIC6**		x
KMI	EE	**FIC7**		x
KMI	Total Waste	**FIC8**	x	
KPI	Process Waste	**FIC9**	x	
KPI	Productivity	**FIC10**		x
KAI	Loss cost tool updates	**FIC11**	x	
KAI	Standards identified and reviewed	**FIC12**		x
KMI	Energy efficiency	**FIC13**	x	
KAI	Pillar skill gaps reduction vs ideal	**FIC14**		x
KAI	Best Practice Sharing (Poke Yoke, X-ideas and standards)	**FIC15**		x
KPI	Pillar assessment score	**FIC16**		x
KPI	Pillar cost savings	**FIC17**		x
		Total Indicators	**8**	**9**

The final stage of this cluster analysis is to acknowledge all the Cluster Analysis Methods that were utilized and their result number of clusters. All the information related with the Cluster Analysis applied in the other seven pillars is depicted in Appendix – B. In order to show which of the four Hierarchical methods was chosen for each of the eight pillars of the company, Table 4.5 was constructed. As stated before the decision to choose one of this for each pillar was based on smallest distance between the clusters selected in the Dendogram.

Table 4.5 - Hierarchical Clusters methods decision

	Nearest	Furthest	Ward	Centroid
FIC			x	
AM		x		
PM			x	
QM			x	
EM				x
ET		x		
SCO			x	
SHE			x	

The first result of the Cluster analysis is depicted in Table 4.6.

Table 4.6 - Results Cluster Analysis

	Number of Clusters		
	Hierarchical	**TwoStep**	**K-Means**
FIC	2	3	2
AM	2	3	2
PM	2	2	2
QM	2	3	2
EM	2	3	2
ET	2	3	2
SCO	2	3	2
SHE	2	3	2

To solve the problem of choosing which Cluster method should be utilized for the purpose of this assessment, the author applied the Analytic Hierarchy Process. This method is going to be described in the following section.

4.2 Analytic Hierarchy Process Results

The Analytic Hierarchy Process is the same for the eight pillars and is depicted next. After defining the Criteria pair comparison table, in Table 3.5 of the previous chapter, the next step is to compile this comparisons in a Comparison Matrix A as the following Table 4.7.

The criterion codes are:

- **I -** Suitability;
- **II -** Cluster Structure (number of Clusters generated);
- **III -** Output;
- **IV -** Sample Size;
- **V** - Bootstrapping;
- **VI -** Automatic definition of the number of Clusters.

Table 4.7 - Comparison Matrix A (AHP)

	I	**II**	**III**	**IV**	**V**	**VI**
I	1	6	1/3	5	3	6
II	1/6	1	1/7	2	2	3
III	3	7	1	7	5	7
IV	1/5	1/2	1/7	1	1/3	3
V	1/3	1/2	1/5	3	1	4
VI	1/6	1/2	1/7	1/3	1/4	1
$\sum$	**4,867**	**15,333**	**1,962**	**18,333**	**11,583**	**24**

After the Comparison Matrix is defined the sum of each column is calculated as in the previous matrix.

The next step is the construction of the Matrix A_{norm} and the definition of the priorities/weighting $\left(\sum a_{jk}/_{6}\right)$ of each of the criteria, which is presented in Table 4.8. Each value is the fraction between each cell and its column sum.

Table 4.8 - Matrix A_{norm} (AHP)

	I	**II**	**III**	**IV**	**V**	**VI**	$\sum a_{jk}/_{6}$
I	0,205	0,391	0,17	0,273	0,259	0,25	**0,258**
II	0,034	0,065	0,073	0,109	0,173	0,125	**0,097**
III	0,616	0,457	0,51	0,382	0,432	0,292	**0,448**
IV	0,041	0,033	0,073	0,055	0,029	0,125	**0,059**
V	0,068	0,033	0,102	0,164	0,086	0,167	**0,103**
VI	0,034	0,022	0,073	0,018	0,022	0,042	**0,035**

Consistency Validation is the next step and the objective is that the $Consistency\ Ratio\ (CR)$ is greater than:

$$CR < 0.1 \tag{12}$$

The first step of the consistency validation is to multiply each value of each column from the comparison Matrix A with the weight of each criteria from the A_{norm} matrix.

$$0.258 \times \begin{bmatrix} 1 \\ 1/6 \\ 3 \\ 1/5 \\ 1/3 \\ 1/6 \end{bmatrix} + 0.097 \times \begin{bmatrix} 6 \\ 1 \\ 7 \\ 1/2 \\ 1/2 \\ 1/2 \end{bmatrix} + 0.448 \times \begin{bmatrix} 1/3 \\ 1/7 \\ 1 \\ 1/7 \\ 1/5 \\ 1/6 \end{bmatrix} + 0.059 \times \begin{bmatrix} 5 \\ 2 \\ 7 \\ 1 \\ 3 \\ 1/3 \end{bmatrix} + 0.103 \times \begin{bmatrix} 3 \\ 2 \\ 5 \\ 1/3 \\ 1 \\ 1/4 \end{bmatrix} + 0.035 \times \begin{bmatrix} 6 \\ 3 \\ 7 \\ 3 \\ 4 \\ 1 \end{bmatrix} = \begin{bmatrix} 1.802 \\ 0.634 \\ 3.073 \\ 0.363 \\ 0.645 \\ 0.220 \end{bmatrix}$$

The next step of this validation is to calculate the mean, λ_{max}, which is the sum of the division of each of the vector elements of the sums obtained by the respective weight, divided by the number of criteria.

$$\lambda_{max} = \frac{\sum\left(\frac{1.802}{0.258} + \frac{0.634}{0.097} + \frac{3.073}{0.448} + \frac{0.363}{0.059} + \frac{0.645}{0.103} + \frac{0.220}{0.035}\right)}{6} = 6.509$$

After λ_{max} is calculated the following step is to calculate the $Consistency\ Index\ (CI)$, where n is the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{6.509 - 6}{6 - 1} = 0.102$$

The last step of the validation of the consistency is to calculate $Consistency\ Ratio\ (CR)$.

$$CR = \frac{CI}{RI} \tag{13}$$

RI is the consistency index of a comparison matrix generated randomly. The values of RI are depicted in Table 4.9.

Table 4.9 - Values of Random Index (RI)

m	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

$$CR = \frac{0.102}{1.24} = 0.082 < 0.1$$

Is this case the consistency was confirmed.

Subsequently, the Comparison Matrixes of each method, for each of the criteria, are compiled and the priorities are calculated. The calculus are the same as the calculus for Criteria pair Comparison Matrix. $Consistency\ Ratio\ (CR)$ is calculated for each of the criteria.

The method codes used in Table 4.10 are:

- **H -** Hierarchical;
- **KM –** K-Means;
- **TS -** TwoStep;

I - Suitability

Table 4.10 - Comparison Matrix S and Priorities (I)

	H	KM	TS
H	1	1/2	1/3
KM	2	1	1/2
TS	3	2	1
$\sum$	**6**	**3.5**	**1.833**

	H	KM	TS	$\sum a_{jk}/3$
H	0.167	0.143	0.182	**0.164**
KM	0.333	0.286	0.273	**0.297**
TS	0.5	0.571	0.545	**0.539**

Consistency Validation is the next step and the objective is that the $Consistency\ Ratio\ (CR)$ is greater than equation (12).

The first step of the consistency validation is to multiply each value of each column from the comparison Matrix S with the weight of each criteria from the S_{norm} matrix.

$$0.164 \times \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix} + 0.297 \times \begin{bmatrix} 1/2 \\ 1 \\ 2 \end{bmatrix} + 0.539 \times \begin{bmatrix} 1/3 \\ 1/2 \\ 1 \end{bmatrix} = \begin{bmatrix} 0.492 \\ 0.895 \\ 1.625 \end{bmatrix}$$

The next step of this validation is to calculate the mean, λ_{max}, which is the sum of the division of each of the vector elements of the sums obtained by the respective weight, divided by the number of criteria.

$$\lambda_{max} = \frac{\sum\left(\frac{0.492}{0.164} + \frac{0.895}{0.297} + \frac{1.625}{0.539}\right)}{3} = 3.01$$

After λ_{max} is calculated the following step is to calculate the $Consistency\ Index\ (CI)$, where n is the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{3.01 - 3}{3 - 1} = 0.004$$

The last step of the validation of the consistency is to calculate $Consistency\ Ratio\ (CR)$.

$$CR = \frac{0.004}{0.58} = 0.008 < 0.1$$

Is this case the consistency was confirmed.

All the other five Criteria Comparison Matrixes of each method are described in Appendix C, their priorities were calculated and their consistency was validated.

The result of the Priorities Calculated for each method are presented in Table 4.11:

Table 4.11 - Priorities Matrix (AHP)

	Criteria					
Methods	I	II	III	IV	V	VI
Hierarchical	0.164	0.137	0.619	0.143	0.608	0.098
K-Means	0.297	0.239	0.096	0.429	0.272	0.334
TwoStep	0.539	0.623	0.284	0.429	0.12	0.568

Finally, the Ranking of the Methods is calculated by the following equation which are presented on Table 4.12.

$$0.258 \times \begin{bmatrix} 0.164 \\ 0.297 \\ 0.539 \end{bmatrix} + 0.097 \times \begin{bmatrix} 0.137 \\ 0.239 \\ 0.623 \end{bmatrix} + 0.448 \times \begin{bmatrix} 0.619 \\ 0.096 \\ 0.284 \end{bmatrix} + 0.059 \times \begin{bmatrix} 0.143 \\ 0.429 \\ 0.429 \end{bmatrix} + 0.103 \times \begin{bmatrix} 0.608 \\ 0.272 \\ 0.12 \end{bmatrix} + 0.035 \times \begin{bmatrix} 0.098 \\ 0.334 \\ 0.568 \end{bmatrix} = \begin{bmatrix} 0.408 \\ 0.208 \\ 0.384 \end{bmatrix}$$

Table 4.12 - Ranking Method Priorities (AHP)

Methods	Priority	Ranking
Hierarchical	0.408	1st
K-Means	0.208	3rd
TwoStep	0.384	2nd

As the priorities of the first and second alternatives are very close, it was decided that the criterion to choose between them would be a discriminant analysis in order to verify which of the cluster analysis methods is valid for the pillar in study. The Discriminant Analysis is going to be described in the following section.

4.3 Discriminant Analysis Results

For the purpose of this work the Discriminant Analysis is utilized after the Cluster Analysis and Analytic Hierarchy Process so it can validate the obtain clusters.

As in the previous Chapters, only the FIC pillar is described in detail to show an example of the progress of the methodology. All of the results obtain from the Discriminant Analysis are going to be explained.

The data to be computed in SPSS is shown in *Table 3.3 - FIC Pillar Cluster Analysis Input*, in *Table 4.1 - FIC Hierarchical Cluster Membership*, and *Table 4.2 – FIC TwoStep Cluster Membership*. After defining the variables the next step is to introduce them in the software. The methods that are going to be tested are:

1. **Hierarchical**;
2. **TwoStep**;

To access to the Discriminant Analysis of the Hierarchical method, in SPSS, the first step was to paste the variables in the *Data Editor – Data View*.

After this it was necessary to perform the following steps depicted in Figures 4.6 and 4.7:

- **Menu**: *Analyse*;
- **Submenu**: *Classify;*
- **Select the Method**: *Discriminant;*
- **Select the variables to be computed.** Select *Independent Variables* (variables from the cluster analysis), *Group Variables* (one of the two cluster methods), and *Use Stepwise Method*;
- **Select Range.** Select *Define Range*;
- **Select Statistics.** Select *Descriptive Means, Univariate ANOVAs,* and *Box's M*. Select *Function Coefficients Fisher's* and *Unstandardized*. Select *Matrices Within-groups correlation;*

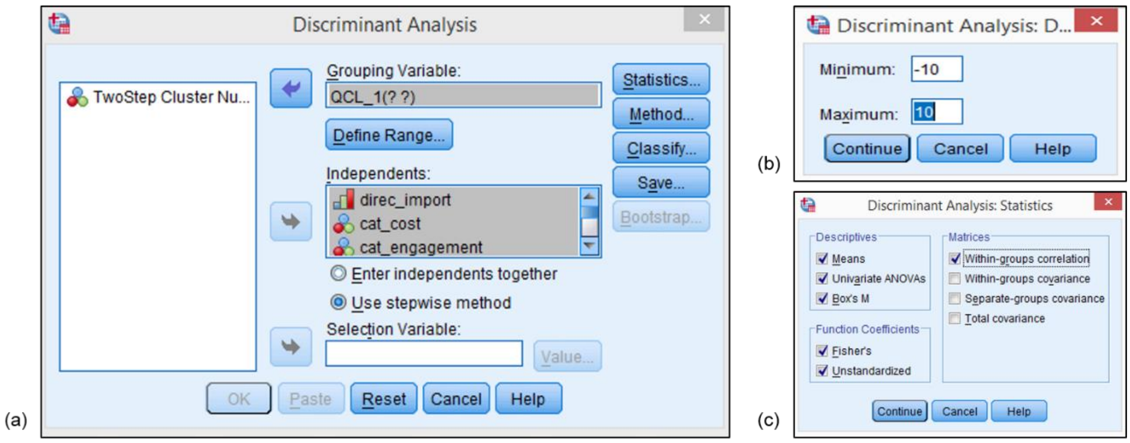

Figure 4.6 - Discriminant Analysis (a) Variables; (b) Range; (c) Statistics

- **Select Method.** Select *Method Wilk's lambda*;
- **Select Classification.** Select *Prior Probabilities Compute from group sizes*. Select *Display Summary table* and *Leave-one-out-classification*. Select *Plots Combined-groups, Separate-groups,* and *Territorial map*.
- **Select Save.** Select *Predicted groups membership, Discriminant scores,* and *Probabilities of group membership.*

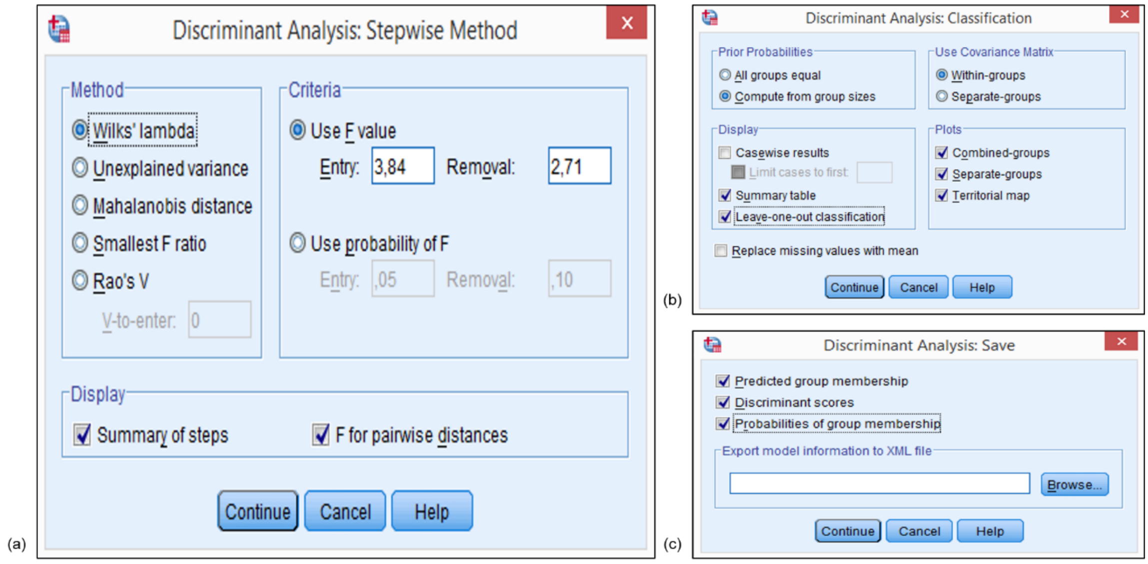

Figure 4.7 - Discriminant Analysis (a) Method; (b) Classification; (c) Save

For the purpose of this work the information collected from the SPSS when utilizing the Discriminant Analysis was:

- **Test of Equality of Group Means.** Verifies if the equality of means is rejected;
- **Eigenvalues.** Determines the relative importance of the discriminant functions;
- **Wilk's lambda.** Global validation of the model**;**
- **Structure Matrix.** Verifies the relative importance of the independent variables**;**
- **Canonical Discriminant Function.** Calculates the discriminant score of the function;
- **Classification Results.** Verifies the reliability of the model.

The Test of Equality of Group Means collected from the *FIC – Focused Improvement Cost Pillar*, is described in Table 4.13.

Table 4.13 - FIC Tests of Equality of Group Means

	Wilk's lambda	F	df1	df2	Sig.
direc_import	,110	120,789	1	15	,000
cat_cost	,630	8,824	1	15	,010
cat_engagement	,416	21,017	1	15	,000
cat_safety	,930	1,134	1	15	,304
cat_quality	,992	,126	1	15	,728
cat_service	,726	5,647	1	15	,031
cat_innovation	.[a]				

a. Cannot be computed because this variable is a constant.

Only in direc_import, cat_cost the null hypothesis of equality of means is rejected.

The Eigenvalues and the Wilk's lambda collected from the FIC pillar, is described in Table 4.14 and 4.15.

Table 4.14 - FIC Eigenvalues

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	20,016[a]	100,0	100,0	,976
a. First 1 canonical discriminant functions were used in the analysis.				

Table 4.15 - FIC Wilk's lambda

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1	,048	42,634	2	,000

From this tables it is possible to conclude that the first discriminant function explains 100% of the variance and that this function is significant, because $Sig < 0.05$.

The Structure Matrix collected from the FIC, is described in Table 4.16.

Table 4.16 - FIC Structure Matrix

	Function 1
direc_import	,634
cat_engagement[a]	,366
cat_quality[a]	-,357
cat_safety[a]	-,338
cat_cost	-,171
cat_service[a]	-,171
Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions	
a. This variable not used in the analysis.	

From this table we can verify that direc_import and cat_cost are correlated with the first function. The remaining variables are excluded.

The Canonical Discriminant Function collected from the FIC pillar, is described in Table 4.17.

Table 4.17 - FIC Canonical Discriminant Function

	Function 1
direc_import	1,634
cat_cost	-2,652
(Constant)	1,872
Unstandardized coefficients	

The discriminant function is equal to:

$$F1 = 1.872 + 1.634 \times (direc\_import\ ) - 2.652 \times (cat\_cost)$$

Finally, the Classification Results collected from FIC pillar is described in Table 4.18.

Table 4.18 - FIC Classification Results

Cluster Number of Case			**Predicted Group Membership**		**Total**
			1	**2**	
Original	Count	1	8	0	8
		2	0	9	9
	%	1	100,0	0,0	100,0
		2	0,0	100,0	100,0
Cross-validated[b]	Count	1	1	7	8
		2	9	0	9
	%	1	12,5	87,5	100,0
		2	100,0	0,0	100,0

a. 100,0% of original grouped cases correctly classified.

b. Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.

c. 5,9% of cross-validated grouped cases correctly classified.

From the Cross-validated results it is possible to verify the robustness of the model. For the purpose of this work the percentage of the cross-validated needs to be greater or equal to 50%. So in this case the objects were not sorted correctly, because the value is 5.9%.

Another Discriminant Analysis was made for the FIC pillar, with the variables of the TwoStep method, and the value of the cross-validated was 17,6%, which does not validate the reliability the model in analysis.

The final stage of this discriminant analysis is to acknowledge the reliability of the Cluster Analysis Methods that were selected. All the information related with the Discriminant Analysis applied in the other seven pillars is depicted in Appendix – D.

As stated before the decision is based on:

$$Cross - validated \geq 50\% \quad (14)$$

In order to show the robustness of the two Cluster Analysis methods, for each of the eight pillars of the company, Table 4.19 was created.

Table 4.19 - Discriminant Analysis of the eight pillars (cross-validated)

	Hierarchical	TwoStep
FIC	5.9%	17.6%
AM	0%	0%
PM	0%	71.4%
QM	65%	10%
EM	90.9%	9.1%
ET	46.7%	-
SCO	0%	50%
SHE	88%	64%

It is possible to verify that in the case of *QM-Quality Maintenance*, *EM – Early Management*, and *SHE – Safety, Health and Environment* pillars the clusters of the Hierarchical Method are robust. For the cases of *PM – Planned Maintenance* and *SCO – Supply Chain and Office* pillars the clusters of the TwoStep method are robust.

In the case of *FIC – Focused Improvement Cost*, *AM - Autonomous Maintenance*, and *ET-Education and Training* pillars the clusters from the both methods are not robust.

When the reliability of the model in the both cases, Hierarchical and TwoStep methods, is not validated it was decided that the study continues with the Principal Component Analysis (PCA). The PCA will define, for the cases when the robustness is not validated in the Discriminant Analysis, which are the Principal components of the pillars. The Principal Component Analysis is going to be addressed in the following section.

4.4 Principal Component Analysis Results

For the purpose of this work the Principal Component Analysis is the last method to be selected. It comes after the Discriminant Analysis, and only for the cases where the robustness isn't validated.

As in the previous Chapters, only the FIC pillar is described in detail to show an example of the progress of the methodology. All of the results obtain from the Principal Component Analysis are going to be explained. The data for the Principal Component Analysis is depicted in Appendix – E.

To access to the Principal Component Analysis, in SPSS, the first step is to paste the variables in the *Data Editor – Data View*. Then the *Variable View* was selected and the name designation and the measure of each variable were changed from FIC1 to FIC17. The data for the Principal Component Analysis is depicted in Appendix – E.

After this it was necessary to perform the following steps depicted in Figure 4.8:

- **Menu**: *Analyse*;
- **Submenu**: *Dimension Reduction;*
- **Select the Method**: *Factor;*
- **Select the variables to be computed**;
- **Select Descriptives.** Select *Initial Solution*, *Coefficients*, *KMO and Bartlett's test of sphericity*, and *Anti-image;*
- **Select Extraction.** Select *Correlation Matrix*;
- **Select Rotation.** Select *Varimax*.

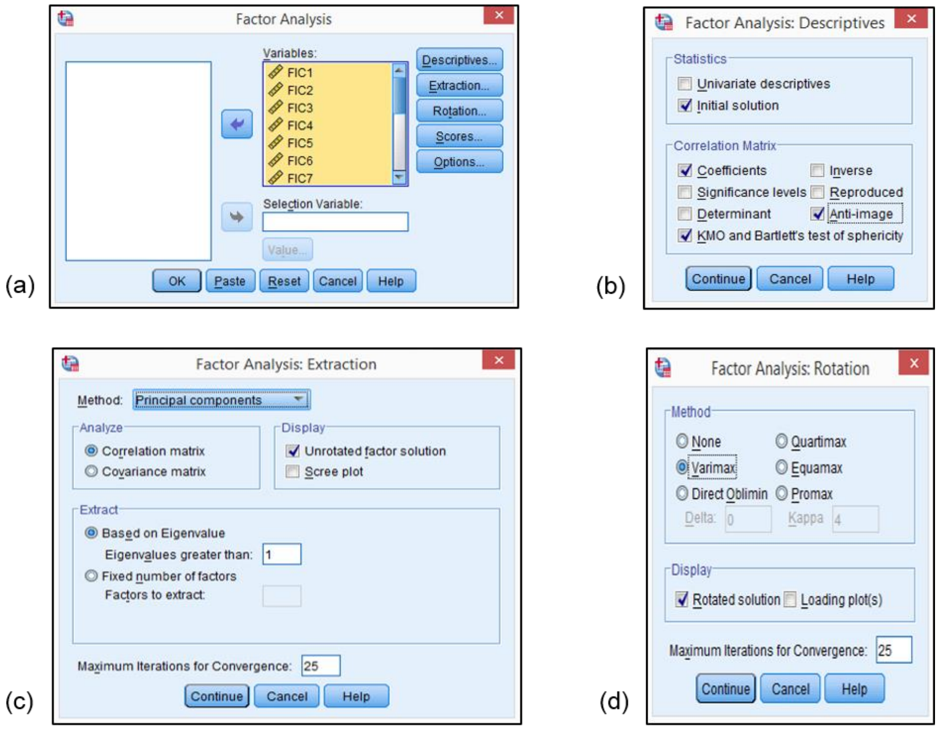

Figure 4.8 - Principal Component Analysis (a) Variables; (b) Descriptive; (c) Extraction; (d) Rotation

For the purpose of this work the information collected from the SPSS when utilizing the Principal Components Analysis was:

- **KMO and Bartlett's Test.** It test the suitability of the data;
- **Total Variance Explained.** It shows the number of Components**;**
- **Rotated Component Matrix.** Loadings of variables in each of the components.

The KMO and Bartlett's Test collected from the *FIC – Focused Improvement Cost Pillar* is described in Table 4.20.

Table 4.20 - FIC pillar KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,920
Bartlett's Test of Sphericity	Approx. Chi-Square	2295,806
	df	136
	Sig	0,000

The value of KMO Test is 0.920, which demonstrates that the data it is highly suitable.

In the Bartlett's Test there are two hypothesis:

$$H_0: The\ correlation\ Matrix\ is\ an\ Identity\ Matrix$$

$$H_1: The\ correlation\ Matrix\ is\ not\ an\ Identity\ Matrix$$

The value of the Sig. of the Bartlett's Test is:

$$Sig. < 0.05 \quad (15)$$

This means that the null hypothesis is rejected.

For the analysis and interpretation purpose the author is only concerned with the Extracted Sums of Square Loading (Chetty & Datt, 2015).

The higher is the absolute value of the loading, the more the factor contributes to the variable. From this results it is possible to recognize three different Components. The first one with thirteen indicators, the second with three indicators and the last one with only one indicator.

The Total Variance Explained and the Rotated component Matrix collected from the *FIC – Focused Improvement Cost Pillar* can be combined in one table. The cumulative value of the Total Variance Explained is 75,25% with 3 Components. This is described in Table 4.21.

Table 4.21 - FIC Total Variance Explained and Rotated Component Matrix

Indicators			Components		
			1	2	3
KMI	Landed Cost	**FIC1**	-,795	,132	-,059
KPI	Transformation Cost	**FIC2**	-,832	,055	,054
KPI	Allocated Expenses	**FIC3**	-,826	,042	-,041
KPI	Logistic Cost	**FIC4**	-,848	,024	-,073
KMI	TEE	**FIC5**	,795	-,059	,147
KMI	OEE	**FIC6**	,819	-,023	,072
KMI	EE	**FIC7**	,826	-,021	-,029
KMI	Total Waste	**FIC8**	-,044	,978	,050
KPI	Process Waste	**FIC9**	,046	,920	-,020
KPI	Productivity	**FIC10**	,904	-,007	-,053
KAI	Loss cost tool updates	**FIC11**	-,005	,070	,977
KAI	Standards identified and reviewed	**FIC12**	,816	,026	-,047
KMI	Energy efficiency	**FIC13**	-,809	-,092	,189
KAI	Pillar skill gaps reduction vs ideal	**FIC14**	,854	-,048	,011
KAI	Best Practice Sharing (Poke Yoke, X-ideas and standards)	**FIC15**	,759	,113	-,057
KPI	Pillar assessment score	**FIC16**	,873	,066	-,046
KPI	Pillar cost savings	**FIC17**	-,043	,978	,050
	Variance Explained		52.5%	16.6%	6.2%
				75.25%	

The first factor account for 52.5% of the variance, the second 16.6%, and the third 6.2%. All the remaining factors are not significant.

The idea of rotation is to reduce the number of factors on which the variables under investigation have high loadings. Rotation does not actually change anything but makes the interpretation f the analysis easier (Chetty & Datt, 2015).

Considering a satisfactory solution 60% of Total Variance it is clearly demonstrated that the PCA is a good solution for the FIC pillar. All the information related with the Principal Component Analysis applied in the other two pillars is depicted in Appendix – E.

4.5 Results Discussion

At the beginning of the proposal the number of existing indicators was 131 divided in eight pillars as presented in Table 4.22.

Table 4.22 - Initial State Pillars and Indicators

Pillar	KMI	KPI	KAI	Pillar's PIs
FIC	6	7	4	17
AM	-	3	12	15
PM	-	11	3	14
QM	3	10	7	20
EM	-	8	3	11
ET	-	3	12	15
SCO	1	7	6	14
SHE	1	16	8	25
Total	**11**	**65**	**55**	**131**

After the development of the methodological proposal the existing pillar indicators were congregate. The result is depicted in Table 4.23, which has the number of cluster or components and the respective Analysis method that originate them.

Table 4.23 - Decision methods and number of Clusters and Components

	Cluster Analysis		**Principal Component Analysis**
Pillars	Hierarchical	TwoStep	
FIC			3 Components
AM			2 Components
PM		2 Clusters	
QM	2 Clusters		
EM	2 Clusters		
ET			2 Components
SCO		3 Clusters	
SHE	2 Clusters		

It is possible to acknowledge that there are three pillars that were clustered with the help of the Hierarchical method, two clusters from the TwoStep method, and finally three components that were created when implementing the Principal Component Analysis.

This Clusters and Factors, and their respective description, are depicted as follows (from Table 4.24 to Table 4.31). The names of each of the components/cluster was select by the author considering the respective belonging indicators.

- **FIC – Focused Improvement and Cost:**
    - **i. Component 1 –** Focus Improvement;
    - **ii. Component 2 –** Operational Waste;
    - **iii. Component 3 –** Lost Cost.

Table 4.24 - FIC pillar Component Description

Components	Indicators	Description of the Component
1. Focused Improvement	FIC1 – Landed Cost FIC2 – Transformation Cost FIC3 – Allocated Expenses FIC4 – Logistic Cost FIC5 – TEE FIC6 – OEE FIC7 – EE FIC10 – Productivity FIC12 – Standards identified and reviewed FIC13 – Energy Efficiency FIC14 – Pillar skill gaps reduction vs ideal FIC15 – Best Practice Sharing (Poke-Yoke, X-ideas and standards) FIC16 – Pillar Assessment Score	**Component focused on the improvement of different areas like costs, efficiencies and company employee's skills.**
2. Operational Waste	FIC8 – Total Waste FIC9 – Process Waste FIC17 – Pillar Cost Savings	**Component focused on the company's operational and structural wastes and the savings associated with improvement implementation**
3. Lost Cost	FIC11 – Lost Cost tool updates	**Component concerns the lost costs that come when the company is updating the tools implemented in the factory.**

- **AM – Autonomous Maintenance:**
  - i. **Component 1 –** Engagement in AM activities;
  - ii. **Component 2 –** Critical Points of diagnosis.

Table 4.25 - AM pillar Component Description

Components	Indicators	Description of the Components
1. Engagement in AM activities	AM1 – Total CIL (Cleaning, Inspection and Lubrication) time loss AM4 – Total tags gap AM5 – Tags removal by operators AM7 – Cleaning time reduction AM8 – Lubrication time reduction AM9 – Inspection time reduction AM10 – Transfer of CIL activities PM to AM AM11 – Operators involvement in BD AM12 – Q and C points under AM care AM13 – AM task completion AM14 – Pillar skill gaps reduction vs ideal AM15 – Pillar assessment score	**Component focused on the engagement of all company's employees in the different activities related with the Autonomous Maintenance pillar and breakdowns problem's solving.**
2. Critical Points of diagnosis	AM2 – Number of Breakdowns (BD) due to lack of CIL AM3 – Total tags AM6 – HT areas and SOD (Severity, Occurance and Detection) eradicated	**Component concerns the critical point that are very important to evaluate the status of the company and the problem's solution implemented**

- **PM – Planned Maintenance:**
  - i. **Cluster 1 –** Breakdowns and Mean Time Measurements;
  - ii. **Cluster 2 –** Performance and Evaluation of the PM pillar.

Table 4.26 - PM pillar Component Description

Components	Indicators	Description of the Components
1. Breakdowns and Mean time Measurements	PM1 – MTBF (Mean Time Between Failures) Consolidated PM2 – MTBF A PM3 – BD Factory (By month) PM4 – BD + Adjustments done by the mechanics PM5 – BD/Mio produced PM6 – MDT (Mean Down Time) PM7 – MTTR (Mean Time To Repair)	**Cluster focused on the breakdowns in the factory, reliability measurements and costs reduction related with Planned Maintenance concerns.**

Table 2.6 - PM pillar Component Description (Cont.)

Components	Indicators	Description of the Components
	PM8 – Zero BD Machines PM9 – Maintenance Cost Reduction PM10 – Spare parts stock reduction value	
2. Performance and Evaluation of the PM pillar	PM11 – PM Task Completion PM12 – Eradication of BD failure modes PM13 – Pillar skill gaps reduction vs ideal PM14 – Pillar assessment score	**Cluster focused on the performance of the PM pillar and also the eradication of the breakdowns.**

- **QM – Quality Maintenance:**
  - i. **Cluster 1 –** Customer Follow-through;
  - ii. **Cluster 2 –** Quality Measurement (Performance and Evaluation).

Table 4.27 - QM pillar Component Description

Components	Indicators	Description of the Components
1. Customer Follow-through	QM1 – Claims QM2 – Technical issues food safety category (specific BRCIOP) QM3 – Claims frequency QM4 – Consolidated issues (CI's) QM5 – Customer issue lead-time IRP (Issue Resolution Procedure) I, II, III QM6 – IRP I (Days) QM7 – IRP II (Days) QM8 – IRP III (Days) QM9 – Total Waste QM10 – Defect Waste QM12 – Internal Claims QM13 – Q and C points gap QM14 – Gage R&R on main parameters	**Cluster focused on the customer follow-through, like the consolidated issues and Issue resolution and all the claims, and the respective wastes.**
2. Quality Measurement (Performance and Evaluation)	QM11 – BRC/IOP or SQF Food Safety audit result QM15 – Cpk on main parameters QM16 – Eradication of defect modes QM17 – Best practice sharing (MP sheets, Poke-Yoke, X-ideas and Standards) QM18 – Pillar Skill gaps reduction vs ideal QM19 – Pillar assessment score QM20 – Pillar cost savings	**Cluster focused on the performance of the QM pillar and the eradication of the defects.**

- **ET – Education and Training:**
  - i. **Component 1 –** Training Performance;
  - ii. **Component 2 –** Improvements and Procedures.

Table 4.28 - ET pillar Component Description

Components	Indicators	Description of the Components
1. Training Performance	ET1 – Pillar skill gaps reduction vs ideal level ET2 – Operational skill gaps reduction vs ideal level ET3 – Technical skill gaps reduction for operators vs ideal level ET4 – Technical skill gaps reduction for maintenance people vs ideal level ET5 – Pillar skill gap closure (vs, yearly target) ET6 – Training hours total ET7 – training hours/employee ET10 – Number of internal trainers ET11 – Training audience achieved ET12 – Training effectiveness (retraining) ET13 – Training material coverage skills ET14 – Pillar assessment score	**This component is focused on the training and performance of the company's employees an on the skills gaps that need to be reduced for each of the specific work area. It also describes the number of the hours required for this training and the respective effectiveness.**
2. Improvements an Procedures	ET8 – Eradicated man or method related loss ET9 – Number of OPL (One-point lesson) and SOP (Standard Operation Procedure)	**This component is concerned with the procedures created by the company's employees, like SOP and OPL, and the improvement in the losses that originate the need for this procedure.**

- **EM – Early Management:**
  - i. **Cluster 1 –** Development Management;
  - ii. **Cluster 2 –** Project non conformities.

Table 4.29 - EM pillar Component Description

Components	Indicators	Description of the Components
1. Development Management	EM1 – VSU (Vertical Start Up) of EM projects EM2 – EM within budget EM3 – Overall investment plan	**Cluster focused on the Early Management pillar development and**

Table 4.29 - EM pillar Component Description (Cont.)

Components	Indicators	Description of the Components
	EM4 – On time EM5 – Alfa beta ratio EM6 – Coverage of A and B class projects with EM EM8 – Pillar Cost savings EM9 – Pillar assessment score EM10 – Best Practice Sharing (MP, Poke-Yoke, X-ideas, standards) EM11 – Pillar skill gaps reduction vs ideal	**performance, like the evaluation of the pillar's projects and its investments.**
2. Project non conformities	EM7 – PDA (Project Defect Analysis) losses	**This cluster is concerned with the analysis of defects related with the pillar's projects and the subsequent losses related to them.**

- **Supply Chain and Office:**
    - **i. Cluster 1 –** Delivery and Inventory Costs;
    - **ii. Cluster 2 –** Customer Satisfaction;
    - **iii. Cluster 3 –** Pillar Assessment (Performance and Evaluation).

Table 4.30 - SCO pillar Component Description

Components	Indicators	Description of the Components
1. Delivery and Inventory Costs	SCO1 – Perfect Delivery SCO2 – Finished goods inventory SCO3 – Finished goods inventory SCO4 – Base material inventory SCO5 – SC logistics costs (outbound)	**This cluster is focused on the perfect delivery to the customer and all the costs related with inventory and logistics operations.**
2. Customer Satisfaction	SCO6 – Customer Satisfaction Index SCO11 – Volume Delivered	**This cluster is focused on the Customer Satisfaction and the results of the company's delivery operations.**

Table 4.30 - SCO pillar Component Description (Cont.)

Components	Indicators	Description of the Components
3. Pillar Assessment (Performance and Evaluation)	SCO7 – Best Practice Sharing (Poke-Yoke, X-ideas and Standards) SCO8 – SC & Office teams and initiatives (VSM Makigami) SCO9 – Pillar skill gaps reduction vs ideal SCO10 – Pillar assessment score SCO12 – Office Tags SCO13 – Office Tags gaps SCO14 – Pillar Cost Savings	**This cluster is concerned with the evaluation and performance of the Supply Chain and Office pillar and the relative tags that are originated and solved.**

- **Safety, Health and Environment:**
  - i. **Cluster 1 –** Risk assessment, Incidents and Control Measures;
  - ii. **Cluster 2 –** Pillar and Incidents Assessment.

Table 4.31 - SHE pillar Component Description

Components	Indicators	Description of the Components
1. Risk assessment, Incidents and Control Measures	SHE1 – Total incidents SHE2 – Fatality SHE3 – Permanent disability accident SHE4 – Lost-time accident (LTA) rate SHE5 – Restricted-work cases (RW) SHE6 – Medical-treatment cases (MT) SHE7 – First-aid treatment cases (FA) SHE8 – Serious near miss (SNM) SHE9 – Near miss reported SHE10 – Occupational Illness cases SHE11 – Lost time due to accident SHE13 – Risk level Reduction (Risks level 1 still active) SHE14 – Risk level Reduction (Risks level 2 still active) SHE15 – BOSS (Behaviour Observation Survey System) reported SHE16 – Safety tags SHE17 – Absenteeism SHE22 – Environmental incidents number/month SHE23 – Water consumption SHE25 – Environment tags + BOSS audits	**This cluster is focused on all incidents related with safety and environment of company and the assessment of the risk activities still active. It also concerns the different control measures implemented for the control of the Safety, Health and Environment pillar, like the BOSS audits and the safety tags.**

Table 4.31 - SHE pillar Component Description (Cont.)

Components	Indicators	Description of the Components
2. Pillar and Incidents Assessment	SHE12 – Near misses analysed SHE18 – Best Practice Sharing (MP, Poke-Yoke, X-ideas, standards) SHE19 – Pillar skill gaps reduction vs ideal SHE20 – Pillar assessment score SHE21 – Pillar cost savings SHE24 – Waste handling, recycling rate	**This cluster evaluates the performance of the incidents control measures like the incidents analysed and the recycling rate. It also concerns the evaluation of the performance of this pillar**

For the purpose of comparing the initial state to the state of the system after the development of the methodology another Table was assembled with the final number of Clusters/Factors. This results are shown in Table 4.32.

Table 4.32 - After methodology development Pillars and Indicators

Pillar	Initial Cluster/Indicators	Final Cluster/Indicators
FIC	17	3
AM	15	2
PM	14	2
QM	20	2
EM	11	2
ET	15	2
SCO	14	3
SHE	25	2
Total	**131**	**18**

Comparing the results obtained with the initial state:

$$Reduction\ of\ the\ number\ of\ indicators(\%) = \left(\frac{131 - 18}{131}\right) \times 100 = 86.2\%$$

This result indicates that the aim of the development of a new innovative methodology was achieved by reducing in 86.2% the number of measures of the system.

5 Chapter – Conclusion & Future Developments

The main purpose of this dissertation was to contribute to Business Process Management improvement through the implementation of a systematic methodology that could easily assess performance pillars. This approach aimed to simplify and improve the communication and data treatment by aggregating several performance indicators into relevant fewer factor/clusters.

The application of different aggregation approaches, such as cluster analysis, discriminant analysis and principal component analysis, allowed to reduce the required indicators of each continuous management pillars, which in the exploratory case used, reduced approximately 86% of the measurements presented in the business process assessment case.

Despite the results the research undertaken in this dissertation has still several issues regarding business process modelling to be explored. Thus, future research in this area will attempt to fill the gap through applying the result model in real work conditions, in order to verify actual improvement impacts when dealing with too many performance indicators. Like if the data reduction is indeed an improvement for communication simplicity, especially when trying to avoid redundancy. Also if it would be useful to explore the use of different, intermedium, level of management hierarchy between pillar management and shift leaders/front-line managers.

The main limitation of the present study was the lack of opportunity to implement the proposed methodology in a real case scenario and potential impacts of using binary data for clustering analysis should be reduced, has just few studies were identified using this type of data. Additionally, the subjectivity related with the decision analysis in the process, may also increase the accountability of the researcher on the results interpretation.

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A Cluster Analysis Inputs Appendix

Autonomous Maintenance Pillar (Cluster Analysis Input)

Table A.1 - AM Pillar Cluster Analysis Input

				Direc_import	Category					
					Cat_ cost	Cat_ engage ment	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innova tion
KPI	Total CIL time loss	%	**AM1**	-2	1	1	1	1	0	0
KPI	Number of BD due to lack of CIL	#	**AM2**	-2	1	1	1	1	0	0
KAI	Total tags	#	**AM3**	-1	0	1	0	1	0	0
KAI	Total tags gap R12	%	**AM4**	-1	0	1	0	1	0	0
KAI	Tags removal by operators R12	%	**AM5**	1	0	1	0	1	0	0
KAI	HT areas and SOD eradicated	#	**AM6**	1	0	1	0	1	0	0
KAI	Cleaning time reduction	%	**AM7**	1	1	0	0	1	0	1
KAI	Lubrication time reduction	%	**AM8**	1	1	0	0	1	0	1
KAI	Inspection time reduction	%	**AM9**	1	1	0	0	1	0	1
KAI	Transfer of CIL activities PM to AM	%	**AM10**	1	0	1	0	1	0	1
KAI	Operators involvement in BD and SS analysis	%	**AM11**	1	0	1	0	1	0	1
KAI	Q and C points under AM care (from step 5)	%	**AM12**	1	0	0	0	1	0	0
KAI	AM Task completion	%	**AM13**	1	0	1	0	0	0	0
KAI	Pillar skill gaps reduction vs ideal	%	**AM14**	1	0	1	0	0	0	0
KPI	Pillar assessment score	%	**AM15**	2	0	1	0	0	0	0

Planned Maintenance Pillar (Cluster Analysis Input)

Table A.2 - PM Pillar Cluster Analysis Input

				Direc_import	Category					
					Cat_ cost	Cat_ engage ment	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innova tion
KPI	MTBF Consolidated	BD/Ho urs	**PM1**	2	1	1	0	1	0	0
KPI	MTBF A	Hours	**PM2**	2	1	0	0	1	0	0
KPI	BD Factory (By month)	#	**PM3**	-2	1	0	0	1	0	0
KPI	BD+Adjustements done by Mechanics	#	**PM4**	-2	1	1	0	1	0	1
KPI	BD/Mio produced (B/D+Adjust.)	#	**PM5**	-2	1	0	0	1	0	0
KPI	MDT	Hours	**PM6**	-2	1	0	0	1	0	0
KPI	MTTR	Hours	**PM7**	-2	1	0	0	1	0	0
KPI	Zero BD Machines	#	**PM8**	2	1	0	0	1	0	0
KPI	Maintenance Cost Reduction	%	**PM9**	3	1	0	0	1	0	1
KPI	Spare parts stock Reduction Value	%	**PM10**	-2	1	0	0	0	0	1
KAI	PM Task Completion	%	**PM11**	1	0	1	0	0	0	0
KAI	Eradication of BD failure modes	%	**PM12**	1	0	1	0	0	0	1
KAI	Pillar skill gaps reduction vs ideal	%	**PM13**	1	0	1	0	0	0	0
KPI	Pillar assessment score	%	**PM14**	2	0	1	0	0	0	0

Quality Maintenance Pillar (Cluster Analysis Input)

Table A.3 - QM Pillar Cluster Analysis Input

				Direc_import	Category					
					Cat_ cost	Cat_ engage ment	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innova tion
KMI	Claims	#	**QM1**	-3	1	0	0	1	0	0
KPI	Technical issues food safety category (specific BRCIOP)	#	**QM2**	-2	1	0	0	1	0	0
KPI	Claims frequency	#/Bio	**QM3**	-2	1	0	0	1	0	0
KPI	Consolidated issues (CI's)	#	**QM4**	-2	0	0	0	1	0	0
KMI	Customer Issue lead-time IRP I, II, III	Days	**QM5**	-3	0	0	0	1	1	0
KPI	IRP I	Days	**QM6**	-2	0	0	0	1	1	0
KPI	IRP II (Days)	Days	**QM7**	-2	0	0	0	1	1	0
KPI	IRP III (Days)	Days	**QM8**	-2	0	0	0	1	1	0
KMI	Total Waste	%	**QM9**	-3	1	0	0	0	0	0
KPI	Defect Waste	%	**QM10**	-2	1	0	0	1	0	0
KAI	BRC/IoP or SQF Food Safety Audit result	Categ ory	**QM11**	1	0	0	0	1	0	0
KAI	Internal Claims	#	**QM12**	-1	1	1	0	1	0	0
KAI	Q and C points gap vs Level 25 5C0D	%	**QM13**	-1	0	0	0	1	0	0
KAI	Gage R&R on main parameters	%	**QM14**	-1	0	1	0	1	0	0
KPI	Cpk on main parameters	#	**QM15**	2	0	0	0	1	0	1
KAI	Eradication of defect modes	%	**QM16**	1	0	0	0	1	0	0
KAI	Best Practice Sharing (MP sheets, Poke Yoke, X-ideas and standards)	#	**QM17**	1	0	1	0	1	0	0
KAI	Pillar skill gaps reduction vs ideal	%	**QM18**	1	0	1	0	0	0	0

Early Management Pillar (Cluster Analysis Input)

Table A.4 - EM Pillar Cluster Analysis Input

				Direc_import	Category					
					Cat_ cost	Cat_ engagement	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innovation
KPI	VSU of EM projects	%	**EM1**	2	1	0	0	0	1	1
KPI	EM within budget	%	**EM2**	2	1	0	0	0	0	1
KPI	Overall Investment Plan	%	**EM3**	2	1	0	0	0	0	1
KPI	On time	%	**EM4**	2	1	0	0	0	0	1
KPI	Alfa beta ratio	%	**EM5**	2	1	0	0	0	0	1
KAI	Coverage of A and B class projects with EM	%	**EM6**	1	1	1	0	0	0	1
KPI	PDA losses	%	**EM7**	-2	1	1	0	0	0	1
KPI	Pillar cost savings	K€	**EM8**	2	0	1	0	0	0	0
KPI	Pillar assessment score	%	**EM9**	2	0	1	0	0	0	0
KAI	Best Practice Sharing (MP, Poke Yoke, X-ideas)	#	**EM10**	1	0	1	0	0	0	0
KAI	Pillar skill gaps reduction vs ideal	%	**EM11**	1	0	1	0	0	0	0

Education and Training Pillar (Cluster Analysis Input)

Table A.5 - ET Pillar Cluster Analysis Input

				Direc_import	Category					
					Cat_ cost	Cat_ engagement	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innovation
KAI	Pillar skill gaps reduction vs ideal level	%	**ET1**	1	0	1	0	0	0	0
KAI	Operational skill gaps reduction vs ideal level	%	**ET2**	1	0	1	0	0	0	0
KAI	Technical skill gaps reduction for operators vs ideal level	%	**ET3**	1	0	1	0	0	0	0
KAI	Technical skill gaps reduction for maintenance people vs ideal level	%	**ET4**	1	0	1	0	0	0	0
KAI	Pillar skill gap closure (vs, Yearly target)	%	**ET5**	1	0	1	0	0	0	0
KAI	Training hours total	hour	**ET6**	2	0	1	0	0	0	1
KAI	Training hours/employee	hour	**ET7**	2	0	1	0	0	0	1
KPI	Eradicated man or method related loss	#	**ET8**	2	0	1	0	0	0	1
KAI	Number of OPL's and SOP's	#	**ET9**	-1	0	1	0	0	0	1
KAI	Number of internal trainers	#	**ET10**	1	0	1	0	0	0	1
KAI	Training audience achieved	%	**ET11**	1	0	1	0	0	0	0
KAI	Training effectiveness (retraining)	%	**ET12**	-2	0	1	0	0	0	0
KAI	Training material coverage skills	%	**ET13**	1	0	1	0	0	0	0
KPI	Pillar assessment score	%	**ET14**	2	0	1	0	0	0	0
KPI	Pillar cost savings	€	**ET15**	2	0	1	0	0	0	0

Supply Chain and Office Pillar (Cluster Analysis Input)

Table A.6 - SCO Pillar Cluster Analysis Input

				Direc_import	Category					
					Cat_ cost	Cat_ engagement	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innovation
KMI	Perfect Delivery III	%	**SCO1**	3	1	0	0	0	1	0
KPI	Finished goods inventory	Days	**SCO2**	-2	1	0	0	0	1	0
KPI	Finished goods inventory	Days	**SCO3**	-2	1	0	0	0	1	0
KPI	Base material inventory	Days	**SCO4**	-2	1	0	0	0	1	0
KPI	SC logistics costs (outbound)	€	**SCO5**	-2	1	0	0	0	0	0
KPI	Customer Satisfaction Index	#	**SCO6**	3	0	0	0	1	1	0
KAI	Best Practice Sharing (Poke Yoke, X-ideas and standards)	#	**SCO7**	1	0	1	0	0	0	0
KAI	SC & Office teams and initiatives (VSM, Makigami)	#	**SCO8**	1	0	1	0	0	0	0
KAI	Pillar skill gaps reduction vs ideal	%	**SCO9**	1	0	1	0	0	0	0
KPI	Pillar assessment score	%	**SCO10**	2	0	1	0	0	0	0
KAI	Volume Delivered	#	**SCO11**	1	0	0	0	1	1	0
KAI	Office Tags	#	**SCO12**	-1	0	1	0	0	0	0
KAI	Office Tags Gaps	%	**SCO13**	1	0	1	0	0	0	0
KPI	Pillar cost savings	€	**SCO14**	2	0	1	0	0	0	0

Safety, Health and Environment Pillar (Cluster Analysis Input)

Table A.7 - SHE Pillar Cluster Analysis Input

				Direc_import	Category					
					Cat_ cost	Cat_ engage ment	Cat_ safety	Cat_ quality	Cat_ service	Cat_ innova tion
KPI	Total incidents	#	**SHE1**	-3	0	0	1	0	0	0
KPI	Fatality	#	**SHE2**	-3	0	0	1	0	0	0
KPI	Permanent disability accident	#	**SHE3**	-3	0	0	1	0	0	0
KMI	Lost-time accident LTA rate	#	**SHE4**	-3	0	0	1	0	0	0
KPI	Restricted-work cases RW	#	**SHE5**	-3	0	0	1	0	0	0
KPI	Medical-treatment cases MT	#	**SHE6**	-3	0	0	1	0	0	0
KPI	First-Aid-treatment cases FA	#	**SHE7**	-2	0	0	1	0	0	0
KPI	Serious near miss SNM	#	**SHE8**	-2	0	0	1	0	0	0
KPI	Near miss NM reported	#	**SHE9**	-2	0	0	1	0	0	0
KPI	Occupational Illness cases	#	**SHE10**	-2	0	0	1	0	0	0
KPI	Lost Time due to accident	Days	**SHE11**	-3	0	0	1	0	0	0
KAI	Near misses analysed	%	**SHE12**	1	0	1	1	0	0	0
KAI	Risk level Reduction (Risks level I still active)	#	**SHE13**	-2	1	1	1	0	0	0
KAI	Risk level Reduction (Risks level II still active)	#	**SHE14**	-1	1	1	1	0	0	0
KAI	BOSS (reported)	#	**SHE15**	-1	0	1	1	1	0	0
KAI	Safety tags	#	**SHE16**	-1	0	1	1	0	0	0
KPI	Absenteeism	%	**SHE17**	-3	1	1	0	1	0	0
KAI	Best Practice Sharing (MP, Poke Yoke, X-ideas)	#	**SHE18**	1	0	1	1	0	0	0
KAI	Pillar skill gaps reduction vs ideal	%	**SHE19**	1	0	1	0	0	0	0
KPI	Pillar assessment score	%	**SHE20**	2	0	1	0	0	0	0
KPI	Pillar cost savings	EUR	**SHE21**	2	0	1	0	0	0	0
KPI	Environmental incidents number/month	#	**SHE22**	-2	1	1	0	1	0	0
KPI	Water Consumption	m3	**SHE23**	-2	1	1	1	0	0	0
KPI	Waste handling, recycling rate	%	**SHE24**	3	1	1	1	0	0	1
KAI	ENV tags + Boss audits environment	#	**SHE25**	-1	0	1	1	0	0	0

B Cluster Memberships & Dendograms Appendix

Autonomous Maintenance Pillar (Cluster Membership)

Table B.1 - AM Cluster Membership (three methods)

			Hierarchical		TwoStep			K-Means	
			Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2
KPI	Total CIL time loss	**AM1**	x		x			x	
KPI	Number of BD due to lack of CIL	**AM2**	x		x			x	
KAI	Total tags	**AM3**	x			x		x	
KAI	Total tags gap R12	**AM4**	x			x		x	
KAI	Tags removal by operators R12	**AM5**		x		x			x
KAI	HT areas and SOD eradicated	**AM6**		x		x			x
KAI	Cleaning time reduction	**AM7**		x			x		x
KAI	Lubrication time reduction	**AM8**		x			x		x
KAI	Inspection time reduction	**AM9**		x			x		x
KAI	Transfer of CIL activities PM to AM	**AM10**		x		x			x
KAI	Operators involvement in BD and SS analysis	**AM11**		x		x			x
KAI	Q and C points under AM care (from step 5)	**AM12**		x		x			x
KAI	AM Task completion	**AM13**		x		x			x
KAI	Pillar skill gaps reduction vs ideal	**AM14**		x		x			x
KPI	Pillar assessment score	**AM15**		x		x			x
	Total Indicators		**4**	**11**	**2**	**10**	**3**	**4**	**11**

Planned Maintenance Pillar (Cluster Membership)

Table B.2 - PM Cluster Membership (three methods)

			Hierarchical		TwoStep		K-Means	
			Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 1	Cluster 2
KPI	MTBF Consolidated	**PM1**	x		x		x	
KPI	MTBF A	**PM2**	x		x		x	
KPI	BD Factory (By month)	**PM3**		x	x			x
KPI	BD+Adjustements done by Mechanics	**PM4**		x	x			x
KPI	BD/Mio produced (B/D+Adjust.)	**PM5**		x	x			x
KPI	MDT	**PM6**		x	x			x
KPI	MTTR	**PM7**		x	x			x
KPI	Zero BD Machines	**PM8**	x		x		x	
KPI	Maintenance Cost Reduction	**PM9**	x		x		x	
KPI	Spare parts stock Reduction Value	**PM10**		x	x			x
KAI	PM Task Completion	**PM11**	x			x	x	
KAI	Eradication of BD failure modes	**PM12**	x			x	x	
KAI	Pillar skill gaps reduction vs ideal	**PM13**	x			x	x	
KPI	Pillar assessment score	**PM14**	x			x	x	
	Total Indicators		**8**	**6**	**10**	**4**	**8**	**6**

Quality Maintenance Pillar (Cluster Membership)

Table B.3 - QM Cluster Membership (three methods)

			Hierarchical		TwoStep			K-Means	
			Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2
KMI	Claims	**QM1**	x				x	x	
KPI	Technical issues food safety category (specific BRCIOP)	**QM2**	x				x	x	
KPI	Claims frequency	**QM3**	x				x	x	
KPI	Consolidated issues (CI's)	**QM4**	x		x			x	
KMI	Customer Issue lead-time IRP I, II, III	**QM5**	x		x			x	
KPI	IRP I	**QM6**	x		x			x	
KPI	IRP II (Days)	**QM7**	x		x			x	
KPI	IRP III (Days)	**QM8**	x		x			x	
KMI	Total Waste	**QM9**	x				x	x	
KPI	Defect Waste	**QM10**	x				x	x	
KAI	BRC/IoP or SQF Food Safety Audit result	**QM11**		x	x				x
KAI	Internal Claims	**QM12**	x			x		x	
KAI	Q and C points gap vs Level 25 5C0D	**QM13**	x		x			x	
KAI	Gage R&R on main parameters	**QM14**	x			x		x	
KPI	Cpk on main parameters	**QM15**		x	x				x
KAI	Eradication of defect modes	**QM16**		x	x				x
KAI	Best Practice Sharing (MP sheets, Poke Yoke, X-ideas and standards)	**QM17**		x		x			x
KAI	Pillar skill gaps reduction vs ideal	**QM18**		x		x			x
KPI	Claims	**QM19**		x		x			x
KPI	Technical issues food safety category (specific BRCIOP)	**QM20**		x		x			x
	Total Indicators		**13**	**7**	**9**	**6**	**5**	**13**	**7**

Early Management Pillar (Cluster Membership)

Table B.4 - EM Cluster Membership (three methods)

			Hierarchical		TwoStep			K-Means	
			Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2
KPI	VSU of EM projects	**EM1**	x		x			x	
KPI	EM within budget	**EM2**	x		x			x	
KPI	Overall Investment Plan	**EM3**	x		x			x	
KPI	On time	**EM4**	x		x			x	
KPI	Alfa beta ratio	**EM5**	x		x			x	
KAI	Coverage of A and B class projects with EM	**EM6**	x			x		x	
KPI	PDA losses	**EM7**		x		x			x
KPI	Pillar cost savings	**EM8**	x				x	x	
KPI	Pillar assessment score	**EM9**	x				x	x	
KAI	Best Practice Sharing (MP, Poke Yoke, X-ideas)	**EM10**	x				x	x	
KAI	Pillar skill gaps reduction vs ideal	**EM11**	x				x	x	
	Total Indicators		**10**	**1**	**5**	**2**	**4**	**10**	**1**

Education and Training Pillar (Cluster Membership)

Table B.5 - ET Cluster Membership (three methods)

			Hierarchical		TwoStep			K-Means	
			Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2
KAI	Pillar skill gaps reduction vs ideal level	**ET1**	x		x				x
KAI	Operational skill gaps reduction vs ideal level	**ET2**	x		x				x
KAI	Technical skill gaps reduction for operators vs ideal level	**ET3**	x		x				x
KAI	Technical skill gaps reduction for maintenance people vs ideal level	**ET4**	x		x				x
KAI	Pillar skill gap closure (vs, Yearly target)	**ET5**	x		x				x
KAI	Training hours total	**ET6**	x			x			x
KAI	Training hours/employee	**ET7**	x			x			x
KPI	Eradicated man or method related loss	**ET8**	x			x			x
KAI	Number of OPL's and SOP's	**ET9**		x		x		x	
KAI	Number of internal trainers	**ET10**	x			x			x
KAI	Training audience achieved	**ET11**	x		x				x
KAI	Training effectiveness (retraining)	**ET12**		x			x	x	
KAI	Training material coverage skills	**ET13**	x		x				x
KPI	Pillar assessment score	**ET14**	x				x		x
KPI	Pillar cost savings	**ET15**	x				x		x
	Total Indicators		**13**	**2**	**7**	**5**	**3**	**2**	**13**

Supply Chain and Office Pillar (Cluster Membership)

Table B.6 - SCO Cluster Membership (three methods)

			Hierarchical		TwoStep			K-Means	
			Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2
KMI	Perfect Delivery III	**SCO1**	x		x			x	
KPI	Finished goods inventory	**SCO2**		x	x				x
KPI	Finished goods inventory	**SCO3**		x	x				x
KPI	Base material inventory	**SCO4**		x	x				x
KPI	SC logistics costs (outbound)	**SCO5**		x	x				x
KPI	Customer Satisfaction Index	**SCO6**	x			x		x	
KAI	Best Practice Sharing (Poke Yoke, X-ideas and standards)	**SCO7**	x				x	x	
KAI	SC & Office teams and initiatives (VSM, Makigami)	**SCO8**	x				x	x	
KAI	Pillar skill gaps reduction vs ideal	**SCO9**	x				x	x	
KPI	Pillar assessment score	**SCO10**	x				x	x	
KAI	Volume Delivered	**SCO11**	x			x		x	
KAI	Office Tags	**SCO12**		x			x		x
KAI	Office Tags Gaps	**SCO13**	x				x	x	
KPI	Pillar cost savings	**SCO14**	x				x	x	
	Total Indicators		**9**	**5**	**5**	**2**	**7**	**9**	**5**

Safety, Health and Enviroment Pillar (Cluster Membership)

Table B.7 - SHE Cluster Membership (three methods)

			Hierarchical		TwoStep			K-Means	
			Cluster 1	Cluster 2	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2
KPI	Total incidents	**SHE1**	x		x			x	
KPI	Fatality	**SHE2**	x		x			x	
KPI	Permanent disability accident	**SHE3**	x		x			x	
KMI	Lost-time accident LTA rate	**SHE4**	x		x			x	
KPI	Restricted-work cases RW	**SHE5**	x		x			x	
KPI	Medical-treatment cases MT	**SHE6**	x		x			x	
KPI	First-Aid-treatment cases FA	**SHE7**	x		x			x	
KPI	Serious near miss SNM	**SHE8**	x		x			x	
KPI	Near miss NM reported	**SHE9**	x		x			x	
KPI	Occupational Illness cases	**SHE10**	x		x			x	
KPI	Lost Time due to accident	**SHE11**	x		x			x	
KAI	Near misses analysed	**SHE12**		x			x		x
KAI	Risk level Reduction (Risks level I still active)	**SHE13**	x			x		x	
KAI	Risk level Reduction (Risks level II still active)	**SHE14**	x			x		x	
KAI	BOSS (reported)	**SHE15**	x				x	x	
KAI	Safety tags	**SHE16**	x				x	x	
KPI	Absenteeism	**SHE17**	x			x		x	
KAI	Best Practice Sharing (MP, Poke Yoke, X-ideas)	**SHE18**		x			x		x
KAI	Pillar skill gaps reduction vs ideal	**SHE19**		x			x		x
KPI	Pillar assessment score	**SHE20**		x			x		x
KPI	Pillar cost savings	**SHE21**		x			x		x
KPI	Environmental incidents number/month	**SHE22**	x			x		x	
KPI	Water Consumption	**SHE23**	x			x		x	
KPI	Waste handling, recycling rate	**SHE24**		x		x			x
KAI	ENV tags + Boss audits environment	**SHE25**	x				x	x	
	Total Indicators		**19**	**6**	**11**	**6**	**8**	**19**	**6**

Autonomous Maintenance Pillar (Cluster Dendograms)

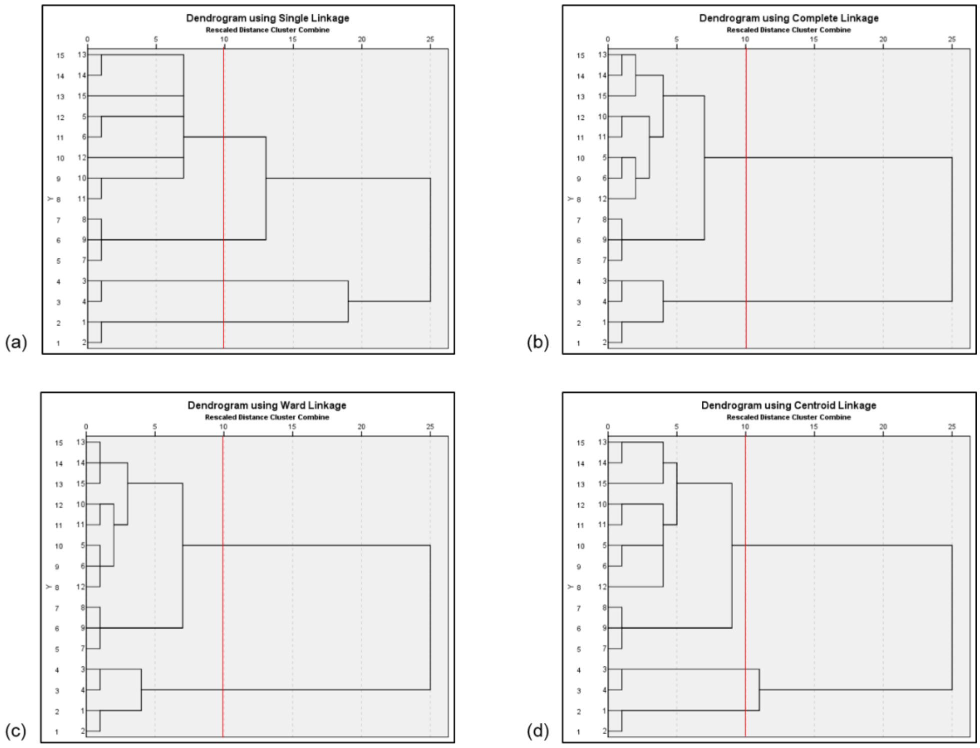

Figure B.1 - AM pillar Hierarchical (a) Nearest; (b) Furthest; (c) Ward; (d) Centroid Method Dendogram

Planned Maintenance Pillar (Cluster Dendograms)

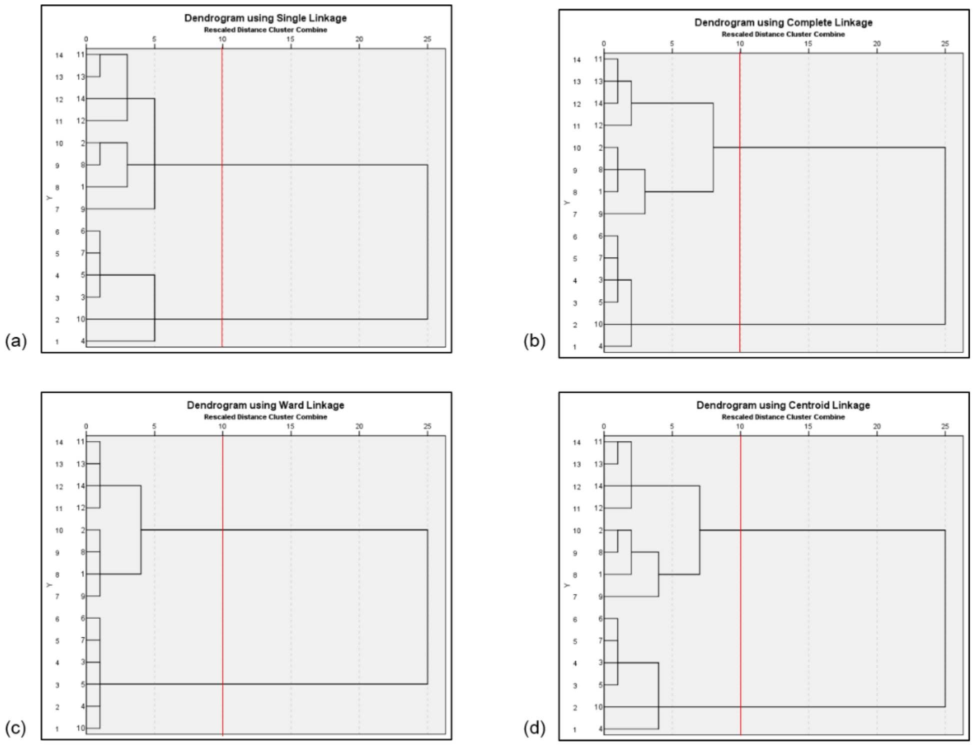

Figure B.2 - PM pillar Hierarchical (a) Nearest; (b) Furthest; (c) Ward; (d) Centroid Method Dendogram

Quality Maintenance Pillar (Cluster Dendograms)

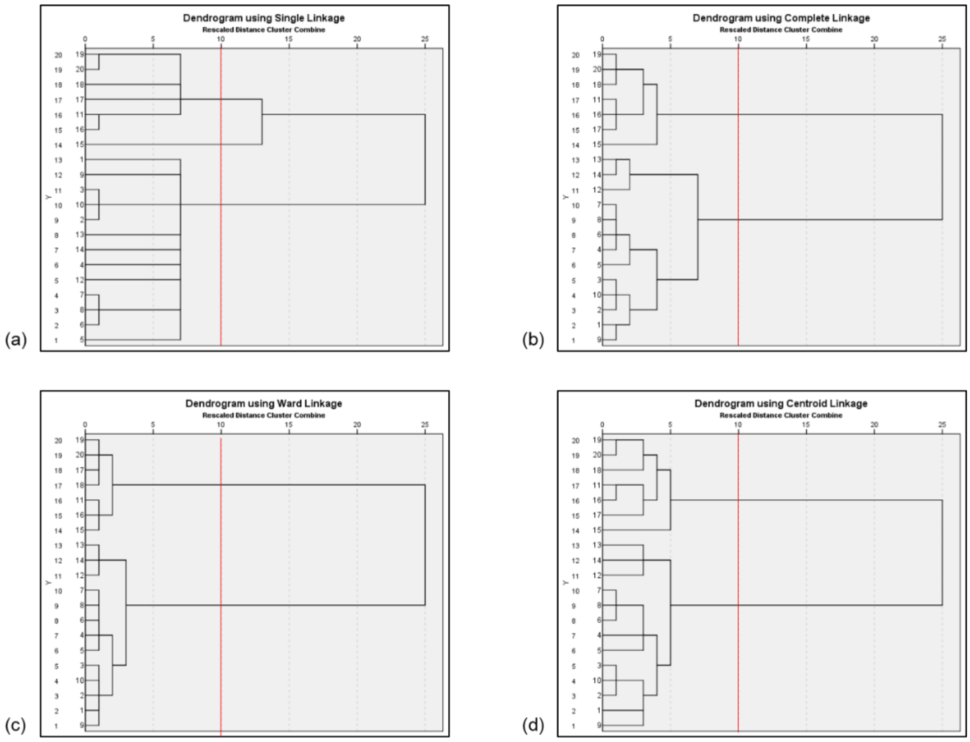

Figure B.3 - QM pillar Hierarchical (a) Nearest; (b) Furthest; (c) Ward; (d) Centroid Method Dendogram

Early Management Pillar (Cluster Dendograms)

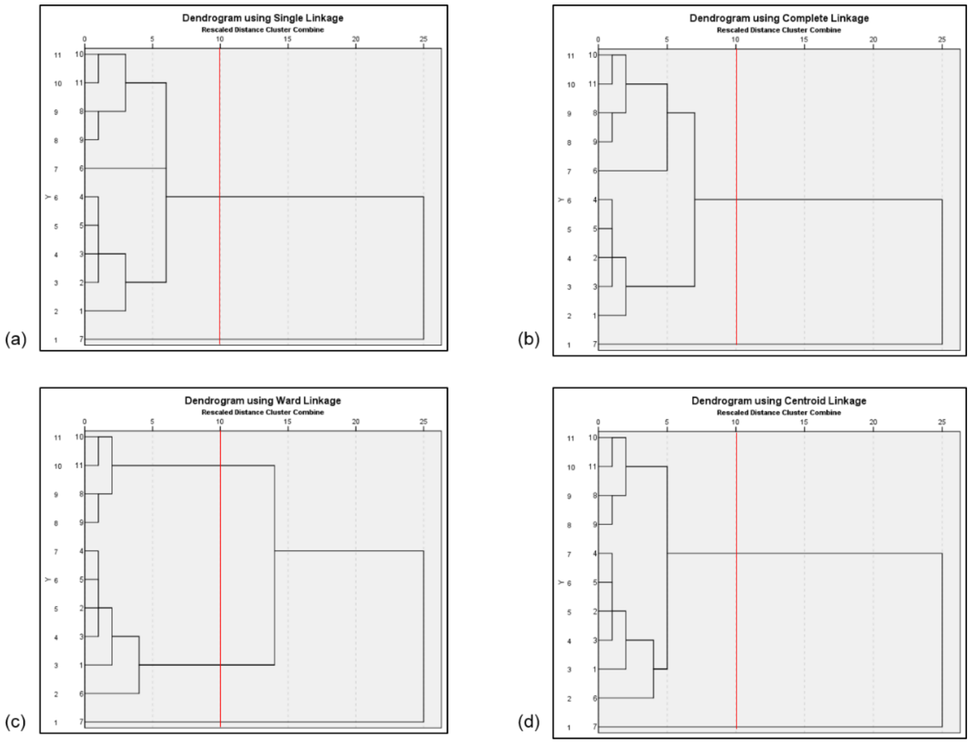

Figure B.4 - EM pillar Hierarchical (a) Nearest; (b) Furthest; (c) Ward; (d) Centroid Method Dendogram

Education and Training Pillar (Cluster Dendograms)

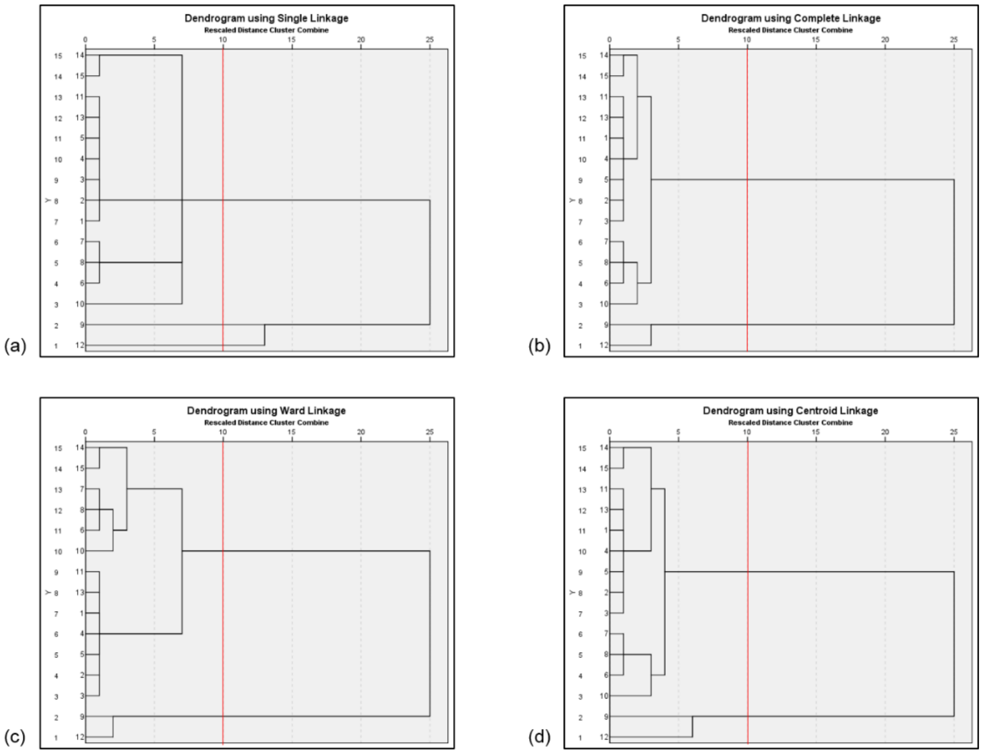

Figure B.5 - ET pillar Hierarchical (a) Nearest; (b) Furthest; (c) Ward; (d) Centroid Method Dendogram

Supply Chain and Office Pillar (Cluster Dendograms)

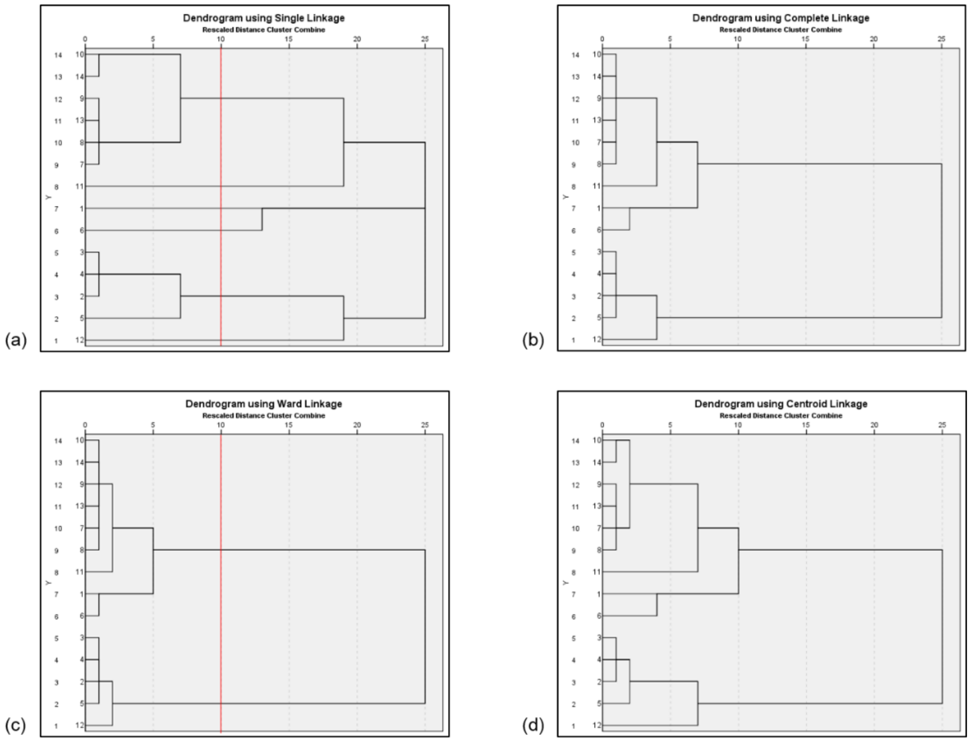

Figure B.6 - SCO pillar Hierarchical (a) Nearest; (b) Furthest; (c) Ward; (d) Centroid Method Dendogram

Safety, Health and Environment Pillar (Cluster Dendograms)

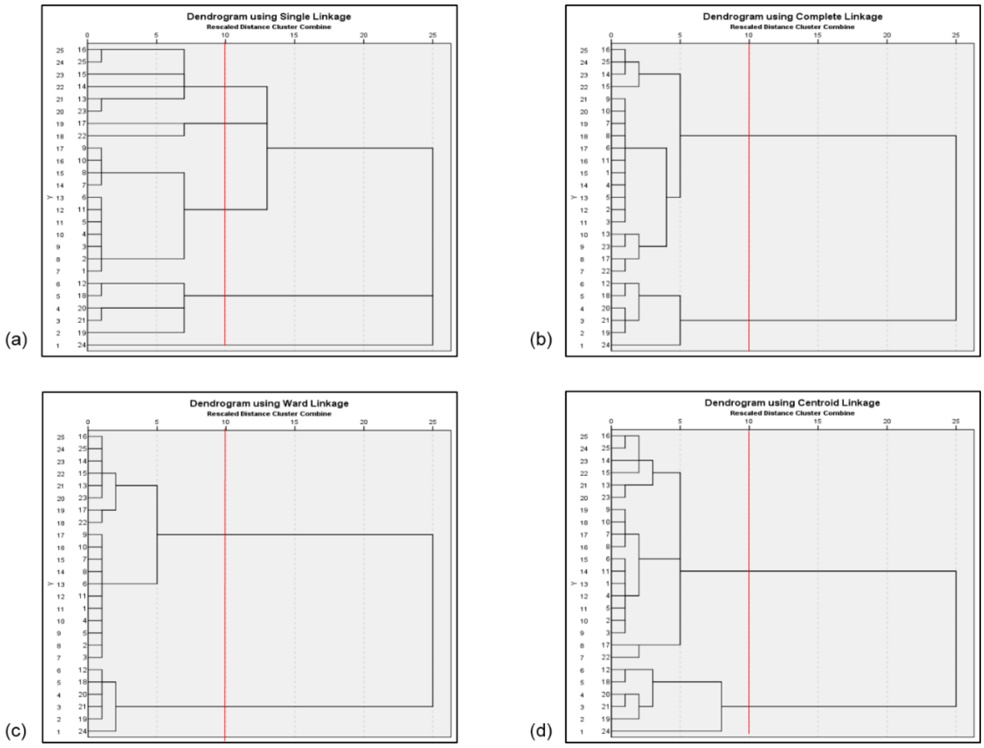

Figure B.7 - SHE pillar Hierarchical (a) Nearest; (b) Furthest; (c) Ward; (d) Centroid Method Dendogram

C AHP Information Appendix

II – Cluster Structure

Table C.1 - Comparison Matrix S and Priorities (II)

	H	KM	TS
H	1	1/2	1/4
KM	2	1	1/3
TS	4	2	1
∑	**7**	**4.5**	**1.583**

	H	KM	TS	$\sum a_{jk}/3$
H	0.143	0.111	0.158	**0.137**
KM	0.286	0.222	0.211	**0.239**
TS	0.571	0.667	0.632	**0.623**

Consistency Validation is the next step and the objective is that $Consistency\ Ratio\ (CR) < 0.1$.

The first step of the consistency validation is to multiply each value of each column from the comparison Matrix S with the weight of each criteria from the S_{norm} matrix.

$$0.137 \times \begin{bmatrix} 1 \\ 2 \\ 4 \end{bmatrix} + 0.239 \times \begin{bmatrix} 1/2 \\ 1 \\ 2 \end{bmatrix} + 0.632 \times \begin{bmatrix} 1/4 \\ 1/3 \\ 1 \end{bmatrix} = \begin{bmatrix} 0.412 \\ 0.721 \\ 1.888 \end{bmatrix}$$

The next step of this validation is to calculate the mean, λ_{max}, which is the sum of the division of each of the vector elements of the sums obtained by the respective weight, divided by the number of criteria.

$$\lambda_{max} = \frac{\sum\left(\frac{0.412}{0.137} + \frac{0.721}{0.239} + \frac{1.888}{0.623}\right)}{3} = 3.02$$

After λ_{max} is calculated the following step is to calculate the $Consistency\ Index\ (CI)$, where n is the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{3.02 - 3}{3 - 1} = 0.009$$

The last step of the validation of the consistency is to calculate $Consistency\ Ratio\ (CR)$.

$$CR = \frac{0.009}{0.58} = 0.016 < 0.1$$

Is this case the consistency was confirmed.

III – Output

Table C.2 - Comparison Matrix S and Priorities (III)

	H	KM	TS
H	1	5	3
KM	1/5	1	1/4
TS	1/3	4	1
$\sum$	**1.533**	**10**	**4.25**

	H	KM	TS	$\sum a_{jk}/3$
H	0.652	0.5	0.706	**0.619**
KM	0.13	0.1	0.059	**0.096**
TS	0.217	0.4	0.235	**0.284**

Consistency Validation is the next step and the objective is that $Consistency\ Ratio\ (CR) < 0.1$.

The first step of the consistency validation is to multiply each value of each column from the comparison Matrix S with the weight of each criteria from the S_{norm} matrix.

$$0.619 \times \begin{bmatrix} 1 \\ 1/5 \\ 1/3 \end{bmatrix} + 0.096 \times \begin{bmatrix} 5 \\ 1 \\ 4 \end{bmatrix} + 0.284 \times \begin{bmatrix} 3 \\ 1/4 \\ 1 \end{bmatrix} = \begin{bmatrix} 1.951 \\ 0.291 \\ 0.874 \end{bmatrix}$$

The next step of this validation is to calculate the mean, λ_{max}, which is the sum of the division of each of the vector elements of the sums obtained by the respective weight, divided by the number of criteria.

$$\lambda_{max} = \frac{\sum\left(\frac{1.951}{0.619} + \frac{0.291}{0.096} + \frac{0.874}{0.284}\right)}{3} = 3.09$$

After λ_{max} is calculated the following step is to calculate the $Consistency\ Index\ (CI)$, where n is the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{3.09 - 3}{3 - 1} = 0.043$$

The last step of the validation of the consistency is to calculate $Consistency\ Ratio\ (CR)$.

$$CR = \frac{0.043}{0.58} = 0.075 < 0.1$$

Is this case the consistency was confirmed.

IV – Sample Size

Table C.3 - Comparison Matrix S and Priorities (IV)

	H	KM	TS
H	1	1/3	1/3
KM	3	1	1
TS	3	1	1
∑	**7**	**2.333**	**2.333**

	H	KM	TS	$\sum a_{jk}/3$
H	0.143	0.143	0.143	**0.143**
KM	0.429	0.429	0.429	**0.429**
TS	0.429	0.429	0.429	**0.429**

Consistency Validation is the next step and the objective is that $Consistency\ Ratio\ (CR) < 0.1$.

The first step of the consistency validation is to multiply each value of each column from the comparison Matrix S with the weight of each criteria from the S_{norm} matrix.

$$0.143 \times \begin{bmatrix} 1 \\ 3 \\ 3 \end{bmatrix} + 0.429 \times \begin{bmatrix} 1/3 \\ 1 \\ 1 \end{bmatrix} + 0.429 \times \begin{bmatrix} 1/3 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 0.429 \\ 1.287 \\ 1.287 \end{bmatrix}$$

The next step of this validation is to calculate the mean, λ_{max}, which is the sum of the division of each of the vector elements of the sums obtained by the respective weight, divided by the number of criteria.

$$\lambda_{max} = \frac{\sum\left(\frac{0.429}{0.143} + \frac{1.287}{0.429} + \frac{1.287}{0.429}\right)}{3} = 3$$

After λ_{max} is calculated the following step is to calculate the $Consistency\ Index\ (CI)$, where n is the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{3 - 3}{3 - 1} = 0$$

The last step of the validation of the consistency is to calculate $Consistency\ Ratio\ (CR)$.

$$CR = \frac{0}{0.58} = 0 < 0.1$$

Is this case the consistency was confirmed.

V – Bootstrapping

Table C.4 - Comparison Matrix S and Priorities (V)

	H	KM	TS
H	1	3	4
KM	1/3	1	3
TS	1/4	1/3	1
$\sum$	**1.583**	**4.333**	**8**

	H	KM	TS	$\sum a_{jk}/3$
H	0.632	0.692	0.5	**0.608**
KM	0.211	0.231	0.375	**0.272**
TS	0.158	0.077	0.125	**0.12**

Consistency Validation is the next step and the objective is that $Consistency\ Ratio\ (CR) < 0.1$.

The first step of the consistency validation is to multiply each value of each column from the comparison Matrix S with the weight of each criteria from the S_{norm} matrix.

$$0.608 \times \begin{bmatrix} 1 \\ 1/3 \\ 1/4 \end{bmatrix} + 0.272 \times \begin{bmatrix} 3 \\ 1 \\ 1/3 \end{bmatrix} + 0.12 \times \begin{bmatrix} 4 \\ 3 \\ 1 \end{bmatrix} = \begin{bmatrix} 1.904 \\ 0.835 \\ 0.363 \end{bmatrix}$$

The next step of this validation is to calculate the mean, λ_{max}, which is the sum of the division of each of the vector elements of the sums obtained by the respective weight, divided by the number of criteria.

$$\lambda_{max} = \frac{\sum\left(\frac{1.904}{0.608} + \frac{0.835}{0.272} + \frac{0.363}{0.12}\right)}{3} = 3.10$$

After λ_{max} is calculated the following step is to calculate the $Consistency\ Index\ (CI)$, where n is the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{3.10 - 3}{3 - 1} = 0.051$$

The last step of the validation of the consistency is to calculate $Consistency\ Ratio\ (CR)$.

$$CR = \frac{0.051}{0.58} = 0.088 < 0.1$$

Is this case the consistency was confirmed.

VI – Automatic definition of the number of Clusters

Table C.5 - Comparison Matrix S and Priorities (VI)

	H	KM	TS
H	1	1/4	1/5
KM	4	1	1/2
TS	5	2	1
$\sum$	**10**	**3.25**	**1.7**

	H	KM	TS	$\sum a_{jk}/_3$
H	0.1	0.077	0.118	**0.098**
KM	0.4	0.308	0.294	**0.334**
TS	0.5	0.615	0.588	**0.568**

Consistency Validation is the next step and the objective is that $Consistency\ Ratio\ (CR) < 0.1$.

The first step of the consistency validation is to multiply each value of each column from the comparison Matrix S with the weight of each criteria from the S_{norm} matrix.

$$0.098 \times \begin{bmatrix} 1 \\ 4 \\ 5 \end{bmatrix} + 0.334 \times \begin{bmatrix} 1/4 \\ 1 \\ 2 \end{bmatrix} + 0.568 \times \begin{bmatrix} 1/5 \\ 1/2 \\ 1 \end{bmatrix} = \begin{bmatrix} 0.295 \\ 1.01 \\ 1.726 \end{bmatrix}$$

The next step of this validation is to calculate the mean, λ_{max}, which is the sum of the division of each of the vector elements of the sums obtained by the respective weight, divided by the number of criteria.

$$\lambda_{max} = \frac{\sum\left(\frac{0.295}{0.098} + \frac{1.01}{0.334} + \frac{1.726}{0.568}\right)}{3} = 3.025$$

After λ_{max} is calculated the following step is to calculate the $Consistency\ Index\ (CI)$, where n is the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{3.025 - 3}{3 - 1} = 0.012$$

The last step of the validation of the consistency is to calculate $Consistency\ Ratio\ (CR)$.

$$CR = \frac{0.012}{0.58} = 0.021 < 0.1$$

Is this case the consistency was confirmed.

D Discriminant Analysis Information Appendix

Table D.1 - Discriminant Analysis Eigenvalue, Wilk's and Cross-Validated

		AM	PM	QM	EM	ET	SCO	SHE
Hierarc.	Eigenvalue	F1 - 100%	F1 -100%	F1 -100%	F1 -100%	F1 -100%	F1 -100%	F1 -100%
	Wilk's lambda	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	Cross-validated	0%	0%	65%	90.9%	46.7%	0%	88%
TwoStep	Eigenvalue	F1 - 66.9%; F2 - 33.1%	F1 -100%	F1 - 93.2%; F2 - 6.8%	F1 -100%	-	F1 -100%	F1 - 89.7%; F2 - 10.3%
	Wilk's lambda	<0.05	<0.05	<0.05	<0.05	-	<0.05	<0.05
	Cross-validated	0%	71.4%	10%	9.1%	-	50%	64%

1) Discriminant Functions Autonomous Maintenance (AM) pillar

- **Hierarchical:**

  F1 = -1,859 + 3,687(direc_import) + 2,885(cat_safety)

- **TwoStep:**

  F1 = -1,996 -0,574*(direc_import) + 3,035*(cat_engagement)

  F2 = -1,952 + 1,082*(direc_import) + 2,071*(cat_engagement)

2) Discriminant Functions Planned Maintenance (PM) pillar

- **Hierarchical:**

  F1 = 1,785 + 2,814(direc_import) - 3,062(cat_cost)

- **TwoStep:**

  F1 = -1,281 - 1,793*(cat_engagement) + 3,187*(cat_quality)

3) Discriminant Functions Quality Maintenance (QM) pillar

- **Hierarchical:**

F = 1,222 + 1,528(direc_import)

- **TwoStep:**

F1 = -0,425 + 4,826*(cat_cost) - 1,279*(cat_quality)

F2 = -2,219 + 0,409*(cat_cost) + 2,620*(cat_quality)

4) Discriminant Functions Early Management (EM) pillar

- **Hierarchical:**

F1 = -2,823 + 2,070*(direc_import)

- **TwoStep:**

F1 = -1,645 + 1,206*(direc_import)

5) Discriminant Functions Education and Training (ET) pillar

- **Hierarchical:**

F1 = -1,823 + 2,324(direc_import) - 1,504(cat_innovation)

6) Discriminant Functions Early Management (SCO) pillar

- **Hierarchical:**

F1 = -0,569 + 1,328(direc_import)

- **TwoStep:**

F1 = -1,589 + 3,708*(cat_service)

7) Discriminant Functions Safety, Health and Environment (SHE) pillar

- **Hierarchical:**

F1 = 1,613 + 1,260(direc_import)

- **TwoStep:**

F1 = 1,640 + 1,271*(direc_import) + 1,792*(cat_quality) - 5,700*(cat_innovation)

F2 = -0,574 - 0,073*(direc_import) + 2,524*(cat_quality) + 4,428*(cat_innovation)

E PCA Information Appendix

FIC – Focused Improvement and Cost Pillar (Principal Component Analysis)

Table E.1 - FIC Principal Component Analysis Input (i)

			1	2	3	4	5	6	7	8	9	10	11
KMI	Landed Cost	**FIC1**	100	123	122	122	89	118	118	118	117	116	104
KPI	Transformation Cost	**FIC2**	100	145	143	130	134	133	131	126	130	128	127
KPI	Allocated Expenses	**FIC3**	100	82	80	79	79	69	78	77	77	77	77
KPI	Logistic Cost	**FIC4**	100	75	70	70	69	68	47	66	44	66	65
KMI	TEE	**FIC5**	0,288	0,314	0,322	0,334	0,47	0,339	0,34	0,397	0,342	0,345	0,392
KMI	OEE	**FIC6**	0,516	0,518	0,52	0,659	0,547	0,548	0,71	0,566	0,567	0,587	0,681
KMI	EE	**FIC7**	0,553	0,577	0,591	0,639	0,906	0,658	0,677	0,756	0,688	0,688	0,691
KMI	Total Waste	**FIC8**	0,029	0,0398	0,0292	0,0462	0,0259	0,0174	0,0291	0,0324	0,0424	0,0342	0,0267
KPI	Process Waste	**FIC9**	0,024	0,0374	0,0243	0,0453	0,0203	0,0223	0,0242	0,0283	0,0406	0,029	0,0213
KPI	Productivity	**FIC10**	25	26	28	27	27	27	28	31	29	29	29
KAI	Loss cost tool updates	**FIC11**	4	5	7	5	4	2	3	4	2	3	6
KAI	Standards identified and reviewed	**FIC12**	5	12	6	6	6	21	7	7	8	8	8
KMI	Energy efficiency	**FIC13**	4958	4930	4905	4524	4873	4873	4844	4278	4821	4383	4785
KAI	Pillar skill gaps reduction vs ideal	**FIC14**	0,674	0,684	0,769	0,691	0,702	0,712	0,713	0,808	0,715	0,716	0,717
KAI	Best Practice Sharing (Poke Yoke, X-ideas and standards)	**FIC15**	0	0	0	0	1	4	1	1	2	2	19
KPI	Pillar assessment score	**FIC16**	0,359	0,37	0,392	0,414	0,507	0,419	0,431	0,679	0,439	0,444	0,449
KPI	Pillar cost savings	**FIC17**	123,98	180,82	125,15	214,23	107,98	63,41	124,61	142,02	194,53	151,2	112,12

Table E.2 - FIC Principal Component Analysis Input (ii)

	12	13	14	15	16	17	18	19	20	21	22	23	24
FIC1	115	114	114	113	110	112	112	112	111	99	110	110	110
FIC2	126	95	125	124	123	123	122	121	117	121	120	119	119
FIC3	77	76	72	76	76	69	75	75	65	75	74	74	74
FIC4	65	64	44	63	61	60	59	59	59	22	57	57	56
FIC5	0,353	0,358	0,358	0,464	0,363	0,363	0,367	0,37	0,371	0,5	0,375	0,378	0,381
FIC6	0,599	0,604	0,605	0,747	0,608	0,609	0,607	0,612	0,613	0,614	0,722	0,616	0,618
FIC7	0,697	0,89	0,704	0,729	0,732	0,821	0,735	0,736	0,738	0,932	0,749	0,752	0,754
FIC8	0,0327	0,026	0,0373	0,0244	0,033	0,0291	0,0329	0,0222	0,0212	0,0316	0,0179	0,0205	0,0246
FIC9	0,0207	0,0204	0,0344	0,0184	0,0247	0,0242	0,0289	0,0157	0,0145	0,0273	0,0104	0,0137	0,0187
FIC10	30	30	39	31	31	31	31	31	44	31	31	31	32
FIC11	5	5	3	5	2	5	3	3	5	8	2	5	4
FIC12	8	8	8	8	13	9	9	10	10	10	10	10	10
FIC13	4784	4779	4770	4765	4588	4739	4738	4736	4517	4716	4714	4709	4893
FIC14	0,718	0,736	0,719	0,719	0,724	0,725	0,853	0,728	0,731	0,731	0,732	0,733	0,733
FIC15	2	3	3	3	6	4	4	8	4	4	1	4	4
FIC16	0,453	0,454	0,457	0,466	0,482	0,418	0,49	0,499	0,5	0,5	0,506	0,67	0,516
FIC17	143,5	108,66	167,83	100,08	145,06	124,54	144,73	88,52	83,35	137,64	65,98	79,86	101,25

Table E.3 - FIC Principal Component Analysis Input (iii)

	25	26	27	28	29	30	31	32	33	34	35	36	37
FIC1	109	109	109	109	108	108	107	93	107	106	106	106	106
FIC2	110	119	118	118	118	113	118	118	118	117	117	112	116
FIC3	67	74	73	73	73	71	73	72	72	73	72	72	72
FIC4	55	43	68	53	53	53	53	35	51	51	51	51	50
FIC5	0,381	0,384	0,447	0,393	0,393	0,396	0,397	0,495	0,4	0,401	0,402	0,414	0,403
FIC6	0,621	0,624	0,625	0,562	0,63	0,632	0,633	0,692	0,635	0,643	0,647	0,647	0,533
FIC7	0,754	0,919	0,758	0,759	0,762	0,686	0,773	0,773	0,776	0,771	0,786	0,786	0,793
FIC8	0,0285	0,035	0,0301	0,029	0,0428	0,0187	0,0262	0,0216	0,031	0,0321	0,0177	0,0233	0,0394
FIC9	0,0235	0,0095	0,0255	0,024	0,0411	0,0114	0,0161	0,015	0,0266	0,028	0,0102	0,0171	0,0369
FIC10	32	33	33	33	34	34	34	34	34	35	35	35	35
FIC11	5	2	3	1	7	1	0	7	5	5	5	6	3
FIC12	11	11	11	5	11	11	11	9	11	11	11	11	12
FIC13	4700	4698	4685	4706	4677	4660	4660	4720	4640	4639	4637	4627	4625
FIC14	0,735	0,689	0,739	0,741	0,749	0,745	0,748	0,748	0,76	0,752	0,754	0,755	0,756
FIC15	6	4	4	11	5	5	5	5	12	5	5	5	11
FIC16	0,52	0,526	0,535	0,536	0,584	0,546	0,546	0,546	0,555	0,605	0,557	0,559	0,561
FIC17	121,79	155,84	130,02	123,95	196,65	70,24	109,74	85,68	134,64	140,69	64,93	94,47	178,67

Table E.4 - FIC Principal Component Analysis Input (iv)

	38	39	40	41	42	43	44	45	46	47	48	49	50
FIC1	106	113	105	105	105	105	88	104	104	104	106	104	103
FIC2	115	115	136	100	115	115	115	114	113	113	121	113	113
FIC3	72	72	70	71	71	71	71	71	70	76	70	70	70
FIC4	50	40	49	48	48	47	63	47	47	46	66	45	45
FIC5	0,408	0,409	0,41	0,51	0,415	0,416	0,416	0,416	0,419	0,456	0,428	0,43	0,431
FIC6	0,653	0,655	0,657	0,598	0,688	0,659	0,661	0,662	0,662	0,663	0,663	0,611	0,665
FIC7	0,793	0,81	0,811	0,734	0,813	0,815	0,816	0,816	0,746	0,823	0,828	0,832	0,834
FIC8	0,043	0,0322	0,0298	0,0291	0,0281	0,0259	0,0279	0,0368	0,0195	0,049	0,0295	0,0211	0,0202
FIC9	0,0414	0,0281	0,025	0,0224	0,023	0,0202	0,0227	0,0314	0,0124	0,0488	0,0337	0,0144	0,0133
FIC10	35	35	36	36	36	26	36	36	37	37	37	37	37
FIC11	4	5	8	4	4	5	2	8	2	3	4	3	3
FIC12	12	12	18	12	12	12	18	13	13	13	13	13	13
FIC13	4619	4613	4610	4463	4606	4597	4414	4577	4577	4567	4548	4546	4543
FIC14	0,757	0,759	0,812	0,761	0,761	0,762	0,791	0,769	0,77	0,714	0,771	0,772	0,773
FIC15	6	6	6	6	6	6	10	6	6	14	7	7	7
FIC16	0,741	0,568	0,571	0,575	0,58	0,583	0,588	0,586	0,586	0,54	0,588	0,59	0,594
FIC17	197,74	141,03	128,12	124,73	119,62	107,74	118,38	164,98	74,63	229,11	126,61	82,83	78,12

Table E.5 - FIC Principal Component Analysis Input (v)

	51	52	53	54	55	56	57	58	59	60	61	62	63
FIC1	103	103	103	102	92	102	102	101	116	101	100	99	101
FIC2	112	112	104	112	111	111	111	107	110	109	109	108	108
FIC3	70	70	70	70	70	70	64	69	69	70	69	69	69
FIC4	45	45	45	44	44	31	44	51	44	43	49	43	42
FIC5	0,375	0,434	0,434	0,436	0,438	0,438	0,341	0,44	0,441	0,441	0,446	0,403	0,451
FIC6	0,666	0,668	0,668	0,668	0,615	0,674	0,675	0,677	0,678	0,68	0,651	0,682	0,684
FIC7	0,847	0,841	0,843	0,843	0,843	0,845	0,845	0,838	0,847	0,847	0,85	0,852	0,863
FIC8	0,0349	0,0185	0,0191	0,0289	0,0255	0,041	0,0286	0,035	0,0258	0,0331	0,0235	0,0304	0,0399
FIC9	0,0313	0,0112	0,0119	0,024	0,0259	0,0389	0,0236	0,0198	0,0201	0,0291	0,0173	0,0156	0,0376
FIC10	38	38	38	38	38	38	38	39	39	39	39	39	39
FIC11	4	3	9	1	6	7	5	5	3	7	5	2	4
FIC12	7	13	13	13	11	14	14	14	14	14	14	14	19
FIC13	4536	4536	4533	4486	4524	4523	4521	4840	4516	4508	4506	4502	4497
FIC14	0,773	0,776	0,77	0,777	0,777	0,779	0,776	0,782	0,783	0,784	0,788	0,727	0,792
FIC15	7	7	7	8	8	8	4	8	16	9	9	9	9
FIC16	0,595	0,6	0,602	0,604	0,638	0,608	0,609	0,616	0,617	0,637	0,622	0,624	0,625
FIC17	154,92	69,27	72,26	123,76	105,83	187,23	122,19	155,4	107,17	145,47	95,26	131,78	181,41

Table E.6 - FIC Principal Component Analysis Input (vi)

	64	65	66	67	68	69	70	71	72	73	74	75	76
FIC1	99	99	99	98	98	97	97	97	97	104	96	96	96
FIC2	114	107	107	107	119	106	105	105	105	105	105	105	105
FIC3	69	66	69	68	68	78	68	68	68	68	67	67	67
FIC4	42	42	40	54	40	40	40	39	46	37	36	35	55
FIC5	0,453	0,454	0,434	0,456	0,458	0,459	0,459	0,463	0,473	0,464	0,464	0,466	0,468
FIC6	0,684	0,688	0,688	0,668	0,69	0,692	0,698	0,694	0,695	0,697	0,697	0,698	0,635
FIC7	0,865	0,866	0,866	0,868	0,87	0,871	0,977	0,874	0,879	0,885	0,886	0,89	0,9
FIC8	0,0218	0,0278	0,0455	0,0288	0,0281	0,0276	0,0301	0,0182	0,0475	0,0217	0,0373	0,0374	0,0295
FIC9	0,0152	0,0227	0,0444	0,0239	0,023	0,0305	0,0255	0,0108	0,0469	0,0151	0,0098	0,0345	0,0247
FIC10	39	30	39	39	39	40	40	48	40	41	41	41	41
FIC11	0	5	0	9	4	3	4	0	5	8	3	1	4
FIC12	15	15	15	15	15	13	15	15	15	15	16	16	16
FIC13	4492	4749	4479	4468	4118	4462	4450	4448	4442	4442	4437	4423	4423
FIC14	0,796	0,719	0,798	0,8	0,801	0,801	0,803	0,817	0,806	0,807	0,779	0,808	0,81
FIC15	9	9	11	10	10	11	5	11	11	11	11	7	11
FIC16	0,627	0,629	0,634	0,557	0,638	0,638	0,619	0,645	0,647	0,652	0,668	0,669	0,765
FIC17	86,31	118,1	210,47	123,2	119,38	116,62	130,17	67,8	220,88	86,16	167,83	168,23	126,88

Table E.7 - FIC Principal Component Analysis Input (vii)

	77	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**	**89**
FIC1	97	95	95	95	96	98	97	97	97	97	104	96	96
FIC2	118	104	103	103	102	119	106	105	105	105	105	105	105
FIC3	67	68	67	67	67	68	78	68	68	68	68	67	67
FIC4	34	33	32	32	32	40	40	40	39	46	37	36	35
FIC5	0,469	0,359	0,473	0,473	0,339	0,458	0,459	0,459	0,463	0,473	0,464	0,464	0,466
FIC6	0,701	0,703	0,706	0,708	0,659	0,69	0,692	0,698	0,694	0,695	0,697	0,697	0,698
FIC7	0,894	0,895	0,781	0,651	0,907	0,87	0,871	0,977	0,874	0,879	0,885	0,886	0,89
FIC8	0,0387	0,0225	0,0234	0,029	0,028	0,0281	0,0276	0,0301	0,0182	0,0475	0,0217	0,0373	0,0374
FIC9	0,0361	0,0344	0,0172	0,0286	0,0229	0,023	0,0305	0,0255	0,0108	0,0469	0,0151	0,0098	0,0345
FIC10	42	42	49	42	42	39	40	40	48	40	41	41	41
FIC11	5	1	10	7	6	4	3	4	0	5	8	3	1
FIC12	13	16	16	17	17	15	13	15	15	15	15	16	16
FIC13	4420	4415	4802	4406	4388	4118	4462	4450	4448	4442	4442	4437	4423
FIC14	0,811	0,812	0,803	0,815	0,816	0,801	0,801	0,803	0,817	0,806	0,807	0,779	0,808
FIC15	11	8	11	11	12	10	11	5	11	11	11	11	7
FIC16	0,674	0,677	0,561	0,684	0,689	0,638	0,638	0,619	0,645	0,647	0,652	0,668	0,669
FIC17	175,24	90,26	94,93	123,94	119,05	119,38	116,62	130,17	67,8	220,88	86,16	167,83	168,23

Table E.8 - FIC Principal Component Analysis Input (viii)

	90	91	92	93	94	95	96	97	98	99	100
FIC1	96	97	95	95	95	96	98	97	97	97	97
FIC2	105	118	104	103	103	102	119	106	105	105	105
FIC3	67	67	68	67	67	67	68	78	68	68	68
FIC4	55	34	33	32	32	32	40	40	40	39	46
FIC5	0,468	0,469	0,359	0,473	0,473	0,339	0,458	0,459	0,459	0,463	0,473
FIC6	0,635	0,701	0,703	0,706	0,708	0,659	0,69	0,692	0,698	0,694	0,695
FIC7	0,9	0,894	0,895	0,781	0,651	0,907	0,87	0,871	0,977	0,874	0,879
FIC8	0,0295	0,0387	0,0225	0,0234	0,029	0,028	0,0281	0,0276	0,0301	0,0182	0,0475
FIC9	0,0247	0,0361	0,0344	0,0172	0,0286	0,0229	0,023	0,0305	0,0255	0,0108	0,0469
FIC10	41	42	42	49	42	42	39	40	40	48	40
FIC11	4	5	1	10	7	6	4	3	4	0	5
FIC12	16	13	16	16	17	17	15	13	15	15	15
FIC13	4423	4420	4415	4802	4406	4388	4118	4462	4450	4448	4442
FIC14	0,81	0,811	0,812	0,803	0,815	0,816	0,801	0,801	0,803	0,817	0,806
FIC15	11	11	8	11	11	12	10	11	5	11	11
FIC16	0,765	0,674	0,677	0,561	0,684	0,689	0,638	0,638	0,619	0,645	0,647
FIC17	126,88	175,24	90,26	94,93	123,94	119,05	119,38	116,62	130,17	67,8	220,88

AM – Autonomous Management Pillar (Principal Component Analysis)

Table E.9 - AM Principal Component Analysis Input (i)

			1	2	3	4	5	6	7	8	9	10	11
KPI	Total CIL time loss	**AM1**	0,198	0,1951	0,1943	0,1936	0,1882	0,1877	0,1877	0,1877	0,1865	0,1851	0,1849
KPI	Number of BD due to lack of CIL	**AM2**	3	3	10	13	1	9	4	7	10	3	6
KAI	Total tags	**AM3**	2827	2520	1989	1678	2187	2211	1938	3460	1448	1481	2346
KAI	Total tags gap R12	**AM4**	0,174	0,163	0,16	0,157	0,035	0,135	0,135	0,135	0,13	0,037	0,124
KAI	Tags removal by operators R12	**AM5**	0,198	0,25	0,258	0,294	0,297	0,299	0,471	0,304	0,314	0,66	0,32
KAI	HT areas and SOD eradicated	**AM6**	74	69	65	72	65	69	64	67	67	64	68
KAI	Cleaning time reduction	**AM7**	0,522	0,527	0,538	0,573	0,58	0,602	0,602	0,609	0,628	0,631	0,631
KAI	Lubrication time reduction	**AM8**	0,37	0,428	0,429	0,456	0,771	0,476	0,477	0,572	0,487	0,672	0,496
KAI	Inspection time reduction	**AM9**	0,397	0,444	0,493	0,494	0,505	0,517	0,536	0,615	0,555	0,555	0,569
KAI	Transfer of CIL activities PM to AM	**AM10**	0,387	0,413	0,433	0,445	0,56	0,454	0,458	0,477	0,478	0,53	0,505
KAI	Operators involvement in BD and SS analysis	**AM11**	0,616	0,679	0,687	0,699	0,773	0,706	0,724	0,725	0,845	0,731	0,734
KAI	Q and C points under AM care (from step 5)	**AM12**	0,357	0,396	0,403	0,412	0,414	0,435	0,437	0,445	0,467	0,469	0,472
KAI	AM Task completion	**AM13**	0,53	0,558	0,564	0,578	0,6	0,602	0,768	0,623	0,635	0,719	0,659
KAI	Pillar skill gaps reduction vs ideal	**AM14**	0,716	0,737	0,743	0,774	0,752	0,763	0,768	0,773	0,837	0,774	0,849
KPI	Pillar assessment score	**AM15**	0,52	0,571	0,571	0,593	0,593	0,595	0,602	0,687	0,614	0,616	0,617

Table E.10 - AM Principal Component Analysis Input (ii)

	12	13	14	15	16	17	18	19	20	21	22	23	24
AM1	0,1836	0,1832	0,1822	0,1708	0,181	0,1804	0,1803	0,1565	0,1789	0,1777	0,1775	0,1774	0,1482
AM2	0	22	9	14	7	21	19	12	9	5	1	8	2
AM3	2565	2657	2371	1440	2559	1751	1838	1698	2166	3006	2645	2552	3389
AM4	0,119	0,118	0,057	0,114	0,111	0,109	0,066	0,107	0,106	0,106	0,105	0,101	0,125
AM5	0,496	0,338	0,342	0,416	0,345	0,349	0,349	0,349	0,588	0,354	0,377	0,383	0,44
AM6	66	77	70	65	62	58	64	69	68	68	62	72	71
AM7	0,647	0,648	0,655	0,658	0,658	0,665	0,666	0,669	0,669	0,669	0,671	0,679	0,685
AM8	0,497	0,504	0,506	0,517	0,741	0,556	0,563	0,566	0,567	0,567	0,569	0,475	0,594
AM9	0,722	0,58	0,59	0,592	0,576	0,595	0,595	0,595	0,597	0,601	0,607	0,817	0,616
AM10	0,514	0,527	0,807	0,534	0,544	0,55	0,553	0,634	0,558	0,558	0,559	0,652	0,561
AM11	0,754	0,735	0,74	0,742	0,791	0,818	0,746	0,752	0,753	0,753	0,753	0,701	0,756
AM12	0,477	0,483	0,483	0,703	0,488	0,49	0,491	0,74	0,522	0,524	0,529	0,529	0,613
AM13	0,665	0,673	0,674	0,676	0,681	0,788	0,685	0,692	0,697	0,701	0,811	0,709	0,714
AM14	0,781	0,783	0,786	0,809	0,79	0,794	0,795	0,796	0,8	0,8	0,824	0,803	0,804
AM15	0,623	0,623	0,633	0,64	0,647	0,668	0,657	0,659	0,662	0,663	0,664	0,606	0,666

Table E.11 - AM Principal Component Analysis Input (iii)

	25	26	27	28	29	30	31	32	33	34	35	36	37
AM1	0,1766	0,1764	0,1764	0,1763	0,1748	0,1646	0,1738	0,1737	0,161	0,172	0,1718	0,1717	0,177
AM2	3	18	5	10	10	14	7	13	7	6	7	11	11
AM3	3376	1846	2031	2110	2420	2298	1695	1857	2156	2938	2849	2556	1992
AM4	0,096	0,095	0,094	0,071	0,092	0,092	0,091	0,085	0,117	0,084	0,081	0,081	0,08
AM5	0,39	0,392	0,399	0,406	0,407	0,413	0,414	0,416	0,389	0,417	0,372	0,427	0,427
AM6	66	62	58	64	64	68	64	61	66	71	74	72	69
AM7	0,685	0,686	0,691	0,696	0,697	0,701	0,702	0,708	0,714	0,716	0,717	0,718	0,718
AM8	0,6	0,602	0,608	0,8	0,611	0,614	0,616	0,619	0,62	0,622	0,623	0,624	0,697
AM9	0,628	0,761	0,64	0,643	0,713	0,646	0,646	0,648	0,656	0,629	0,665	0,67	0,675
AM10	0,562	0,562	0,563	0,571	0,676	0,577	0,577	0,587	0,791	0,589	0,59	0,596	0,596
AM11	0,833	0,758	0,758	0,759	0,76	0,763	0,766	0,77	0,772	0,867	0,775	0,775	0,776
AM12	0,54	0,54	0,542	0,543	0,545	0,678	0,55	0,553	0,531	0,555	0,557	0,559	0,649
AM13	0,718	0,718	0,719	0,83	0,722	0,732	0,733	0,735	0,797	0,738	0,738	0,742	0,746
AM14	0,801	0,807	0,807	0,839	0,81	0,81	0,811	0,813	0,814	0,861	0,816	0,818	0,819
AM15	0,666	0,746	0,668	0,669	0,68	0,725	0,681	0,685	0,686	0,686	0,716	0,69	0,691

Table E.12 - AM Principal Component Analysis Input (iv)

	38	39	40	41	42	43	44	45	46	47	48	49	50
AM1	0,1716	0,1714	0,1712	0,1709	0,1487	0,1703	0,1698	0,1697	0,1697	0,1717	0,1688	0,1687	0,1686
AM2	9	5	8	2	0	11	9	9	13	12	12	13	8
AM3	2956	2408	1882	2051	1727	2468	2697	1783	1311	851	2324	2386	2142
AM4	0,062	0,074	0,074	0,073	0,084	0,072	0,072	0,071	0,097	0,071	0,07	0,068	0,066
AM5	0,432	0,432	0,558	0,44	0,446	0,448	0,453	0,453	0,461	0,463	0,468	0,321	0,474
AM6	69	82	72	71	65	62	64	72	71	64	73	71	69
AM7	0,718	0,722	0,722	0,723	0,724	0,727	0,729	0,729	0,737	0,738	0,74	0,743	0,746
AM8	0,628	0,632	0,632	0,627	0,635	0,636	0,638	0,643	0,645	0,821	0,648	0,483	0,659
AM9	0,657	0,676	0,679	0,681	0,688	0,689	0,594	0,69	0,691	0,691	0,695	0,697	0,697
AM10	0,606	0,602	0,604	0,604	0,727	0,608	0,608	0,619	0,874	0,625	0,625	0,626	0,631
AM11	0,777	0,778	0,779	0,782	0,782	0,745	0,787	0,787	0,789	0,791	0,812	0,793	0,795
AM12	0,563	0,576	0,577	0,578	0,601	0,58	0,585	0,586	0,591	0,549	0,607	0,611	0,612
AM13	0,702	0,754	0,757	0,76	0,763	0,767	0,768	0,921	0,77	0,77	0,772	0,774	0,636
AM14	0,819	0,75	0,82	0,82	0,821	0,822	0,824	0,879	0,827	0,828	0,789	0,831	0,832
AM15	0,692	0,692	0,695	0,695	0,696	0,698	0,698	0,761	0,699	0,7	0,7	0,841	0,703

Table E.13 - AM Principal Component Analysis Input (v)

	51	52	53	54	55	56	57	58	59	60	61	62	63
AM1	0,1684	0,1697	0,1674	0,167	0,1667	0,168	0,1663	0,1657	0,165	0,1527	0,1643	0,163	0,1628
AM2	24	3	8	12	16	14	8	17	5	9	8	1	13
AM3	2965	2756	1873	1702	2575	2622	1797	1447	2445	1842	2454	1938	1974
AM4	0,013	0,066	0,066	0,062	0,025	0,062	0,061	0,059	0,057	0,092	0,056	0,056	0,055
AM5	0,48	0,481	0,489	0,491	0,494	0,605	0,496	0,5	0,503	0,504	0,509	0,3	0,515
AM6	69	65	66	64	67	66	66	68	69	62	70	65	69
AM7	0,748	0,753	0,755	0,758	0,758	0,76	0,764	0,768	0,773	0,777	0,78	0,782	0,782
AM8	0,66	0,66	0,662	0,667	0,668	0,647	0,675	0,686	0,686	0,753	0,698	0,702	0,713
AM9	0,698	0,699	0,703	0,703	0,8	0,707	0,708	0,711	0,823	0,715	0,715	0,716	0,717
AM10	0,661	0,636	0,643	0,647	0,649	0,557	0,652	0,653	0,66	0,661	0,447	0,661	0,662
AM11	0,796	0,796	0,797	0,735	0,799	0,744	0,803	0,81	0,81	0,811	0,786	0,815	0,816
AM12	0,613	0,579	0,614	0,627	0,628	0,659	0,639	0,641	0,644	0,553	0,65	0,653	0,653
AM13	0,781	0,782	0,788	0,735	0,794	0,794	0,796	0,854	0,801	0,805	0,806	0,938	0,815
AM14	0,834	0,777	0,837	0,838	0,845	0,842	0,842	0,843	0,843	0,843	0,82	0,846	0,847
AM15	0,703	0,704	0,699	0,708	0,708	0,712	0,805	0,719	0,719	0,72	0,814	0,726	0,727

Table E.14 - AM Principal Component Analysis Input (vi)

	64	65	66	67	68	69	70	71	72	73	74	75	76
AM1	0,1664	0,1622	0,1621	0,1616	0,1596	0,1604	0,1602	0,1602	0,1599	0,18	0,159	0,1584	0,1583
AM2	14	10	1	7	7	0	10	13	5	1	10	0	9
AM3	1925	2175	2170	1766	1881	2614	1699	3199	2226	1908	1911	1616	2467
AM4	0,053	0,108	0,052	0,051	0,048	0,046	0,073	0,04	0,039	0,038	0,019	0,037	0,075
AM5	0,515	0,522	0,583	0,528	0,53	0,533	0,535	0,425	0,54	0,542	0,547	0,55	0,551
AM6	57	62	63	71	66	80	66	67	72	63	68	75	62
AM7	0,783	0,784	0,784	0,793	0,794	0,797	0,802	0,805	0,81	0,812	0,819	0,826	0,827
AM8	0,713	0,714	0,717	0,717	0,49	0,718	0,723	0,726	0,728	0,734	0,737	0,717	0,752
AM9	0,721	0,749	0,724	0,726	0,732	0,733	0,735	0,74	0,746	0,747	0,787	0,755	0,76
AM10	0,663	0,672	0,672	0,675	0,489	0,677	0,678	0,622	0,683	0,683	0,695	0,698	0,707
AM11	0,727	0,82	0,822	0,826	0,83	0,756	0,833	0,839	0,88	0,85	0,853	0,856	0,858
AM12	0,767	0,656	0,657	0,658	0,486	0,659	0,665	0,669	0,675	0,655	0,679	0,689	0,693
AM13	0,819	0,82	0,823	0,753	0,829	0,898	0,83	0,832	0,836	0,839	0,849	0,852	0,872
AM14	0,87	0,849	0,85	0,852	0,852	0,854	0,854	0,857	0,86	0,815	0,861	0,804	0,862
AM15	0,737	0,745	0,681	0,748	0,752	0,752	0,755	0,755	0,76	0,706	0,763	0,767	0,771

Table E.15 - AM Principal Component Analysis Input (vii)

	77	78	79	80	81	82	83	84	85	86	87	88	89
AM1	0,1582	0,1577	0,1573	0,1816	0,1562	0,1561	0,1558	0,1745	0,1552	0,1545	0,1543	0,1537	0,1558
AM2	0	5	0	6	9	16	0	3	11	7	8	16	6
AM3	2437	2190	1008	2494	2412	2678	2492	3323	2989	1790	2185	2218	1191
AM4	0,033	0,03	0,03	0,029	0,029	0,027	0,053	0,023	0,022	0,022	0,02	0,02	0,137
AM5	0,553	0,554	0,524	0,56	0,564	0,566	0,573	0,345	0,584	0,588	0,32	0,596	0,597
AM6	62	71	74	73	72	67	72	66	62	66	68	67	72
AM7	0,831	0,832	0,832	0,832	0,833	0,834	0,834	0,834	0,835	0,838	0,841	0,846	0,849
AM8	0,753	0,549	0,757	0,763	0,771	0,635	0,777	0,61	0,781	0,795	0,798	0,779	0,815
AM9	0,88	0,765	0,768	0,783	0,784	0,786	0,689	0,793	0,793	0,797	0,644	0,806	0,815
AM10	0,709	0,721	0,726	0,587	0,731	0,732	0,737	0,6	0,744	0,746	0,754	0,758	0,765
AM11	0,858	0,862	0,863	0,865	0,866	0,801	0,867	0,869	0,873	0,875	0,876	0,878	0,798
AM12	0,694	0,695	0,699	0,631	0,704	0,707	0,709	0,561	0,71	0,718	0,728	0,735	0,782
AM13	0,86	0,87	0,872	0,61	0,888	0,891	0,891	0,897	0,897	0,898	0,829	0,9	0,919
AM14	0,862	0,862	0,863	0,863	0,865	0,866	0,868	0,829	0,871	0,871	0,86	0,872	0,873
AM15	0,777	0,78	0,782	0,782	0,785	0,665	0,793	0,795	0,656	0,806	0,808	0,701	0,822

Table E.16 - AM Principal Component Analysis Input (viii)

	90	91	92	93	94	95	96	97	98	99	100
AM1	0,1522	0,1489	0,1734	0,1487	0,1484	0,1624	0,1475	0,1474	0,1444	0,1443	0,1427
AM2	9	6	0	11	5	7	2	10	9	1	8
AM3	2413	2292	2374	2124	3060	2249	2642	1579	2315	2456	1709
AM4	0,016	0,015	0,014	0,014	0,045	0,013	0,011	0,008	0,007	0,005	0,001
AM5	0,601	0,536	0,605	0,623	0,625	0,653	0,657	0,509	0,682	0,692	0,727
AM6	59	73	66	59	71	66	69	70	70	73	64
AM7	0,85	0,859	0,86	0,88	0,884	0,895	0,9	0,902	0,928	0,933	0,937
AM8	0,817	0,82	0,659	0,824	0,829	0,84	0,845	0,878	0,883	0,954	0,969
AM9	0,675	0,819	0,82	0,705	0,839	0,844	0,873	0,876	0,547	0,901	0,961
AM10	0,773	0,681	0,803	0,805	0,576	0,818	0,82	0,824	0,74	0,947	0,959
AM11	0,886	0,887	0,888	0,89	0,899	0,901	0,918	0,92	0,931	0,937	0,982
AM12	0,756	0,762	0,709	0,779	0,78	0,494	0,787	0,788	0,797	0,802	0,807
AM13	0,684	0,924	0,925	0,93	0,93	0,778	0,939	0,951	0,972	0,988	0,994
AM14	0,874	0,874	0,875	0,878	0,872	0,879	0,882	0,885	0,891	0,893	0,906
AM15	0,825	0,828	0,788	0,841	0,843	0,849	0,875	0,876	0,888	0,921	0,94

AM – Autonomous Management Pillar (Results of the Principal Component Analysis)

Table E.17 - AM pillar KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,951
Bartlett's Test of Sphericity	Approx. Chi-Square	1435,401
	df	105
	Sig	,000

Table E.18 - AM Total Variance Explained and Rotated Component Matrix

Indicators			**Components**	
			1	2
KPI	Total CIL time loss	**AM1**	-,886	-,017
KPI	Number of BD due to lack of CIL	**AM2**	-,103	-,654
KAI	Total tags	**AM3**	-,097	,640
KAI	Total tags gap R12	**AM4**	-,839	-,037
KAI	Tags removal by operators R12	**AM5**	,819	-,024
KAI	HT areas and SOD eradicated	**AM6**	,006	,660
KAI	Cleaning time reduction	**AM7**	,980	,051
KAI	Lubrication time reduction	**AM8**	,865	-,050
KAI	Inspection time reduction	**AM9**	,844	,056
KAI	Transfer of CIL activities PM to AM	**AM10**	,837	-,061
KAI	Operators involvement in BD and SS analysis	**AM11**	,886	,077
KAI	Q and C points under AM care (from step 5)	**AM12**	,889	-,032
KAI	AM Task completion	**AM13**	,879	,016
KAI	Pillar skill gaps reduction vs ideal	**AM14**	,896	-,099
KPI	Pillar assessment score	**AM15**	,898	,072
Variance Explained			61.73	8.73
			70.46%	

ET – Education and Training Pillar (Principal Component Analysis)

Table E.19 - ET Principal Component Analysis Input (i)

			1	2	3	4	5	6	7	8	9	10	11
KAI	Pillar skill gaps reduction vs ideal level	**ET1**	0,663	0,678	0,742	0,682	0,683	0,687	0,695	0,775	0,699	0,699	0,7
KAI	Operational skill gaps reduction vs ideal level	**ET2**	0,617	0,619	0,633	0,635	0,654	0,821	0,673	0,673	0,677	0,68	0,682
KAI	Technical skill gaps reduction for operators vs ideal level	**ET3**	0,54	0,603	0,66	0,67	0,743	0,69	0,697	0,702	0,704	0,763	0,715
KAI	Technical skill gaps reduction for maintenance people vs ideal level	**ET4**	0,771	0,773	0,783	0,788	0,792	0,792	0,892	0,801	0,808	0,855	0,81
KAI	Pillar skill gap closure (vs, Yearly target)	**ET5**	0,571	0,571	0,575	0,582	0,692	0,587	0,592	0,595	0,696	0,619	0,75
KAI	Training hours total	**ET6**	182,9	202,8	228	258	470,6	419,1	458,2	745,3	494,2	525,2	537,4
KAI	Training hours/employe e	**ET7**	5,1	5,6	6,3	7,2	13,1	11,6	12,7	20,7	13,7	14,6	14,9
KPI	Eradicated man or method related loss	**ET8**	7	10	7	10	12	5	1	9	7	4	12
KAI	Number of OPL's and SOP's	**ET9**	56	119	72	32	120	105	86	65	61	66	63
KAI	Number of internal trainers	**ET10**	8	9	10	10	10	10	10	11	11	11	11
KAI	Training audience achieved	**ET11**	0,854	0,863	0,863	0,867	0,87	0,871	0,902	0,874	0,874	0,875	0,918
KAI	Training effectiveness (retraining)	**ET12**	0,135	0,131	0,131	0,086	0,129	0,127	0,126	0,1	0,126	0,125	0,124
KAI	Training material coverage skills	**ET13**	0,082	0,083	0,086	0,096	0,464	0,098	0,105	0,106	0,38	0,119	0,134
KPI	Pillar assessment score	**ET14**	0,626	0,626	0,656	0,673	0,79	0,685	0,687	0,75	0,701	0,7	0,705

Table E.20 - ET Principal Component Analysis Input (ii)

	12	13	14	15	16	17	18	19	20	21	22	23	24
ET1	0,702	0,748	0,707	0,712	0,712	0,715	0,767	0,717	0,718	0,72	0,72	0,72	0,721
ET2	0,683	0,704	0,708	0,922	0,718	0,721	0,73	0,801	0,733	0,734	0,739	0,739	0,859
ET3	0,718	0,732	0,736	0,738	0,74	0,743	0,868	0,747	0,751	0,753	0,754	0,755	0,779
ET4	0,912	0,818	0,819	0,84	0,828	0,83	0,832	0,833	0,882	0,86	0,837	0,839	0,813
ET5	0,64	0,641	0,643	0,651	0,666	0,885	0,67	0,671	0,676	0,683	0,687	0,777	0,694
ET6	560,2	567,9	582,4	595,5	1494,3	630,4	638	642,3	673,7	676,4	679	1620,5	695,4
ET7	15,6	15,8	16,2	16,5	41,5	17,5	17,7	17,8	18,7	18,8	18,9	45	19,3
ET8	2	13	17	0	4	13	2	1	8	6	9	8	8
ET9	89	114	96	20	50	123	50	78	85	43	77	64	135
ET10	11	11	11	11	11	11	11	11	11	12	12	12	12
ET11	0,875	0,876	0,877	0,877	0,877	0,879	0,879	0,88	0,88	0,88	0,906	0,882	0,883
ET12	0,124	0,122	0,121	0,121	0,095	0,12	0,119	0,119	0,118	0,118	0,118	0,118	0,117
ET13	0,136	0,139	0,148	0,159	0,164	0,174	0,35	0,184	0,184	0,191	0,192	0,276	0,216
ET14	0,705	0,764	0,719	0,72	0,721	0,723	0,723	0,724	0,724	0,731	0,731	0,703	0,735

Table E.21 - ET Principal Component Analysis Input (iii)

	25	26	27	28	29	30	31	32	33	34	35	36	37
ET1	0,722	0,806	0,726	0,727	0,678	0,732	0,732	0,733	0,821	0,735	0,737	0,739	0,739
ET2	0,742	0,742	0,743	0,744	0,745	0,915	0,755	0,755	0,87	0,76	0,768	0,768	0,841
ET3	0,756	0,761	0,761	0,874	0,765	0,767	0,772	0,775	0,823	0,783	0,784	0,785	0,786
ET4	0,843	0,843	0,844	0,847	0,848	0,851	0,852	0,853	0,823	0,855	0,877	0,861	0,861
ET5	0,695	0,696	0,717	0,703	0,709	0,709	0,71	0,635	0,713	0,714	0,714	0,667	0,723
ET6	698,9	701,2	719,1	815,4	761,7	772,2	774,5	788	788,8	802,5	804,3	809,8	935,3
ET7	19,4	19,5	20	22,7	21,2	21,5	21,5	21,9	21,9	22,3	22,3	22,5	26
ET8	0	0	5	15	8	10	4	8	0	14	5	4	3
ET9	126	87	133	97	105	53	87	111	94	19	123	90	86
ET10	12	12	12	12	12	12	12	12	12	12	12	12	12
ET11	0,935	0,885	0,886	0,889	0,899	0,89	0,891	0,891	0,892	0,923	0,892	0,892	0,893
ET12	0,117	0,117	0,116	0,11	0,114	0,114	0,114	0,114	0,101	0,114	0,121	0,113	0,113
ET13	0,223	0,251	0,525	0,266	0,276	0,488	0,281	0,281	0,282	0,282	0,291	0,294	0,296
ET14	0,735	0,736	0,738	0,739	0,776	0,742	0,746	0,748	0,749	0,757	0,75	0,75	0,751

Table E.22 - ET Principal Component Analysis Input (iv)

	38	39	40	41	42	43	44	45	46	47	48	49	50
ET1	0,741	0,741	0,715	0,742	0,743	0,745	0,735	0,748	0,749	0,698	0,75	0,75	0,751
ET2	0,772	0,773	0,773	0,775	0,797	0,778	0,78	0,78	0,781	0,894	0,782	0,784	0,784
ET3	0,788	0,787	0,787	0,787	0,707	0,788	0,789	0,79	0,894	0,793	0,795	0,796	0,797
ET4	0,862	0,864	0,937	0,867	0,867	0,869	0,87	0,871	0,874	0,874	0,876	0,8	0,877
ET5	0,726	0,73	0,808	0,737	0,745	0,583	0,753	0,756	0,598	0,762	0,768	0,768	0,774
ET6	817,8	818,7	843,6	1304,5	865,5	881,7	921,9	923,3	927,9	1022,7	938,7	1161,6	975,8
ET7	22,7	22,7	23,4	36,2	24	24,5	25,6	25,6	25,8	28,4	26,1	32,3	27,1
ET8	7	13	4	7	6	6	5	8	5	9	13	8	13
ET9	57	55	83	78	82	80	39	146	92	82	70	93	60
ET10	12	12	12	12	13	13	13	13	13	13	13	13	13
ET11	0,895	0,897	0,896	0,896	0,897	0,897	0,895	0,898	0,899	0,899	0,924	0,899	0,9
ET12	0,113	0,113	0,113	0,113	0,112	0,112	0,114	0,111	0,111	0,111	0,11	0,09	0,11
ET13	0,303	0,322	0,422	0,34	0,348	0,348	0,108	0,351	0,356	0,359	0,363	0,366	0,096
ET14	0,734	0,751	0,752	0,752	0,753	0,754	0,831	0,758	0,758	0,843	0,765	0,768	0,769

Table E.23 - ET Principal Component Analysis Input (v)

	51	52	53	54	55	56	57	58	59	60	61	62	63
ET1	0,752	0,754	0,754	0,755	0,755	0,757	0,73	0,758	0,759	0,76	0,763	0,749	0,764
ET2	0,785	0,74	0,786	0,787	0,79	0,758	0,797	0,798	0,798	0,732	0,802	0,806	0,806
ET3	0,846	0,804	0,807	0,808	0,831	0,813	0,814	0,816	0,818	0,682	0,825	0,826	0,829
ET4	0,878	0,878	0,88	0,882	0,882	0,835	0,884	0,885	0,887	0,89	0,891	0,809	0,894
ET5	0,737	0,782	0,788	0,789	0,795	0,71	0,8	0,843	0,805	0,805	0,822	0,809	0,813
ET6	980,6	993,9	1009,1	1010,1	1012,3	357,1	1025,6	1048,6	1064,1	1201	1096,2	1121,4	1129,9
ET7	27,2	27,6	28	28,1	28,1	9,9	28,5	29,1	29,6	33,4	30,5	31,2	31,4
ET8	7	9	0	11	12	5	14	10	10	9	13	10	8
ET9	24	68	89	99	76	48	64	33	59	120	153	102	109
ET10	13	13	13	13	13	13	13	13	13	13	13	13	13
ET11	0,9	0,919	0,901	0,901	0,901	0,884	0,902	0,902	0,902	0,873	0,906	0,906	0,907
ET12	0,108	0,108	0,126	0,107	0,107	0,107	0,102	0,106	0,105	0,105	0,114	0,105	0,104
ET13	0,383	0,384	0,39	0,399	0,394	0,397	0,599	0,401	0,417	0,417	0,42	0,613	0,434
ET14	0,771	0,772	0,773	0,773	0,804	0,777	0,779	0,788	0,788	0,802	0,793	0,794	0,795

Table E.24 - ET Principal Component Analysis Input (vi)

	64	65	66	67	68	69	70	71	72	73	74	75	76
ET1	0,766	0,758	0,769	0,771	0,772	0,773	0,774	0,778	0,776	0,777	0,726	0,778	0,78
ET2	0,715	0,812	0,815	0,816	0,775	0,83	0,833	0,837	0,838	0,746	0,843	0,847	0,847
ET3	0,83	0,933	0,833	0,834	0,835	0,838	0,914	0,848	0,853	0,859	0,79	0,872	0,809
ET4	0,894	0,896	0,901	0,898	0,898	0,9	0,901	0,96	0,902	0,903	0,903	0,905	0,907
ET5	0,813	0,818	0,819	0,837	0,821	0,804	0,824	0,826	0,828	0,828	0,828	0,832	0,76
ET6	1149,9	1157,4	1158,4	1160	1328,9	1164,1	1077	1203,7	1237,3	1238,8	1297,5	844,9	1313,2
ET7	31,9	32,2	32,2	32,2	36,9	32,3	29,9	33,4	34,4	34,4	36	23,5	36,5
ET8	3	4	2	12	12	7	10	2	16	9	13	16	6
ET9	71	57	81	151	78	89	93	61	71	91	60	136	37
ET10	14	14	14	14	14	14	14	14	14	14	14	14	14
ET11	0,907	0,9	0,908	0,909	0,915	0,915	0,915	0,917	0,881	0,918	0,918	0,919	0,892
ET12	0,104	0,104	0,105	0,104	0,103	0,103	0,103	0,13	0,102	0,101	0,101	0,115	0,1
ET13	0,442	0,448	0,449	0,216	0,477	0,548	0,492	0,504	0,508	0,512	0,517	0,178	0,54
ET14	0,795	0,798	0,798	0,674	0,802	0,803	0,812	0,805	0,808	0,811	0,811	0,811	0,74

Table E.25 - ET Principal Component Analysis Input (vii)

	77	78	79	80	81	82	83	84	85	86	87	88	89
ET1	0,783	0,784	0,763	0,786	0,787	0,785	0,79	0,795	0,801	0,802	0,803	0,803	0,805
ET2	0,848	0,85	0,856	0,807	0,859	0,865	0,869	0,781	0,886	0,886	0,89	0,891	0,786
ET3	0,879	0,879	0,88	0,881	0,882	0,883	0,803	0,894	0,898	0,91	0,912	0,912	0,755
ET4	0,908	0,912	0,865	0,914	0,914	0,915	0,919	0,921	0,924	0,926	0,897	0,929	0,931
ET5	0,837	0,839	0,821	0,85	0,85	0,858	0,871	0,872	0,875	0,799	0,893	0,905	0,912
ET6	1313,5	955,5	1370,8	1374,3	1376,6	1480,6	1486,9	620,2	1501,5	1505,5	1519,3	1519,5	1540
ET7	36,5	26,5	38,1	38,2	38,2	41,1	41,3	17,2	41,7	41,8	42,2	42,2	42,8
ET8	13	5	3	17	11	16	2	8	2	0	1	15	4
ET9	70	55	63	106	107	94	107	114	100	66	93	59	72
ET10	14	15	15	15	15	15	15	15	15	15	15	15	15
ET11	0,92	0,921	0,922	0,922	0,908	0,923	0,924	0,889	0,927	0,927	0,928	0,932	0,932
ET12	0,1	0,1	0,108	0,099	0,099	0,098	0,097	0,096	0,095	0,106	0,094	0,092	0,092
ET13	0,547	0,336	0,558	0,562	0,565	0,566	0,584	0,592	0,391	0,6	0,606	0,611	0,262
ET14	0,814	0,816	0,707	0,818	0,821	0,823	0,823	0,824	0,825	0,826	0,827	0,829	0,831

Table E.26 - ET Principal Component Analysis Input (viii)

	90	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**	**100**
ET1	0,707	0,807	0,808	0,81	0,811	0,819	0,789	0,822	0,823	0,829	0,83
ET2	0,9	0,914	0,654	0,916	0,92	0,771	0,929	0,931	0,936	0,957	0,978
ET3	0,919	0,923	0,929	0,932	0,786	0,937	0,945	0,958	0,974	0,984	0,993
ET4	0,934	0,929	0,94	0,943	0,945	0,947	0,949	0,835	0,96	0,961	0,982
ET5	0,913	0,914	0,926	0,93	0,933	0,938	0,943	0,949	0,954	0,971	0,973
ET6	1540,9	1545,8	687,6	1634,6	1661,2	1696,3	1699,9	1749,8	1811,7	1835,3	1990,6
ET7	42,8	42,9	19,1	45,4	46,1	47,1	47,2	48,6	50,3	51	55,3
ET8	7	11	16	0	8	5	1	4	4	4	15
ET9	89	116	105	77	92	81	112	112	91	44	103
ET10	15	15	16	16	16	16	16	16	17	18	19
ET11	0,932	0,934	0,875	0,937	0,939	0,943	0,943	0,944	0,947	0,955	0,956
ET12	0,112	0,09	0,089	0,089	0,087	0,104	0,086	0,086	0,083	0,077	0,071
ET13	0,624	0,637	0,641	0,653	0,658	0,662	0,677	0,692	0,702	0,716	0,797
ET14	0,817	0,832	0,832	0,837	0,751	0,845	0,846	0,86	0,877	0,878	0,957

ET – Education and Training Pillar (Results of the Principal Component Analysis)

Table E.27 - ET pillar KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		,934
Bartlett's Test of Sphericity	Approx. Chi-Square	2366,304
	df	91
	Sig	0,000

Table E.28 - ET Total Variance Explained and Rotated Component Matrix

Indicators			Components	
			1	2
KAI	Pillar skill gaps reduction vs ideal level	ET1	,838	,008
KAI	Operational skill gaps reduction vs ideal level	ET2	,803	-,142
KAI	Technical skill gaps reduction for operators vs ideal level	ET3	,883	,060
KAI	Technical skill gaps reduction for maintenance people vs ideal level	ET4	,834	-,001
KAI	Pillar skill gap closure (vs, Yearly target)	ET5	,903	,184
KAI	Training hours total	ET6	,917	-,048
KAI	Training hours/employee	ET7	,917	-,047
KPI	Eradicated man or method related loss	ET8	-,023	,811
KAI	Number of OPL's and SOP's	ET9	,060	,668
KAI	Number of internal trainers	ET10	,970	,069
KAI	Training audience achieved	ET11	,863	-,034
KAI	Training effectiveness (retraining)	ET12	-,812	-,068
KAI	Training material coverage skills	ET13	,858	,106
KPI	Pillar assessment score	ET14	,874	,149
Variance Explained			65.49	8.64
			74.13%	