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LEAN AND PERFORMANCE MEASURING

DEVELOPING A NEW PERFORMANCE MEASUREMENT FRAMEWORK TO FIT LEAN

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Biographical Note

Rúdi Gualter de Oliveira was born in December 18th, 1990 in Coimbra, Portugal. His academic path began by studying "Science and Technology" in high school. However, after better deciding on a career path, he decided to go to a technical school, to undertake the Professional and Technical Management Course. During his journey at this course, he successfully completed two internships, at Cooplecnorte, Limited Cooperative, from the French E.Leclerc group, and at CALCOB, Limited Cooperative.

His work experiences and knowledge gathered interested him, and drove Rúdi to take his studies forward. He successfully graduated with a bachelor's degree in Management from University of Évora. Never one to be satisfied, he also enrolled in the Erasmus program, which drove him to Uniwersytet Jagiellonski w Krakowie, in Poland, where he completed his last year of studies.

Rúdi then went on to enthusiastically pursue a Master's degree in Management at the Faculty of Economics of Porto from University of Porto (FEP). During his studies, he enrolled as a Lean Consultant at Bisilque S.A.

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Abstract

Purpose: This dissertation aims to develop a performance measurement framework to fit lean perspective. Improving performance is one of the main issues found within industrial business environments. Given the nature of demand nowadays, industrial processes should be both customizable and maintain its agility in the face of an ever-changing world. Lean management puts these issues at the core of its philosophy.

Design/ Methodology Approach: The methodology adopted in this dissertation is a conceptual literature review. Case studies were used to assess KPIs and to create the performance measurement framework to fit lean.

Findings: The proposed framework evaluates organizational performance under eight categories – customer issues, supplier issues, manufacturing management, internal management, research and development, manufacturing efficiency, learning perspective and investment priority – and eleven clusters. In total, 421 KPIs were identified and distributed amongst the clusters and categories. The research was able to determine that VSM is the most used tool in different papers, and that cycle time was the most used indicator, through frequency analyses.

Originality/value: This dissertation helps fill a gap in the literature on the relationship between lean and performance in the perspective of measurement. Though that relationship has been increasingly studied through questionnaires and literature reviews, there is still a gap regarding the creation of a performance measurement framework made specifically for lean.

Practical Implications: This study contributes to the field of Management by proposing an innovative performance measurement framework, that takes into account the particularities of Lean manufacturing. It provides managers with valuable information regarding the usage of performance indicators and lean tools in multiple papers. It aims to help managers choose the best KPIs and lean tools, improving the performance measurement process.

JEL-codes: M11, L25, L68, L10

Keywords: lean manufacturing, performance management, lean tools, operational performance, key performance indicators

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List of Acronyms and Terms

Acronyms

3M - Muda-Mura-Muri – waste, overburden and unevenness (Japanese word used in Lean)

5Cs – Clear out, Configure, Clean and Check, Conformity, Custom & practice

5(+1)S – Sort, Set in Order, Shine, Standardize, Sustain, Safety

5S - Seiri-Seiton-Seiso-Seiketsu-Shitsuke – Sort, Set in Order, Shine, Standardize, Sustain (Japanese words used in Lean)

5W –5 Whys

5W2H –5 Whys 2 How's

7MP – 7 Management and Planning tools

7W –Seven Wastes

A3 –Report in A3 format

ABC/TOC – Activity Based Costing / Theory of Constraints

ANOVA – Variance Analysis

BSC – Balanced Score Card

CEO – Chief Executive Officer

CFS – Continuous Flow Systems

CiMO- Structured and contextual approach to developing an answerable question

CONWIP – Constant Work In Process

CRT – Current Reality Tree

DFMA – Design for Manufacture and Assembly

DMAIC/DMADV – Define, Measure, Analyze, Implement, Control / Design, Verify

DMP – Dynamic Multi-Dimensional Performance

DOE – Design of Experiments

DToR – Deconstructed Terms of Reference

EFQM – European Foundation for Quality Measurement

FIFO – First In First Out

FMEA – Failure Modes and Effects Analysis

FRT – Future Reality Tree

GM – General Motors

HR – Human Resources

HRM – Human Resources Management

IDEF0 – Integrated Definition Language 0

IDMP – Integrated Dynamic Performance Measurement

IDPMS – Integrated Dynamic Performance Measurement System

ILP – Integer Linear Programming

IPMS – Integrated Performance Measurement System

IRR – Internal Rate of Return

JIT – Just-in-Time

KPI's – Key performance Indicators

LCA – Life Cycle Assessment

LCM – Life Cycle Manufacturing

LEMS – Lean Ergonomics Manufacturing Systems

LPD – Lean Product Development

LRCDA – Lean Root Cause and Defect Analysis

MBR – Master Batch Records

MDT – Downtime Analysis

MMSUR – Multiple Machine Setup Reduction

MSME - Micro, Small & Medium Enterprises

NPV – Net Present Value

OEE – Overall Equipment Efficiency

OSKKK – Observe, Standardize, Kaizen 1, Kaizen 2, Kaizen 3

PDCA –Plan Do Check Act

PMIS – Performance Mesurement Improvement System

PMQ – Performance Measurement Questionnaire

PMS – Performance Measurement System

PRT – Production Resource/Tool Availability

QFD – Quality Function Deployment

QIP – Quality Improvement Project

ROI – Return on Investment

SPCE – Set Based Concurrent Engineering

SIPOC –Supplier, Inputs, Process, Outputs, Customer

SMART – Specific, Measurable, Achievable, Relevant and Time-bounded

SMED – Single Minute Exchange of Die

SOP – Sales Operations Planning

SPC – Statistical Process Control

SREDIM – Select, Record, Examine, Develop, Install/Implement, Maintain

SWAN – Learning Through Doing

TISM – Total Interpretive Structural Modelling

TOPS/8D –Team Oriented Problem Solution 8 Disciplines

ToR – Terms of Reference

TPM – Total Productive Maintenance

TPS – Toyota Production System

TQM – Total Quality Management

TRIZ – Theory of Inventive Problem

TRT – Transportation Research Thesaurus

VA/NVA – Value Added/Non-Value Added

VASA - Lean Production System Implementation Model

VOC – Voice Of the Customer

VSAD – Value Stream Analysis and Design

VSC – Value Stream Costing

VSM – Value Stream Mapping

Terms

Andon – Notify management

Gemba –Place or floor (Japanese word used in Lean)

Hansei – Auto-reflection (Japanese word used in Lean)

Heijunka – Production leveling (Japanese word used in Lean)

Hoshin Kanri – Policy Deployment (Japanese word used in Lean)

Hourensou –Require reports (Japanese word used in Lean)

Ishikawa –Diagram (Japanese word used in Lean)

Jidoka –Automation (Japanese word used in Lean)

Junjo –Order (Japanese word) – lean concept

Kaizen – Change is good (Japanese word used in Lean)

Kanban – A card (Japanese word used in Lean)

Milk-Run – Delivery systems

Mizumashi - Inflation

Poka-Yoke –Error proofing (Japanese word used in Lean)

Spiderman – Make sure that materials are supplied

Supermarket – Material self-service

Takt-time – Rhythm

1. Introduction

Manufacturing processes are an integral part of modern life. Their evolution has been the basis for some worldwide changes, such as the Industrial Revolutions, creation of unions and political movements and funding for technological development and research (Groover, 2010). Although up until the mid-19th Century production was mostly based on artisanal or craft manufactured items, the first and second industrial revolutions gave way to new technological advances that allowed for the creation and evolution of the mass-manufacturing process (Groover, 2010).

Nowadays, while mass production is still the main form of factory production, it has become clear that its golden age is over. In spite of mass consumption and an increase in worldwide population, factories have had to find new ways of producing while maintaining and increasing their profit (Groover, 2010).

Kiichiro Toyoda founded the Toyota Motor Corporation in Japan. The levels of demand during the Post-War period in Japan made mass manufacturing much more expensive than in America (Womack, Jones, & Roos, 1991). The problem, Taiichi Ohno noticed, was that scheduling of work should not be guided by sales targets, but by actual sales (Ohno, 1988).

Nowadays, Lean has evolved to include a number of tools in order to achieve the organization's goals. The theory behind it has also developed beyond factory floors, so that Lean can also be applied to the services industry (Sorooshian & Fen, 2017). Because managers have to find new ways of gaining competitiveness, it has recently gained popularity as a way of developing the organization without resorting to traditional mass production techniques, which don't always answer to these needs (Belekoukias, Garza-Reyes, & Kumar, 2014).

Performance is the action or process of performing a task or function. In management, performance can also be considered a measure for the execution of these tasks (Mirea, 2013). Quantifying and measuring performance is important because it gives managers data on the times needed to complete separate tasks, the quality of these tasks and whether or not they can be improved (Eaidgah, Maki, Kurczewski, & Abdekhodaee, 2016).

The growing competitiveness of worldwide markets demands that factories pursue operational perfection (Belekoukias et al., 2014). One of the focuses of Lean is the pursuit of perfection, and its tools have been used to achieve managers' objectives. By seeking to decrease costs, while increasing efficiency, it makes organizations more competitive (Belekoukias et al., 2014).

To be properly implemented, lean is supported by a number of tools and methods, such as *kaizen*, *kanban*, just-in-time production, value stream mapping amongst others that target multiple areas of the factory, seeking to bring down waste (Pinto, 2009).

The main aim of this dissertation is to create a performance measurement framework to fit lean manufacturing. This research is important because, in spite of numerous studies on Lean, it seeks to present a framework for performance to fit a lean manufacturing environment, thus enriching the existing literature on the relations between Lean and performance.

The innovative character of the proposed framework lies in the fact that it has been built taking Lean tools, philosophies, work techniques and principles into account. It objectively looks at existing performance measurement frameworks and seeks out a way to improve on certain aspects with the proposed framework.

The dissertation uses a conceptual literature review as the main methodology. Studies in literature are used to define a performance measurement base model and define performance categories and clusters. Then, case studies are compiled, screened and analyzed to gather a list of KPIs, which will then be fit into the different clusters and categories.

The main research question is: what is the best way to measure performance in a Manufacturing environment wherein Lean has been implemented? As secondary research question the author sought to answer which key performance indicators are the most used by companies?

Besides this chapter, the dissertation contains six chapters. Chapter 2 presents relevant theoretical background and a brief historical review of craft and mass productions, the basic principles of lean and reviews the theory on its conception and application within a factory environment. It moves on to present the definition of performance, relevant theoretical background on performance indicators and the relationship between them.

Chapter 3 covers the methods used in the paper and details how the research was done. It presents the steps of a conceptual review and describes how the KPIs, clusters and categories were chosen and the stages of the construction of the framework.

Chapter 4 presents the results. It details how the performance measurement framework was designed. It presents an overview of the case studies and performance measurement models, followed by a detailed account of how the KPIs were gathered and listed. It then moves on to define the clusters and categories. It then shows a graphical representation of the proposed framework design.

It also details the frequency of indicators, the most used lean tools, philosophies and work techniques, analyzing the relationship between them through frequency analyzes.

Chapter 5 presents the finished framework. It details the different categories and shows a representation of the completed framework. This chapter also presents the possible relations between the proposed framework and existing performance measurement systems and implementation recommendations.

The dissertation ends with the conclusion where the final considerations regarding the research are presented, alongside its implications and limitations. It also details the practical and theoretical contributions of the research.

2. Literature Review

According to the needs of humans and the possibilities of the producer different methods have been employed to create production. Production has evolved from handmade craft production to industrial mass production, going from a place of personal, costly, handmade work to less specialized, cheaper and standardized products (Womack et al., 1991).

To keep their competitiveness, companies must find new solutions for production issues. Lean thinking arises as a potential answer to these problems (Bhamu & Sangwan, 2014). Created in Japan after World War II, lean production focuses on perfecting the industrial chain, getting rid of waste and becoming more productive and competitive (Krafcik, 1988).

This chapter briefly presents lean predecessors. Then, moves on to present the current theoretical aspects behind lean production and lean management, its principles and tools. Finally, it presents operational performance indicators and former researches on the relation between Lean and performance.

2.1. Lean Background and Lean Definition

From the 1800s to the first World War, the main production method was craft production (Womack et al., 1991). Companies weren't interested in churning out thousands of the same product, and customization was available and widely acceptable (Bhamu & Sangwan, 2014). However, craft production is no longer a viable option for most industries, given the rise in demand and the need for competitive pricing (Womack et al., 1991).

Henry Ford saw a way to improve craft production: Ford's unique vision, alongside the technological advances of his time, created the conditions for the creation of a mass production factory (Womack et al., 1991). With it, the interchangeable worker was formed, making it so that unspecialized workers were now the backbone of industrial production, though his extreme division was later criticized (Chaplin, 1936). Ford tried to mass-produce everything, leaving the invisible hand assumption behind, going for what was later described as the visible hand (Chandler Jr, 1993). On the other hand, Sloan, GM's CEO, had the idea of using decentralized divisions (Holweg, 2007), dividing the company to create new roles (Womack et al., 1991).

Figure 1 shows a timeline of the developments in manufacturing, staring at craft manufacturing and going all the way towards Lean.

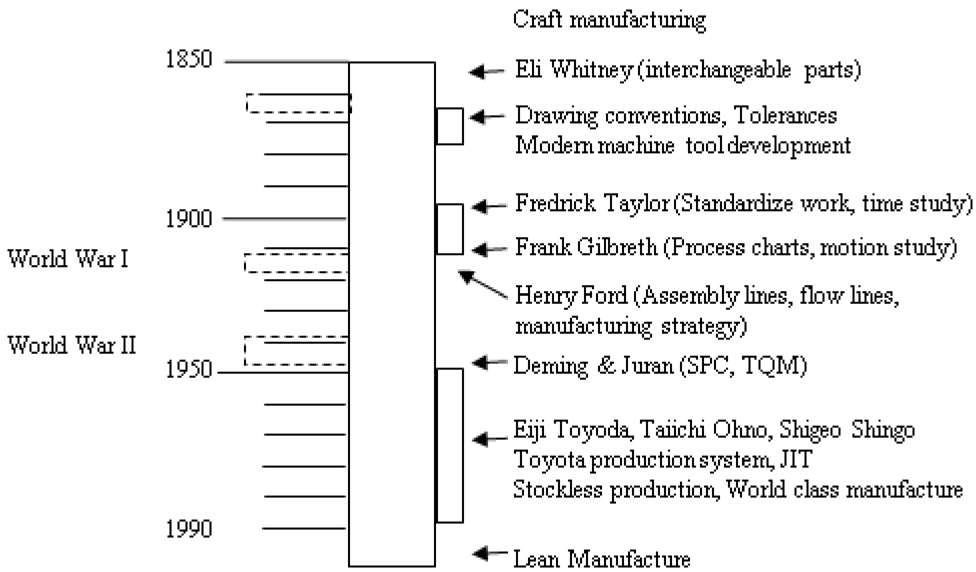


Figure 1 - From Craft to Lean

Source: (Chawla, 2016)

On the other side of the world, in Japan, the Toyota Motor Systems faced a different problem, due to the conditions in Japan and Japanese consumers (Holweg, 2007). Unlike in America, levels of demand were low, making the main focal point of mass production (lowest cost per item) have little application (Womack et al., 1991). Those conditions created a need for a new approach to manufacturing, creating the lean philosophy (Hines, Holwe, & Rich, 2004).

Lean is a systematic method to improve productivity while eliminating waste, unevenness in work and overburden. It is also a continuously developing philosophy (Bhamu & Sangwan, 2014). This methodology includes a set of tools that help identify and eliminate different types of waste and continuous search for improvement (Womack et al., 1991). Lean philosophy can help bringing down costs and decreasing unevenness in the final product, while increasing productivity of workers, therefore increasing the overall performance of the company (Bhamu & Sangwan, 2014).

Lean methodology ultimately focuses on value and efficiency. Eliminating waste is one of the answers to creating more value for the customer (Bhamu & Sangwan, 2014). By identifying the seven types of waste: transport, inventory, motion, waiting, over-processing, overproduction and defects (or non-value added components of the process), lean can reduce costs, times and improve efficiency and competitiveness (Thürer, Tomašević, & Stevenson, 2017).

Lean thinking can be applied to different contexts: while lean manufacturing or lean production focuses on the production process, lean management is an organizational management approach that can be applied to other industries (Sorooshian & Fen, 2017).

Creating and maintaining a smooth work flow is one of the main aims of lean, which helps to expose any differences in work. That means that, instead of optimizing separate technologies, assets or vertical departments, lean seeks to optimize the flow of products through the entire value stream in a horizontal manner (Womack et al., 1991). Due to its cyclic nature, lean methods' results aren't a one-time solution. Implementing a lean philosophy requires a steady cycle of maintenance, assessment, mapping and solving (Alaskari, Ahmad, & Pinedo-Cuenca, 2016). Because of that, implementing lean tools takes time and involves different levels within a company, from top management to *gemba* workers (Groover, 2010).

2.2. Lean Principles

The Toyota Production System developed a set of fourteen guiding principles to achieve the goals of lean thinking, which make up the Toyota Way, or the company's managerial approach and production system (Ohno, 1988). The fourteen TPS principles can be illustrated by a pyramid, shown in Figure 2 (Liker, 2003).

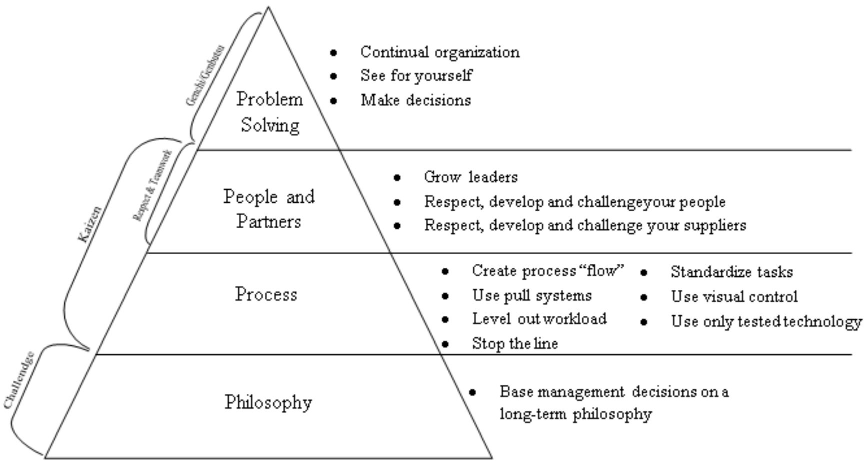


Figure 2 - Toyota production system pyramid

Source: (Liker, 2003)

Based on the fourteen principles of TPS, authors Womack & Jones (2010), defined five key lean principles: value, value stream, flow, pull and perfection, shown in Figure 3 (McCarron, 2013).

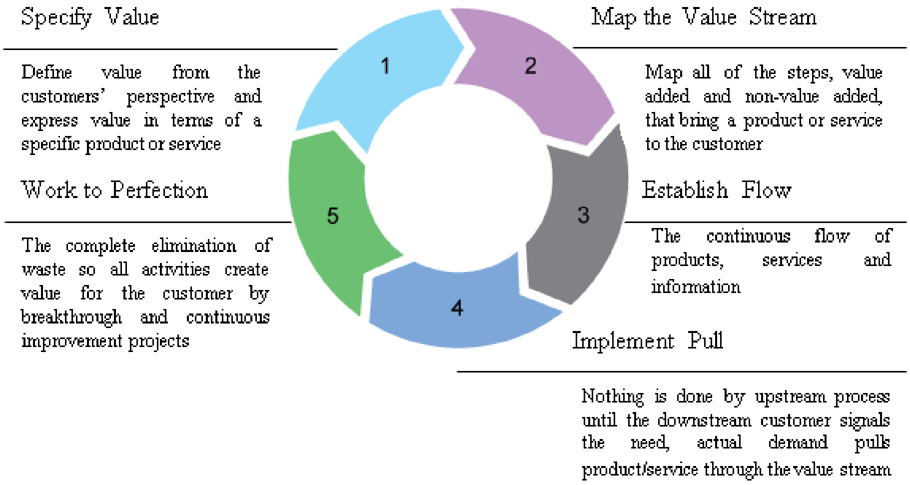


Figure 3 - Womack and Jones' 5 Lean Principles

Source: (McCarron, 2013)

Toyota's principles are more encompassing of all different areas of production. It provides detailed guidelines including a guiding philosophy for the company, process principles, the people and problem solving (Ohno, 1988). Meanwhile, Womack and Jones' (2010) principles focus specifically on process.

The base of the Toyota production system pyramid is a guiding philosophy. By having a guiding philosophy, managers can align the entire organization towards a common purpose that is bigger than any short-term goals (Ohno, 1988). For Womack and Jones' (2010), the first principle is to specify value, because it will create the guidelines for the production and where it can be improved (Womack & Jones, 2010).

For Womack and Jones' (2010), this is followed by mapping the value stream. By recognizing all the steps that take the product from its raw materials to the final product, manufacturers can identify which steps generate value for the customer. Those steps which do not generate value must be questioned (Womack & Jones, 2010). Toyota's principles, on the other hand, do not have a value-stream mapping step, but their continuous improvement principle is considered essential, and includes continuously identifying problems and waste in production to eliminate them (Liker, 2003).

Creating flow is present in both sets of principles, and is a part of the process step of the Toyota pyramid. According to Liker (2003), creating a continuous process flow makes managers able to link people and processes together, making it so that problems are identified and solved quickly, and that no work sits idly by. According to Womack and Jones' (2010), creating flow is making sure that value-creating steps occur in a tight sequence. By doing that, it is ensured that no interruptions, delays or bottlenecks happen, thus making the product flow smoothly to the customer (Womack & Jones, 2010).

The process step of the Toyota pyramid is also made up of other principles, such as level out workload, stop the line, standardize tasks, use visual control and use only tested technology. Although Womack and Jones' (2010) do not consider these key principles, they have a certain level of importance. Stopping a culture of fixing problems, instead getting good quality right away, through continuous quality assessments and by imbuing machines with the capability of recognizing and stopping mistakes (Liker, 2003).

Standardizing tasks is used to control times and maintain a certain level of predictability and regularity within the production system (Liker, 2003). Meanwhile, visual control aids employees in identifying problems and making decision; technology is meant to support, and not replace, people, and be used to maintain flow, instead of disrupting it (Liker, 2003; Ohno, 1988).

Implementing pull is the next step of Womack and Jones' (2010) principles. Pull systems stem from the just in time philosophy. It leads to controlled production and eliminates the need for unnecessary inventory, which is expensive and takes time and space to manage (Ohno, 1988). For Womack and Jones (2010), improving flow decreases time to market (Womack & Jones, 2010).

Work to perfection is the next step in Womack and Jones' (2010) principles. It is also a guideline of the Toyota principles. Striving towards perfection is seeking out the point where the company generates zero waste, and products have perfect flow from factory to customer and through all the steps in between (Womack & Jones, 2010).

The Toyota pyramid shows a complete picture of what Lean entails, from philosophy to action, while Womack and Jones (2010) condensed it into the five key principles. These two views complement each other, with Womack and Jones' principles focusing more on action, as opposed to philosophy (Bhasin, 2015).

2.3. Lean Perspectives

There are three perspectives on Lean and its implementation. The first is Shigeo Shingo's, derived from his industrial engineering background. Shingo's main focus was on the flow of operations, that should function smoothly as to avoid creating any inventory (Szwejczewski & Jones, 2012). The second is Fujimoto's evolutionary learning perspective. The author identifies three main points of TPS: reliable standard methods, reliable standard problem-solving techniques and experimentation. These three characteristics make up how lean was implemented at Toyota (Fujimoto, 1999). Finally, the third perspective is H. Thomas Johnson's. Toyota focuses on means, rather than results. By implementing strategies based on process, the results follow naturally (Johnson & Bröms, 2011). Table 1 shows the three perpectives.

Table 1 - Lean Perspectives

Perspective	Flow of Operations	Evolutionary Learning	Means, rather than results
Author	*Shigeo Shingo (Szwejczewski & Jones, 2012)*	*(Fujimoto, 1999)*	*(Johnson & Bröms, 2011)*
Description	Is an Engineering perspective, Lean is seen as a non-stock production – produce with minimal inventory. "The longer anything is in the factory, the more it costs." (Szwejczewski & Jones, 2012, p. 213)	Lean is viewed as a standard learning process, Fujimoto identifies three characteristics, "reliable standard methods, reliable problem-solving techniques and experimentation." (Fujimoto, 1999, p. 114)	Lean is focused on process and then the results will appear. The process is understood and are not derived from the task.

Source: Author based on referenced papers and books

2.4. Lean Tools and the Industry

To achieve its goals to improve the manufacturing process, Lean Manufacturing is supported by a set of tools, built to help managing all the aspects of lean and to properly implement it in companies, as well as provide continuous feedback, so that problems can be identified and fixed (Pettersen, 2009). Different industries require different tools, according to their particular needs (Alaskari et al., 2016).

Sumant and Patel (2014) analyzed the needs of different industries, and suggested that, 5S, Just in Time, *Kanban* and Value Stream Mapping have major contribution in Industrial Sectors, and that 5S is the preferred waste elimination Lean tool. They also showed that different industrial sectors frequently employ more than one tool, and that Six Sigma is often combined with other tools. Additionally, the Textile, Automobile, Manufacturing, Process and MSME sectors are the ones that more often employ the usage of Lean tools in their production (Sumant & Patel, 2014).

Shah and Ward (2003), have divided the lean tools in four bundles: Just-in-time (JIT), Total Productive Maintenance (TPM), Total Quality Management (TQM) and Human Resources Management (HRM). JIT tools are used to produce what the customer wants, when they want it, in the quantities requested, where they want it, without it being delayed in inventory. TPM is an approach to equipment maintenance that aims to achieve perfection in production, by eliminating breakdowns, small stops, slow running and defects. It emphasizes the need for preventive maintenance and the maximization of operational efficiency of equipment (Shah & Ward, 2003). TQM tools help organizations identify and analyze qualitative and quantitative data that is relevant to their businesses. They can identify issues relevant to their organizations and can be used to enhance the effectiveness, efficiency and the overall quality of their procedures and processes (Shah & Ward, 2003). In the fifth bundle, HRM, the tools are designed to manage people within the organization, and are divided in three main fields, staffing, employee compensation and benefits, and defining work (Shah & Ward, 2003).

On the other hand, Pinto (2009), divides the lean tools in six bundles (Pinto, 2009): i) Planning, Operations and Logistics, ii) Disposal of Waste, iii) Identification and Resolution of Problems, iv) Six Sigma Tools, v) Value Creation and vi) Theory of Constraints Tools.

Table 2 merges Pinto's (2009) and Shah and Ward's (2003) approaches to lean tools and details the pool of tools inside each bundle.

Table 2 - Lean Tools in Bundles

(Shah & Ward, 2003)	**(Pinto, 2009)**	**Lean Solutions**
JIT	Planning, Operations and Logistics	*Kanban** | *Heijunka** | JIT/Pull system* | *Hoshin kanri**
		Andon & Visual management* | *Poka-Yoke* & *Jidoka**
		Mizusumashi & Milk run* | Takt-time*
		One piece flow | SOP - Sales and operations planning
		Lean supermarket | Two bin system | *Junjo*
	Disposal of waste	Good Housekeeping 5(+1)S* | Zero Defects*
		SMED e quick-changeover* | VSM*
		7W | 3M | Waste registration and analysis
TPM	Identification and resolution of problems	5W* | PDCA* | *Ishikawa** | Flow chart*
		5W2H | ABC Analysis | A3 | Check sheet | TOPS/8D
		Histogram of frequencies | OSKKK
	Six Sigma Tools	SIPOC* | DMAIC/DMADV | Spaghetti diagram*
TQM		SPC | SMART[1] | OEE* | DOE | *Kano* diagram
	Value creation	QFD* | *Hourensou**
		VOC & HOQ | Design for X | FMEA
		Value Stream Analysis and Design (VSAD)
HRM	Theory of constraints tools	Bottlenecks | CRT | Conflict Resolution Diagram | FRT
		NBR | PRT | TRT
		* Main Lean Tools

Source: Author based on referenced papers and books and adapted from (Pinto, 2009; Shah & Ward, 2003)

The Planning, Operations and Logistics tools make up part of Shah and Ward's (2003), JIT bundle and relate to planning the company's operations and manufacturing processes, and the logistics in order to decrease inventory (Pinto, 2009; Shah & Ward, 2003).

Disposal of Waste tools make up the rest of Shah and Ward's (2003), JIT bundle, and focus on the disposal of waste such as unnecessary inventory, decreasing lead-times, defects, and continuously improving the identification and elimination of waste (Pinto, 2009; Shah & Ward, 2003).

Identification and Resolution of Problems is part of Shah & Ward's (2003), TPM bundle. It aims to identify and solve any issues, in order to achieve lean's continuous improvement (Pinto, 2009; Shah & Ward, 2003).

Six sigma tools are divided between the TPM and TQM bundles, and aim to eliminate defects while systematically improving processes (Pinto, 2009; Shah & Ward, 2003). Creating value for the customer is one of lean's main goals. Six sigma tools aim to create more value by improving productivity and creating a link between customers' wants and needs and the production. These tools fall under Shah & Ward's (2003), TQM bundle (Pinto, 2009; Shah & Ward, 2003).

Theory of Constraints Tools are the same as Shah & Ward's (2003), HRM tools. They are meant to manage people and their relationship within the company (Pinto, 2009; Shah & Ward, 2003).

2.5. Lean Advantages & Risks

The main idea behind the implementation of Lean is the increase of value for the customers, through the decrease of resources and elimination of waste. Therefore, it is evident that this philosophy has its advantages (Čiarnienė & Vienažindienė, 2012).

Melton (2005) lists six typical benefits of lean implementation: inventory reduction, lead times reduction, rework reduction, increase of process understanding, less waste, cost reduction.

Lean Production presents multiple advantages and risks, as shown in Table 3.

Table 3 - Advantages & Risks of Lean Manufacturing

Advantages		Risks	
Client Satisfaction	With the reduction of waste, the client receives only what carries value for them. That generates bigger client satisfaction	Problems with client insatisfaction	Since Lean relies strongly on suppliers, one supplier failure can generate delays
Productivity	Productivity increases because production focuses on eliminating waste	Productivity costs	In order to maintain productivity, an initial investment is needed, which may halt the process of implementation
Attitude Changes	Lean implementation demands significative attitude change, which may prove challenging if the company is not ready	Lack of employee acceptance	Implementing Lean includes significant changes in the production system, which can be met with resistance from employees
Quality	As the process improves, so does product quality	High implementation costs	Lean implementation leads to changes in the work environment and might incur costs like employee training, buying new machines or reconfiguring the factory layout
Delivery times	Just in Time production decreases delivery times, because it does not allow for excess inventory	Supply issues	Since Lean decreases inventory, the production becomes reliant on suppliers.

Source: (Melton, 2005)

2.6. Performance Management and Lean

Performance management consists in managing the accomplishment of any tasks ordered or undertaken within a company (Mirea, 2013). In this process, managers work with employees to determine goals, and measure results, aiming to affect the organization positively (Eaidgah et al., 2016).

According to Eaidgah et al. (2016) there are three major elements in performance: Planning and Implementation, Measurement, and Evaluation.

Planning and Implementation means defining goals, metrics and setting targets to be achieved by the organization or specific employees. Planning and implementation is the basis for any successful performance management because it sets the guiding lines for future actions (Eaidgah et al., 2016). Once goals are set, measurement is essential to keep track of how tasks are being handled. It is done using pre-determined metrics (Eaidgah et al., 2016).

Evaluation (assessing the tasks according to the pre-determined targets) is key to continuous improvement, because it provides feedback to employees and managers alike, and can help redesign future strategies and set new goals (Eaidgah et al., 2016).

Lean tools are intimately related with performance (Behrouzi & Wong, 2011). The "pull" system implemented through lean depends on a regular flow of work, which involves all of those on the production line in a permanent effort to achieve perfection (Eaidgah et al., 2016). Given that perfection is its ultimate goal, Lean also determines the continuous measurement of the performance and improvement of the production process (Karim & Arif-Uz-Zaman, 2013).

The aim of Lean in terms of performance is cyclical improvement (Demeter, Losonci, Matyusz, & Jenei, 2009). Perfect flow depends on employees not only doing their job, but doing it seamlessly enough so that any problems that arise can be immediately identified and fixed (Eaidgah et al., 2016).

In order to reach organizational objectives and goals, companies have realized that performance management is essential. Through it, organizations manage to establish the extent to which activities within a specific process achieve their specified goals (Iuga, Kifor, & Rosca, 2015).

Measuring and managing performance is a system that requires key metrics. Performance measurement should facilitate decision making and align actions with the company's strategic objectives, providing feedback on operational performance (Kibira, Brundage, Feng, & Morris, 2018). The Key Performance Indicators (KPIs) are these metrics. To select the proper KPIs, organizations must ensure that these are a good fit both with their competitive environment and the organization's goals and strategies (Iuga et al., 2015). However, determining performance measures can prove challenging. While financial measures have been widely considered effective, it is difficult to properly determine non-financial measures. Managers must consider the cause-and-effect relationship in strategy when linking it with measures (Sanjay, 2008).

Lean management involves making decisions based on real data, and its indicators are a system that allows decision-making based on the analysis of this data, information and objective evidence, acquired through proper methods of quantification and estimation with minimal effort, in minimal time and with minimal costs (Iuga et al., 2015). In implementing lean, an organization needs to understand how key performance measures can guide and help the success of lean manufacturing implementation (Iuga et al., 2015). Theoretically, leanness can also be measured by different lean indicators, though there are differences in opinion regarding the relevance of this indicators contributing towards the measure of lean practices (Susilawati, Tan, Bell, & Sarwar, 2013).

On Table 4, it is possible to see the main KPIs divided in two different sets of bundles.

Table 4 - Main Key Performance Indicators

(Iuga et al., 2015)	(Belekoukias et al., 2014)	Directions to implement Lean KPIs management (Iuga et al., 2015)	Main KPI's (Belekoukias et al., 2014; Iuga et al., 2015)
Moving	VSM	Select the KPIs taking into consideration the possibility to be managed directly at the production place	Lead-time
			Cycle-time
			Process defects
			Plant efficiency
			Fabric utilization ratio
			Value added time ratio
Waiting		Select the KPIs taking into consideration the utility in process management	Lead-time
			Cycle-time
Transport	JIT	Implement standards: go and see/ management by wandering around etc.	On-time delivery
			Supplier on-time delivery
			Dock-to-dock
Inventory (stocks)		Select the KPIs taking into consideration the utility in processes management	On-time delivery
			Unit cost
			Fabric utilization ratio
			Inventory turnover
			Inventory level reduction
Over-production		Select the KPIs taking into consideration the utility in process management	Productivity
			Unit cost
	TPM		OEE
			Facility/machine productivity
Over-processing		Select the KPIs taking into consideration the amount of human activity needed. Select the KPIs taking into consideration the investments in special trainings needed. Select the KPIs taking into consideration the investments in machines and software needed	Facility/machine productivity
			OEE
Defects	TQM	Select the KPIs that are familiar at the shop floor and involve the personnel	Product defects
			Process defects
			Nº Rework
Others	HRM	Select the KPIs that are familiar at the shop floor and involve the personnel and Customer	%Customer satisfaction
			%Employee satisfaction
			%Employee education/training

Source: Author based on (Belekoukias et al., 2014; Iuga et al., 2015)

Iuga et al. (2015), divides the KPIs according to the seven types of waste: moving, waiting, transport, inventory, over-production, over-processing, defects and other (Iuga et al., 2015). On the other hand, on Belekoukias et al. (2014), we can see a division of the main KPIs in the following bundles: VSM, JIT, TPM, TQM and HRM (Belekoukias et al., 2014).

The first bundle is Moving. These KPIs relate mostly to how long certain processes take and measures relating to time and value. Second, Waiting, also relates to time, specifically cycle and lead times (Iuga et al., 2015). Moving and Waiting make up the VSM (Value Stream Mapping) bundle from Belekoukias et al. (2014).

Transport relates to the logistics. It includes indicators on deliveries and dock-to-dock times. This makes up part of Belekoukias et al. (2014), Just in Time (JIT) bundle. Next is Inventory, which includes KPIs related to delivery times, raw materials needed and amount of stock needed. They are also included in the JIT bundle (Belekoukias et al., 2014; Iuga et al., 2015).

Over-production KPIs fall both under JIT and Total Productive Maintenance (TPM) bundles. These KPIs relate to the amount produced and general factory productivity. Over-processing KPIs are included in the TPM bundle. These are related to machine productivity and effectiveness (Belekoukias et al., 2014; Iuga et al., 2015).

The Defects and Total Quality Management (TQM) bundles are made up of the same indicators. They relate to the rate of defects in product and process, as well as rework time (Belekoukias et al., 2014; Iuga et al., 2015).

Finally, the Others and Human Resources Management (HRM) bundles are also made up of the same indicators, and relate to client and employee satisfaction and training (Belekoukias et al., 2014).

It's essential to highlight that some indicators, such as OEE, are also considered tools. Belekoukias et al. (2014), uses it as a KPI, while others use it as a tool for Lean (Iannone & Nenni, 2013).

2.7. Performance Categories and Clusters according to Lean Philosophy

This section presents current literature's findings regarding categories and clusters and brief reviews of these concepts and their usage in existing research.

Categories are important within frameworks because they divide the KPIs into subjects. They are used to facilitate visualization, allowing for easier referencing. According to Susilawati, Tan, Bell, and Sarwar (2012), there are eight main categories in performance, divided according to which aspect of the company the indicators impact. These are broader than clusters or dimensions. The categories found in the multidimensional framework proposed by Susilawati, Tan, Bell, and Sarwar (2012) are:

Consumer issues: includes all KPIs that assess information which may impact consumer experience with the product or brand, such as quality, delivery and customization, or how the company is impacted by the consumer (Susilawati, Tan, Bell, & Sarwar, 2012).

Supplier issues: groups the KPIs related to supplier activities, such as quality of materials, supply cost and distance between suppliers and manufacturers (Susilawati et al., 2012).

Manufacturing management: refers to all of the KPIs assessing the overall management of the manufacturing process and the company, with the exception of efficiency. This category can include KPIs relating to defects, scheduling, inventory and cycle times (Susilawati et al., 2012).

Internal management: this category groups KPIs related to internal company processes, such as shop floor layout, delegations of functions and employee evaluation (Susilawati et al., 2012).

Research and development: the KPIs present in this category refer to all research done by the company, including KPIs related to design, standardization and development (Susilawati et al., 2012).

Manufacturing efficiency: refers to the KPIs related to the efficiency of the manufacturing process, such as lead times, idle time and worker movement (Susilawati et al., 2012).

Learning perspective: this category groups KPIs related to training and visual aids within the company (Susilawati et al., 2012).

Investment priority: groups the KPIs related to all investment actions, such as training investment and research investment (Susilawati et al., 2012).

Clusters, often referred to as dimensions in literature, have been used by Pakdil and Leonard (2014), to measure leanness through their study's lean assessment tool. The clusters briefly presented below were created using the lean production principles as a basis, correlated with the seven wastes defined by Ohno (Pakdil & Leonard, 2014).

Wahab, Mukhtar and Sulaiman, (2013), also use dimensions in their work, though these are closely related to those found in Pakdil and Leonard (2014). The findings of these two authors and their categorizations are presented on Table 5.

Table 5 - Clusters

Clusters	Description	Authors
Time effectiveness	This cluster groups all of the KPIs of time-related variables, such lead or setup times. and includes all KPIs meant to synchronize production and market demands.	(Pakdil & Leonard, 2014; Wahab, Mukhtar, & Sulaiman, 2013)
Quality	KPIs related to defects, quality guarantees and reworks. It is related to the defects waste and the lean expectation of quality standards.	(Pakdil & Leonard, 2014; Wahab et al., 2013)
Process	It groups KPIs related to machinery efficiency, maintenance, space utilization and any other indicators which may affect manufacturing processes, includes quality assurance, and all machine and process related times, such as setup times.	(Pakdil & Leonard, 2014; Wahab et al., 2013)
Cost	Refers to the financial KPIs and was included due to their importance for lean manufacturing, and the fact that many authors add cost reduction as one of Lean's benefits for companies.	(Pakdil & Leonard, 2014; Wahab et al., 2013)
Human resources	This is related to the over motion waste. KPIs such as labor turnover, absenteeism rate and number of employers are grouped under this cluster.	(Pakdil & Leonard, 2014; Wahab et al., 2013)
Delivery	Refers to both internal and external activities, and is correlated to the over handling waste. Internal processes, such as time from one machine to another, transporting of raw materials and unfinished products and external processes, such as delivery.	(Pakdil & Leonard, 2014; Wahab et al., 2013)
Customer	KPIs in this cluster refer to client satisfaction and market share, which are essential for any organization includes also delivery related KPIs.	(Pakdil & Leonard, 2014; Wahab et al., 2013)
Inventory	This cluster relates to the waste excess inventory. It groups KPIs such as inventory, stock turnover rate and raw materials rate.	(Pakdil & Leonard, 2014; Wahab et al., 2013)
Visual Information System	Relates to the establishment of information flow within the manufacturing company, through the direct access to this information. It includes all KPIs geared towards these actions, such as the number of products made.	(Wahab et al., 2013)
Product Development and Technology	Relates to the product development phase of manufacturing and includes all KPIs linked to structure, materials and technical solutions.	(Wahab et al., 2013)

Source: Author based on referenced papers

2.8. Current Theories on Performance Measurement

Conventional performance measurement systems have limitations. To overcome those, a number of alternative approaches to performance management and assessment have been developed, like Strategic Measurement and Reporting Technique (SMART), Balanced Score Card (BSC) and Performance Measurement Questionnaire (PMQ). They are designed to provide managers and operators with relevant information (including non-financial aspects) to improve processes, one of performance assessment's key roles (Susilawati et al., 2013). Table 6 synthetizes the main performance management systems.

Table 6 - Performance Measurement Systems

Balanced Scorecard (BSC)	The Balance Scorecard offers four perspectives to the performance in an organization: innovation and learning, financial, customer and internal business. The BSC gathers data on core indicators at discrete time intervals and the integration of an organization's vision and its actions, but it can't view performance at manufacturing level, it struggles to measure long-term results and can't identify performance measurement at a specific level.	(S. & P., 1996)
Dynamic multi-dimensional performance (DMP)	DMP is a multidimensional perspective that provides information to assess an organization's performance in multiple time horizons and examine various research streams. This model has five major dimensions, Financial, Customer, Process, People and Future.	(Michael, 2006)
The Strategic Measurement Analysis and Reporting Technique (SMART)	"Strategic Measurement Analysis and Reporting Technique (SMART) is a system developed by Wang Laboratories to integrate both financial and non-financial performance indicators. This system is designed as a four-step system that can integrate organization objectives with operational performance indicators. However, it excludes continuous improvement." (F. Cross & L. Lynch, 2007)	(F. Cross & L. Lynch, 2007)
Performance Measurement Questionnaire (PMQ)	The Performance Measurement Questionnaire was developed to assess the existing performance measurements used in an organization. The PMQ consists of two parts: the first, to evaluate specific improvement areas and existing performance improvement; second, to evaluate the long-term relevance of improvements achieved by the company. The identified three improvement areas categories are: quality, labor efficiency and machine efficiency.	(Dixon, Nanni, & Vollmann, 1990)
Performance Prism	The Performance Prism is a framework developed with five performance perspectives: stakeholder satisfaction, strategies, processes, capabilities and stakeholder contribution. Though it has a comprehensive external organization view, it gives little less attention processes.	(Dixon et al., 1990; Mike & Andy, 2002)
Integrated Dynamic Performance Measurement System (IDPMS)	The IDPMS focuses on integrating three main areas of measurement: management, process improvement teams and factory shop floor. This framework can measure general and specific areas of success, utilization of improvement and performance measurement reporting, but it can't evaluate the company's overall performance score.	(Ghalayini, Noble, & Crowe, 1997)

Integrated Performance Measurement System (IPMS)	The Integrated Performance Measurement System (IPMS) is a model with four levels of performance management: corporate, business units, business processes and activities. Though the IPMS has strength to drive continuous improvement, it doesn't provide clear measurements in a logical order, manage relationship between measures or provides a structured process specifying objectives and timelines.	(Umit, Allan, & Liam, 1997)
European Foundation for Quality Management (EFQM)	The EFQM is a self-assessment framework based on nine criteria, divided between "enablers (leadership, people, policy and strategy, partnership and resources, and processes) and results (people results, customer results, society results, and key performance results)." (EFQM, 2009). It does not involve external assessments or comparisons with competitors, and lacks attention to flexible factors such as the implementation that might be different between company's type and the company maturity.	(EFQM, 2009)

Source: Author based on referenced papers and books

Undeniably, there are certain guidelines organizations need to consider when implementing effective performance measurement systems. Frequently, organizations use generic measures, which are sometimes irrelevant. The challenge is choosing the right measures for each level of the organization (Sanjay, 2008).

Lean's benefits are difficult to quantify. Performance measures can help a company develop its productivity and quickly identify and eliminate problems, thus achieving superior results. However, many companies focus on performance measures related to internal processes, but with no ties to customer needs in their respective targeted markets, misguiding the company's actions (Sanjay, 2008).

Companies need to not only recognize the importance of key performance measures, but also know that in order to achieve better results they should install a system that can provide a full assessment of the company's current situation, its issues and what remedial actions should be taken (Sanjay, 2008).

2.9. Performance Measuring Frameworks to fit Lean

There are studies concerning theories of performance measuring systems appropriate to fit lean, the similar studies of this research. Table 7 includes these studies, their respective aims, conclusions and their limitations and future applications.

Table 7 - Performance Measuring Frameworks to fit Lean

Author(s)	Aim of the study	Main Conclusions	Limitations / Future Applications
(Belekoukias et al., 2014)	- Investigates the impact of five essential lean methods, on performance measures.	- JIT and automation have the strongest significance on operational performance; - *Kaizen*, TPM and VSM seem to have a lesser, or even negative, effect on it.	- Provides further evidence regarding the effects that lean practices have on the performance of organizations.
(Gama & Cavenaghi, 2009)	- Lean Production's main characteristics; - Performance Measurement System that has adherence to lean management model.	- Develops a Visual Performance Measuring Model.	- PMS needs to be adequate to the organization aiming to implement principles of lean production.
(Ghalayini et al., 1997)	- Presents an integrated dynamic performance measurement system (IDPMS)	- Adoption of the IDPMS is an incremental process.	- A complete implementation of the IDPMS would require adoption of the half-life concept for setting improvement objectives.
(Sanjay, 2008)	- The need for organizations to adopt a more holistic and comprehensive approach to performance measurement on Lean	- Creates a DMP framework embracing five dimension"; - "more robust than its predecessors; - stresses the need to utilize a smaller set of multidimensional metrics.	- Organizations need to promote a portfolio of measures directed at both the internal and external environments.
(Susilawati et al., 2013)	- Propose a Performance Measurement and Improvement System (PMIS) framework for lean manufacturing practice.	- Proposes a framework that could be applicable in real implementation by lean manufacturing companies.(Susilawati et al., 2013)	- Within the current PMS models there is relatively less information which specifically addresses PMS for lean manufacturing.

Source: Author based on referenced papers

It is possible to notice, however, that all but one of the studies showed a redundancy about the interaction of lean and performance, some of the studies did not consider lean, while others consider it only partially.

Existing frameworks either consider few aspects of Lean, or none at all. Gama and Cavenagha (2009) construct a visual model for performance, restricting it to production, and do not build a tangible framework. Sanjay (2008) proposes a dynamic framework to measure performance, but considers just five dimensions, using smaller, multidimensional metrics. Susilawati et al. (2013) don't include all of the dimensions of lean, while Belekoukias et al. (2014) only consider five lean methods to measure performance.

3. Methodological Considerations

This chapter presents a detailed account of the methodology adopted to conduct this research. It reviews the methodological aspects considered in similar studies, followed by the steps of a conceptual literature review.

3.1. Conceptual Review

Conceptual reviews address issues such as the existence of clashing discoveries in literature by synthetizing areas of conceptual knowledge (Petticrew & Roberts, 2008). The aim of a conceptual literature review is to present key aspects and ideas of the theme discussed, highlighting the significance of past research in constructing a new conceptual framework (Baumeister & Leary, 1997). This dissertation contributes to existing research by adopting this method in order to propose a new performance measurement framework to fit lean.

3.1.1. Scoping

Many major businesses have been trying to adopt lean philosophy, but firms fail to develop performance measurement metrics needed to evaluate their improvement (Karim & Arif-Uz-Zaman, 2013). The main aim of the dissertation is to develop a new Performance Measurement Framework to fit Lean, in order to answer the following research question:

RQ: "What is the best way to measure performance in a Manufacturing environment wherein Lean has been implemented?"

The main research question must be supported by secondary questions, presented below:

SRQ1: "How do traditional Performance Measurement Systems need to change to adequate to lean?"

SRQ2: "Which key performance indicators are the most used by companies?"

- "Which Lean tools are the most used?"
- "Which KPIs are the most used in these tools?"

A few studies have been made in that particular subject, some more similar than others. The following table (Table 8) presents the main methodological aspects of studies with similar characteristics to this one.

Table 8 - Methodological aspects of similar studies

Author(s)	Country	Sector	Methodology	Data Sources
Gama, K.T.; Cavenaghi, V. (2009)	Several	Generalized	Literature Review	Online articles Books
Sanjay Bhasin, (2008)	United Kingdom	Generalized	Literature Review	Online articles Books
Susilawati et al, (2013)	Indonesia	Manufacturing	Literature Review	Online articles Books
Belekoukias et al, (2014)	Several	Manufacturing	Hypothesis Testing	Surveys
Ghalayini et al, (1995)	United States of America	Manufacturing	Case Study	Company Data

Source: Author based on referenced papers

3.1.2. Planning

Table 9 shows the breakdown of the research questions and the research criteria. As case studies aim to assess and detail the reality of specific issues and their solutions, these documents were chosen as sources for this research. This choice deliberately aimed to create a framework that properly reflects the reality of manufacturing companies All case studies found that matched the criteria were considered in the study, in order to validate it.

Table 9 - Research protocol

Research protocol			
Keywords	Primary	Secondary	Tertiary
	Lean, Performance	Case Study, Case Studies, Indicators, Manufacturing	Performance Framework, Performance Measurement, Tools, KPI
Boolean operator	AND and OR		
Data base	Web of Knowledge, SCOPUS, EMERALD, EBSCO, b-on		
Inclusion criteria	Relevant to the topic, Manufacturing environment, Lean related, Performance related, Case studies related with lean indicators and performance indicators		
Exclusion criteria	Organization Sector, Service Sector, Non-Lean related, Non-performance related, Patents and citations are excluded		
Language	Portuguese, English, French, Spanish		
Document type	Case studies		
Publication years	no filters		

Source: Author

3.1.3. Identification (Searching)

Search terms are used to search in the different (relevant) electronic databases, mentioned on the search protocol. The results were carefully inspected, and, additional searches were conducted on a need basis, to ensure that is located all potentially relevant published work. A total of 15570 articles were found in the initial searching process.

3.1.4. Screening

After scanning the titles and abstracts of works searched, the researcher decided whether or not the articles were to be included in the research (F. Baumeister, 2013). Case studies done in manufacturing industries, relating to the use of lean tools, performance and the relationship between these two concepts were selected. After the screening process, a total of 583 articles were considered fitting for the research.

3.1.5. Eligibility

Case studies related to lean manufacturing and performance evaluations were considered eligible, as long as they contained the following information:

- Were conducted within a manufacturing sector, industry or organization;

- Were successful in achieving the desired or proposed results;

- How individual lean tools impact performance;

- Which area(s) of performance is (are) directly impacted;

- Which indicators are directly affected;

Only studies that were successful in achieving their desired results were considered, because the information from unsuccessful cases wouldn't be considered valid in terms of lean tools appropriately impacting performance and wouldn't properly reflect reality. After this process, 302 case studies were found eligible. Figure 4 represents the Research diagram.

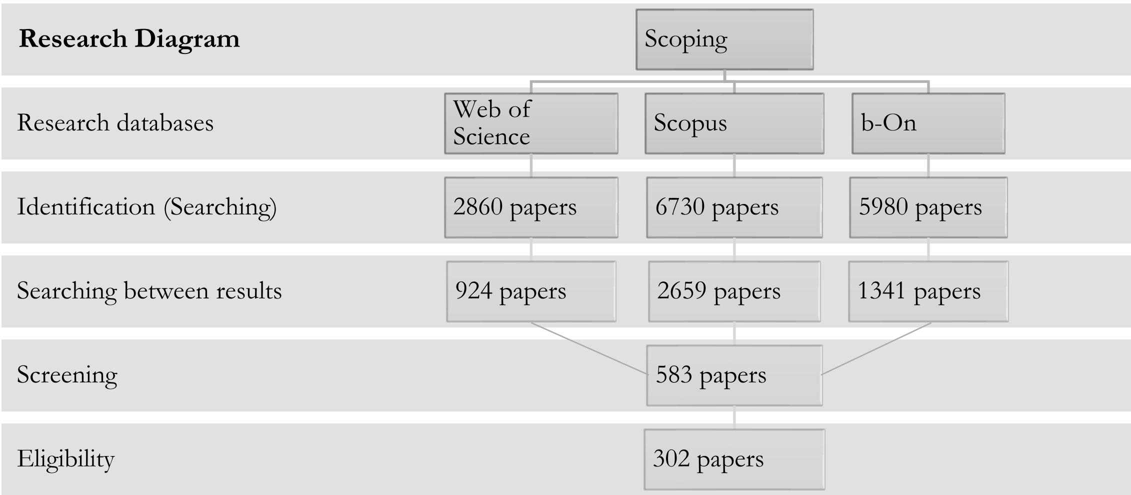


Figure 4 - Research Diagram

Source: Author

Additionally, the author also used this phase to decide which tools would be considered. Once the case studies had been gathered, it was concluded that many of the presented work techniques that, although not formally considered *lean tools*, worked towards the achievement of lean goals or in connection with lean tools. These were, therefore, considered as part of the group of tools, philosophies and work techniques.

3.1.6. Decide Between Quantitative or Qualitative Research Synthesis

Table 10 shows, according to F. Baumeister (2013) and Petticrew and Roberts (2008), when a qualitative and quantitative review synthesis is appropriated.

Table 10 - Quantitative or Qualitative Research Synthesis

Qualitative Reviews	**Quantitative Reviews**
(F. Baumeister, 2013)	(Petticrew & Roberts, 2008)
- A group of studies are so methodologically diverse as to make meta-analytic aggregation impractical; - Conceptual and methodological approaches to research on a topic have changed over time and you argue that there is benefit in reviewing all of this research; - When developing a new theory or critiquing one or more existing theories; - When reviewing measurement approaches in a particular literature	- Central tendency researches; - Pre/post contrasts; - Association between variables; - Measurement research; - Individual differences research.

Source: Author based on referenced papers

This dissertation will adopt a combined approach, using both qualitative and quantitative synthesis to evaluate different parts of the work. A qualitative approach will be primarily used in order to identify, evaluate and choose the following:

- An appropriate base model for the performance measurement framework;
- Performance categories;
- Performance clusters

A quantitative approach, namely a frequency analysis, will be applied to the key performance indicators, according to their recorded usage in case studies and their relationship with Lean tools, philosophies and work techniques.

4. Results

This chapter will present the results of the investigation. It begins by introducing the design of the framework, then the frequency analyses of indicators and tools. It, then, presents the finished framework, its relationship with other existing performance measurement systems and recommendations for implementation.

4.1. Performance Measurement System Design

A total of 302 case studies were considered valid for the research. As these were conducted in various settings within manufacturing companies, ranging from environmental impact to manufacturing efficiency, a table containing the subjects and authors of each of these case studies was built (inserted in appendix A).

Figure 5 shows the number of articles found according to the year, from 1996 to 2018. The evolution of the number of papers published shows an expected behavior, as Lean (as an academic subject) only started gaining traction in the 90s (Dekier, 2012).

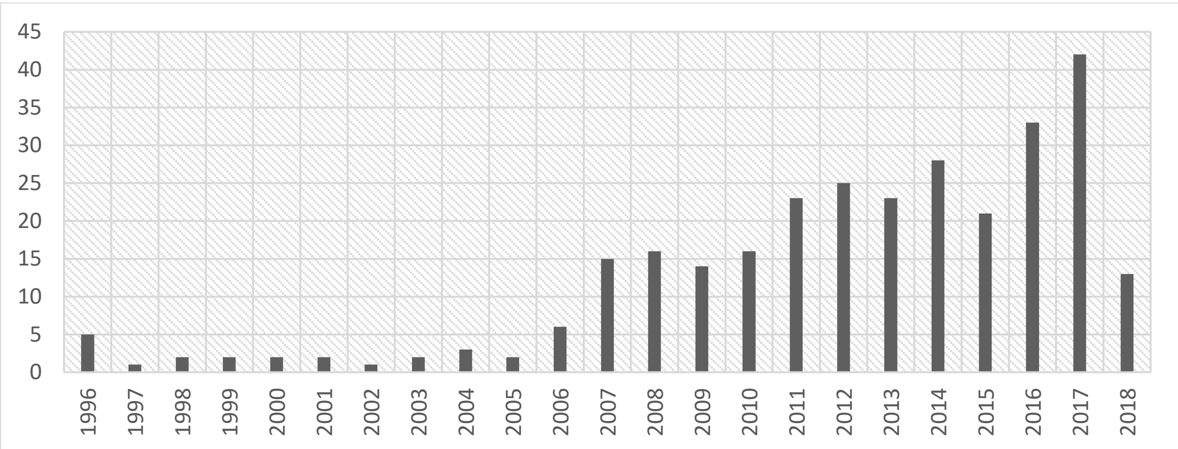


Figure 5 - Case studies years distribution

Source: Author

Table 11 shows a condensed view of existing performance measurement models and the characteristics of each one. It was created based on Table 6 (found on the literature review), in order to make it possible to analyze the key aspects of these models and choose the best one as a base.

Table 11 - Performance measurement models characteristics

Balanced Scorecard (BSC)	- 4 perspectives: innovation and learning, financial, customer and internal business; - Gathers data on core indicators at discrete time intervals; - Integration of an organization's vision and its actions; - Can't view performance at manufacturing level; - Struggles to measure long-term results; - Can't identify performance measurement at a specific level.
Dynamic multi-dimensional performance (DMP)	- 5 dimensions: Financial, Customer, Process, People and Future; - Assess performance in multiple time horizons; - Various research streams.
The Strategic Measurement Analysis and Reporting Technique (SMART)	- Integrate both financial and non-financial performance indicators; - Integrate organization objectives with operational performance indicators; - Excludes continuous improvement.
Performance Measurement Questionnaire (PMQ)	- Evaluate specific improvement areas and existing performance improvement; - Evaluate the long-term relevance of improvements achieved by the company.
Performance Prism	- Five performance perspectives: stakeholder satisfaction, strategies, Processes, capabilities and stakeholder contribution; - Comprehensive external organization view; - It gives little less attention to processes.
Integrated Dynamic Performance Measurement System (IDPMS)	- Integrate three main areas of measurement: management, process Improvement teams and factory shop floor; - Can measure general and specific areas of success; - Can't evaluate the company's overall performance score.
Integrated Performance Measurement System (IPMS)	- Four levels of performance management: corporate, business units, business processes and activities; - Has strength to drive continuous improvement; - Doesn't provide clear measurements in a logical order.
European Foundation for Quality Management (EFQM)	- Self-assessment framework based on nine criteria; - It does not involve external assessments or comparisons with competitors; - Lacks attention to be flexible.

Source: Author

It is possible to conclude that although the BSC presents four perspectives, it lacks a view of the manufacturing level and struggles with measuring long-term results. The DMP also has multiple dimensions and assesses performances in different time horizons. SMART excludes continuous improvement. PMQ focuses on specific areas and performance improvement. Performance Prism focuses less on processes. IDPMS is hindered by the fact that it can't evaluate overall performance. IPMS, on the other hand, can drive continuous improvement. EFQM isn't as flexible as other systems.

For the framework, an adaptation of IPMS was chosen, as these model is dynamic, provide active monitoring and works well with Lean (Umit et al., 1997). After an analysis of the key characteristics of each model, the researcher chose to use IPMS. It would be possible to use a variation of IPMS, DMP or IDPMS, but the fact that IPMS works with continuous improvement (Umit et al., 1997) was a deciding factor in its usage for this framework. IPMS is also composed of four levels (corporate, business units, business process, activities), which will be modified to reflect the reality of Lean and this framework.

In order to identify the main measures included in the PMS, both the objectives of performance measurement and the characteristics of lean manufacturing are considered. To define the KPIs used in a framework, there are two different approaches, the bottom-up and top-down. The bottom-up starts with identifying current and necessary metrics and then assembling them into a new KPI (Kibira et al., 2018).

For this dissertation, the author has reviewed all the case studies contained in the 302 papers that fulfilled the eligible criteria. In order to validate them, indicators had to be related to either a lean tool, lean principle or work technique that led to the achievement of a Lean goal. It's important to note that a few of the indicators could also appear as lean tools, as is the case of OEE – Overall Equipment Efficiency, which is considered both an indicator and a tool (Kang, Zhao, Li, & Horst, 2016).

Before a more detailed analysis, a total of 889 indicators were found. Once these had been screened, by grouping similar indicators and deleting those that were not relevant or didn't fulfill the aforementioned requirements, a total of 421 indicators were accepted as key performance indicators.

After listing all indicators found, they were generalized and analyzed to match the KPI criteria and similar indicators were grouped under an all-encompassing tag (e.g. a case study might present the number of white boards produced, which the researcher will then generalize as "number of items produced"). A frequency analysis was then conducted.

The indicators which appear in case studies were considered as the key performance indicators, in accordance with their frequency. Indicators were accepted as key in spite of their low frequency due to the specificity of certain case studies and the inexistence of similar indicators.

In order to be considered valid, indicators had to fulfill one or more the requirements presented on Table 12.

Table 12 - KPI's Requirements

Dedicated to organizational goals	KPIs should be aligned with the organizational goals of the companies.
Data reliability and complexity	It is essential that data gathered by KPIs has quality and provides complete and correct information.
Dynamic	Real time performance depends on dynamic measures.
Time horizon	Indicators should be suitable for either short and long-term strategies.
Easy to understand	KPIs have to be simple to measure, monitor and analyze.
Socio-technical	KPIs must consider either technical or social aspects of the company.
Duplication	Indicators that measure the same thing, but have slightly different names, have to be deleted.

Source: Author based on (Kibira et al., 2018)

Considering these characteristics, an analysis of the 889 KPIs found was conducted. Once these were screened, a list of 421 KPIs that were found eligible for the framework was compiled in a Table inserted in Appendix B.

After defining all of the key performance indicators, the researcher grouped then into lean performance clusters, which in turn were be divided among categories.

Performance clusters were taken from literature. These clusters consider different aspects of production and aim to subdivide the categories as to further detail the usage of each KPI, making the framework more meticulous.

Due to the existence of environment-specific indicators, which did not fit any of the preexisting clusters, the researcher saw the need to create a new cluster, which has not been found in literature. The existence of multiple case studies relating lean manufacturing to environmental issues further highlighted this need. Thus, the cluster "Green and Sustainability" was created based on a perceived lack of an environment-specific subcategory.

It is important to note, however, that these clusters won't all appear in every category. Due to disparaging subjects (e.g. the "Green and Sustainability" cluster doesn't appear on the "Customer" category, due to the inexistence, in this research, of KPIs that would fit into this combination of cluster and category). The clusters used in the framework are detailed below on Table 14.

Table 13 - Clusters of Proposed Framework

Time effectiveness	Groups the KPIs relating to time of operations and actions, such lead or setup times.
Quality	Brings together the KPIs related to defects, quality guarantees and reworks, and arises from Lean's continuous search towards perfection.
Process	Refers to the indicators related to operational practices.
Cost	Refers to financial KPIs, dividing all cost related KPIs according to their primary function within the company.
Human resources	This cluster groups the KPIs related to the workforce and HR issues, such as labor turnover.
Delivery	This cluster refers to activities, correlated to the handling and delivery of materials, finished goods and supplies.
Customer	Refers to client satisfaction and market share, and any issues that may arise with customers.
Inventory	Groups the KPIs related to inventory and the usage of space and resources related to it.
Visual Information System	Relates to the establishment of information flow within the manufacturing company, through the direct access to this information.
Product Development and Technology	Groups the KPIs referring to the product development stage of production.
Green and Sustainability	Groups the KPIs related to environmental waste, research and impact.

Source: Author

Case studies were analyzed and, depending on how the indicators were used, they were assigned to clusters and categories. As case studies detail why the indicators were used and to which section(s) of the companies they were applied, it was possible to fit them into the corresponding clusters. Indicators, then, might belong to one or more clusters.

Originally, IPMS is composed of four categories, or levels: corporate, business units, business processes and activities. However, these did not properly fit the goals of this idealized performance framework. As measurements usually start with core competences of the organization, and this research deals with Lean companies, a new set of Lean categories had to defined. Considering the goals of the researcher and the data gathered, new categories were defined.

These performance categories were taken from literature and are divided according to different areas within companies. These aim to group KPIs according to how they affect and pertain to these areas. The performance categories detailed on Table 15 are not a complete change from the traditional IPMS levels, but a more detailed version of those, that aim to present a more complete picture of organizations, considering continuous improvement.

Table 14 - Categories of Proposed Framework

Consumer issues	Includes KPIs that may affect the customer directly, or their relationship with the company.
Supplier issues	Groups the KPIs that pertain to the relationship with the suppliers and supplier activity.
Manufacturing management	KPIs that assess the overall management of the manufacturing process.
Internal management	Groups KPIs related to internal company processes, visual management and the employees.
Research and development	As the name suggests, this category refers to KPIs related to research and the development of new products.
Manufacturing efficiency	KPIs related to the efficiency of the manufacturing process, time management, production and productivity.
Learning perspective	KPIs that pertain to training and visual aids within the company.
Investment priority	Groups KPIs related to all investment actions.

Source: Author

Figure 6 graphically represents how the framework is divided.

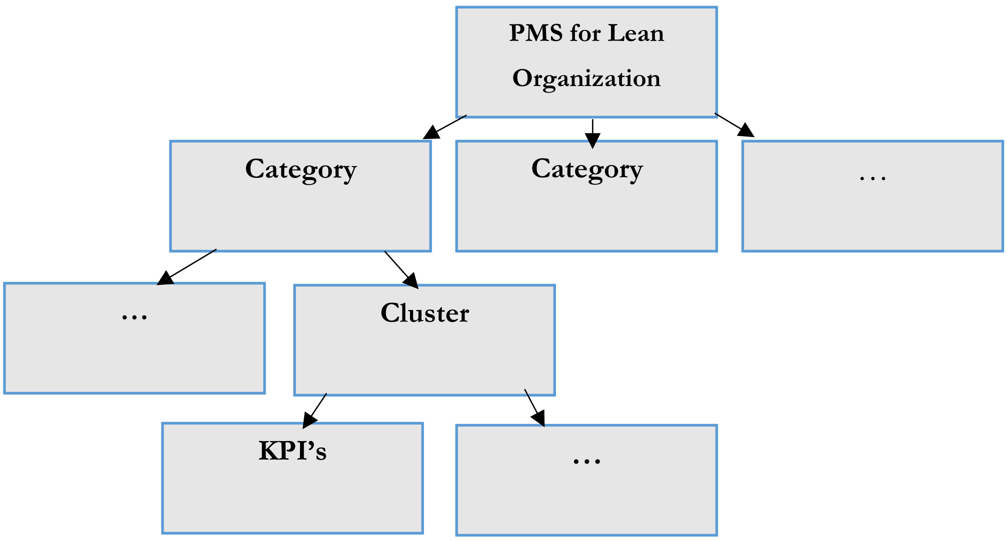


Figure 6 - Framework design

Source: Author

4.2. Frequency of Indicators

Figure 7 presents a frequency analysis of the indicators. It shows how many times the indicators appeared on the papers, and how many times they interacted (when a indicator is used with a technique) with Lean tools, philosophies and work techniques. However, given the big number of indicators, the table only shows those that were found in over 4% of the 302 cases and in over 20% that were most frequently interacted with lean tools, philosophies and work techniques.

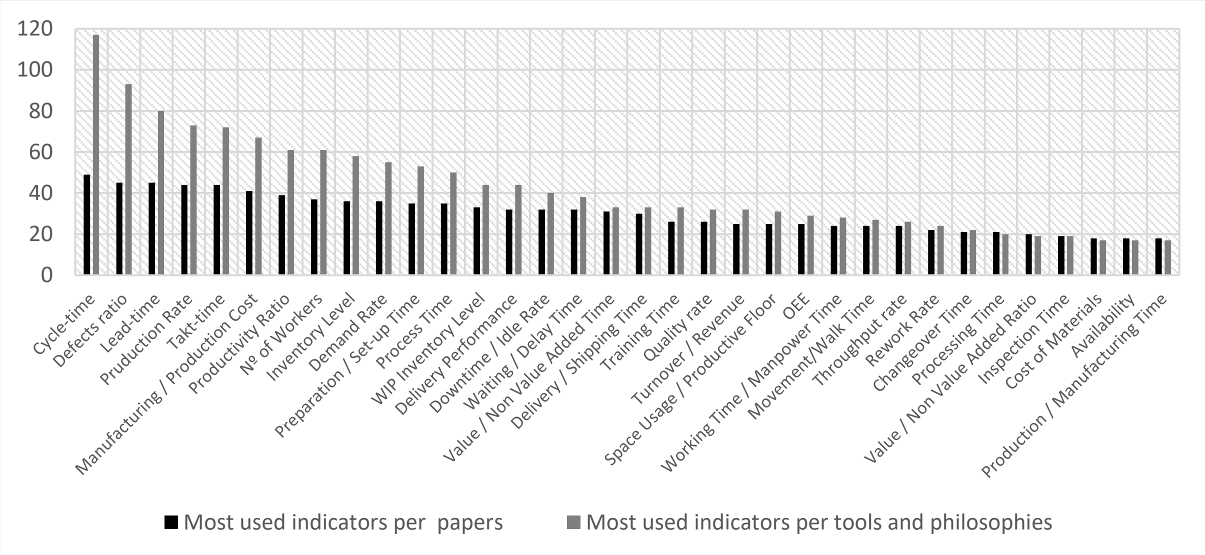


Figure 7 Most Used Indicators

Source: Author

It is possible to see that cycle-time, defects rate and lead-time had the highest frequency, and were utilized in about 50% of the papers analyzed and 19% of the tools, philosophies an work techniques, respectively.

Indicators related to time were, in fact, amongst those most frequent, alongside other basic performance measurement indicators, such as "defects ratio", "takt time", "inventory level", "productivity ratio", "process time", "changeover time", amongst others.

In contrast, the least frequent KPI found was "investment in HR", found in less than 0.32% of the studies analyzed (not shown in Figure 7).

Regarding the tools, philosophies and work techniques, the three least frequent were "nº of new products", "equipment cost" and "% of waste". In spite of Lean's preoccupation with waste, it is curious to notice that "% of waste" was the least frequent indicator in relation with lean tools, but that might be explained by the use of other, more detailed indicators to measure different kinds of waste (e.g. "cycle time", "wait time", "value/non-value added time" etc.).

This, however, does not mean that some indicators are more important than others. Indicators with a lower frequency rate are necessary for specific issues and were found only in specific case studies. Meanwhile, base indicators are used in a wider array of lean manufacturing-related studies, as they are present in multiple manufacturing situations.

4.3. Most Used Lean Tools, Philosophies, Work Techniques and Principles

From the 302 case studies considered valid, a total of 88 Lean tools, philosophies and work techniques were identified. The table below (Table 16) shows all of the tools, philosophies and work techniques found.

Table 15 - Lean Tools, Philosophies and Work Techniques

5S	Digitalization	Lean ABC-TOC	SIPOC
5 Why's	DMAIC	Lean Office	Six Sigma
5C's	DOE	LEMS	SMED
5W1H	Employee Cross-training	Line Balancing	Spaghetti diagram
6S	FIFO	LPD	Spiderman
7 Quality Tools	Flow Charts	LRCDA	SREDIM
7MP Tools	FMEA	MDT	Standardization
7W's	Gap Analysis	Milk-Run	Supermarket
A3 Report	*Heijunka*	*Mizumashi*	SWAN
Andon	*Hoshin Karin*	MMSUR	Team Improvement
ANOVA	House of Quality	OEE	Time Analysis
Automation	IDEF0	Operation Times Chart	TISM
Axiomatic design	ILP Model	Pareto Analysis	TOPS
Bayesian Belief Networks	*Jidoka*	PDCA	TPM
BSC	JIT	Plug & Lean CiMo Framework	TQM
Cause-effect Diagram	*Kaizen*	*Poke-Yoke*	TRIZ
Cellular Manufacturing	*Kaizen* Workshops	Power Model - Learning Curve	VA/NVA Analysis
CFS	*Kanban*	QFD	VASA Model
CONWIP	KANO	QIP	Visual Management
Cross-functional Flow Chart	Layout Redesign	Quotation Analysis	VSC
Cyclical schedules	LCA	SBCE	VSM
DFMA	LCM	Shingo Assessment	Waste Analysis

Source: Author

Figure 8 details the usage of Lean tools, philosophies and work techniques according to two things: the number of interactions within case studies (i.e. the number of times case studies interact with tools, philosophies and work techniques) and the number of indicators that were used for each tool, philosophy and work technique. A total of 5820 interactions and 421 indicators were considered.

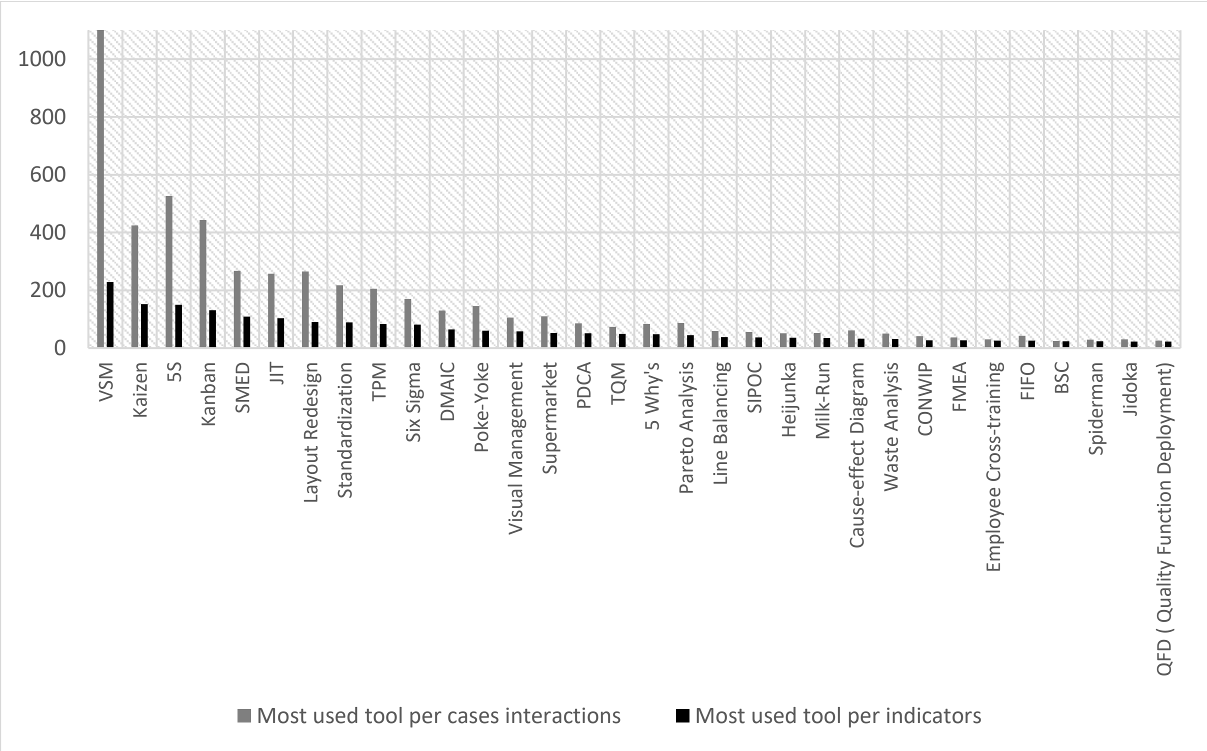


Figure 8 - Usage of Lean tools, philosophies and work techniques

Source: Author

VSM showed both the largest amount of indicator usage and case interactions representing more than 18% of the cases interactions and use more than 50% of the 421 indicators, meaning that it used a wider array of indicators, and appeared in a larger number of case studies.

Amongst the most used tools, philosophies and work techniques are also 5S, *Kanban* and *Kaizen*, with *Kanban* and *Kaizen* showing a slightly smaller number of case interactions than 5S, but *Kaizen* with a larger frequency of indicator usage.

The figure below (Figure 9) follows the same organization as Figure 8, but with the five principles of Lean. It shows the frequency of lean principles by case interactions and indicator usage.

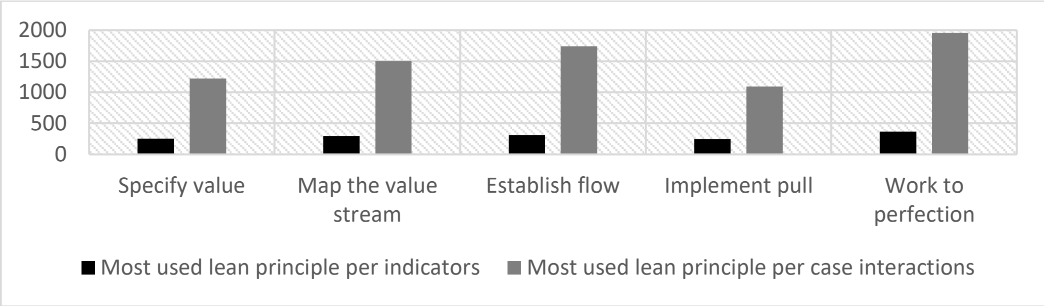


Figure 9 - Usage of Lean Principles

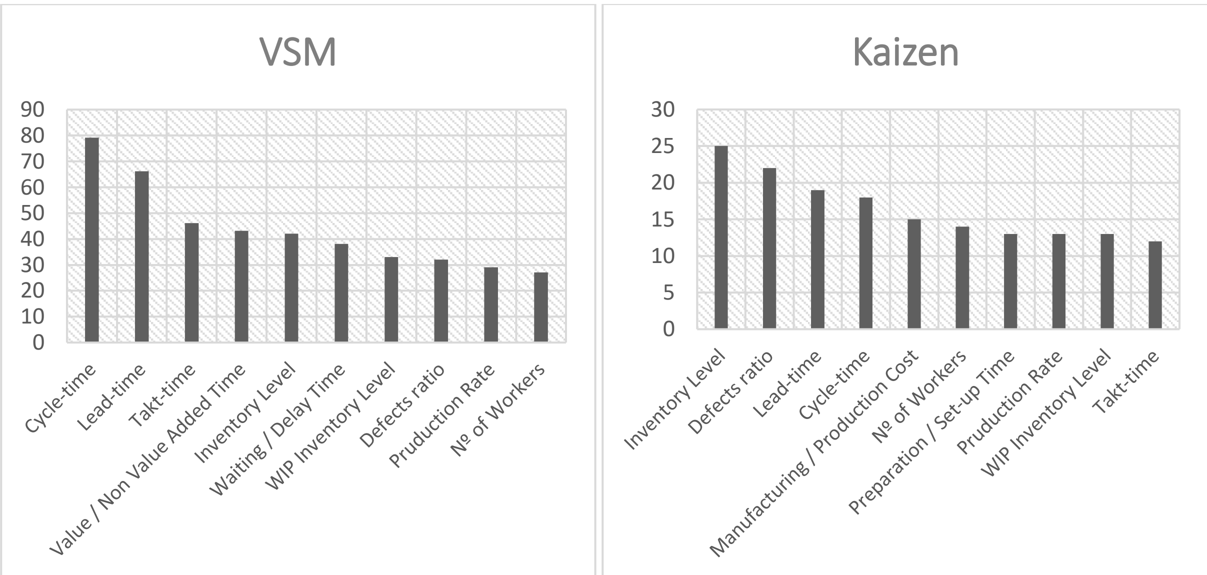
Source: Author

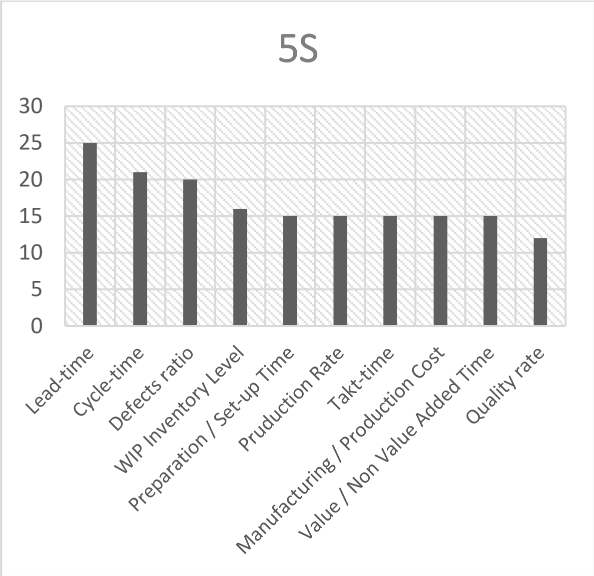
Although Lean states that all of its principles should be applied by companies, it is possible to see that this does not happen. Work to Perfection showed the highest number in both categories, closely followed by Establish Flow. The image also shows that while Work to Perfection is the most applied lean principle, the other four principles are more congruent amongst themselves.

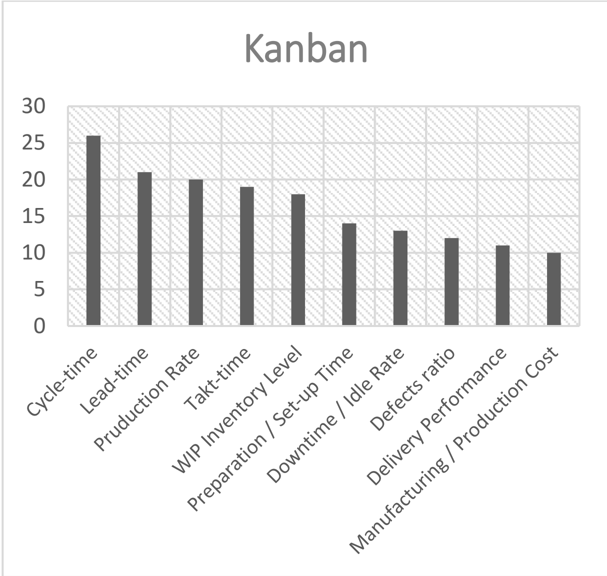
4.4. Usage of indicators per Lean tool, philosophy or work technique

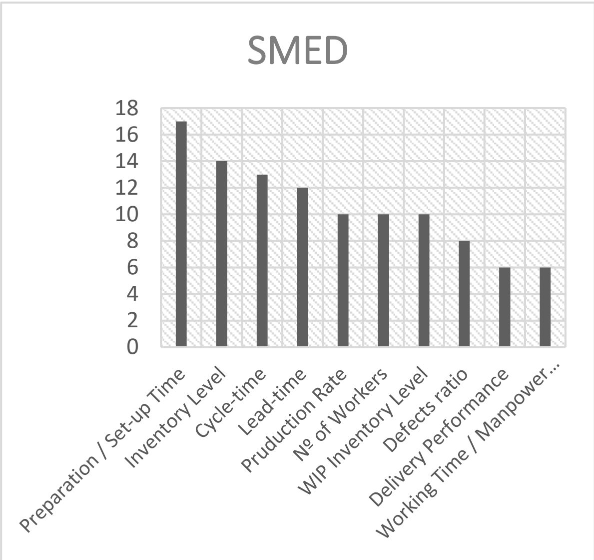
This section shows the most used indicators per lean tool, philosophy or work technique. However, only the ten most used tools, philosophies and work techniques will be detailed, as well as the ten most used indicators by each tool, philosophy or work technique. This analyses can help researchers better grasp the importance and usage of indicators according to the Lean tools and techniques applied within the company.

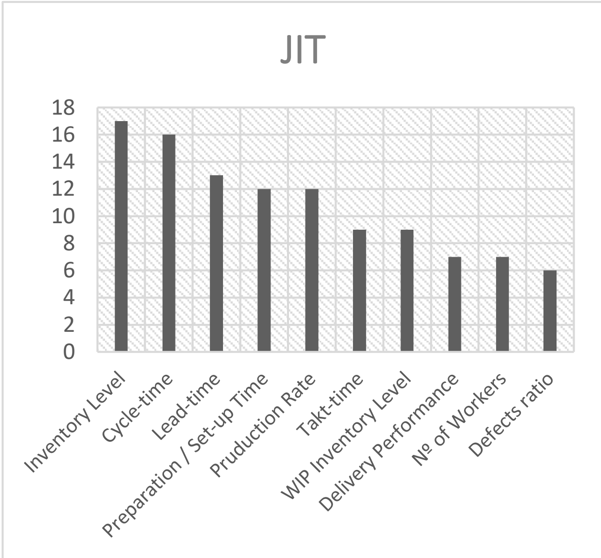
The following figure (Figure 10) will illustrate the usage of indicators per lean tool, philosophy or work technique.

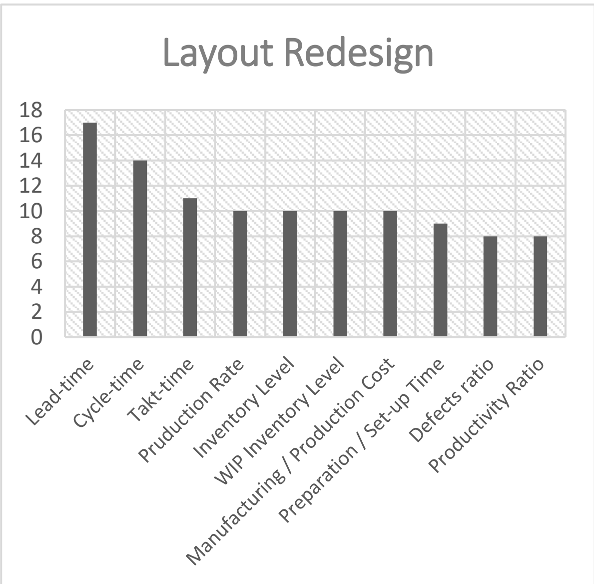


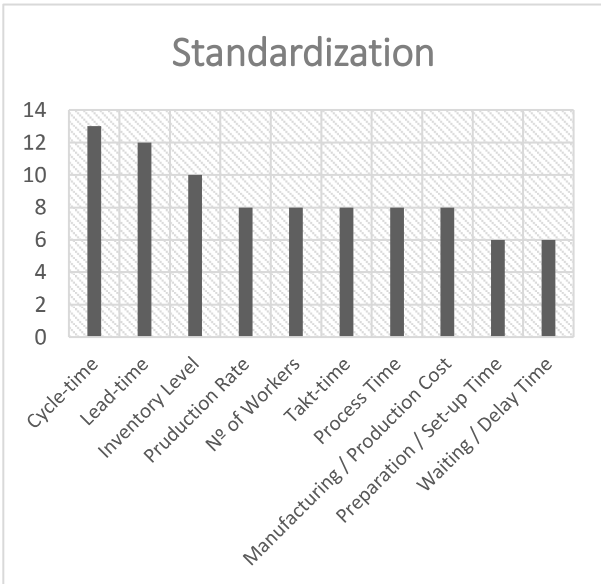

5S
30
25
20
15
10
5
0
Lead-time
Cycle-time
Defects ratio
WIP Inventory Level
Preparation / Set-up Time
Pruduction Rate
Takt-time
Manufacturing / Production Cost
Value / Non Value Added Time
Quality rate


Kanban
30
25
20
15
10
5
0
Cycle-time
Lead-time
Pruduction Rate
Takt-time
WIP Inventory Level
Preparation / Set-up Time
Downtime / Idle Rate
Defects ratio
Delivery Performance
Manufacturing / Production Cost


SMED
18
16
14
12
10
8
6
4
2
0
Preparation / Set-up Time
Inventory Level
Cycle-time
Lead-time
Pruduction Rate
Nº of Workers
WIP Inventory Level
Defects ratio
Delivery Performance
Working Time / Manpower...


JIT
18
16
14
12
10
8
6
4
2
0
Inventory Level
Cycle-time
Lead-time
Preparation / Set-up Time
Pruduction Rate
Takt-time
WIP Inventory Level
Delivery Performance
Nº of Workers
Defects ratio


Layout Redesign
18
16
14
12
10
8
6
4
2
0
Lead-time
Cycle-time
Takt-time
Pruduction Rate
Inventory Level
WIP Inventory Level
Manufacturing / Production Cost
Preparation / Set-up Time
Defects ratio
Productivity Ratio


Standardization
14
12
10
8
6
4
2
0
Cycle-time
Lead-time
Inventory Level
Pruduction Rate
Nº of Workers
Takt-time
Process Time
Manufacturing / Production Cost
Preparation / Set-up Time
Waiting / Delay Time

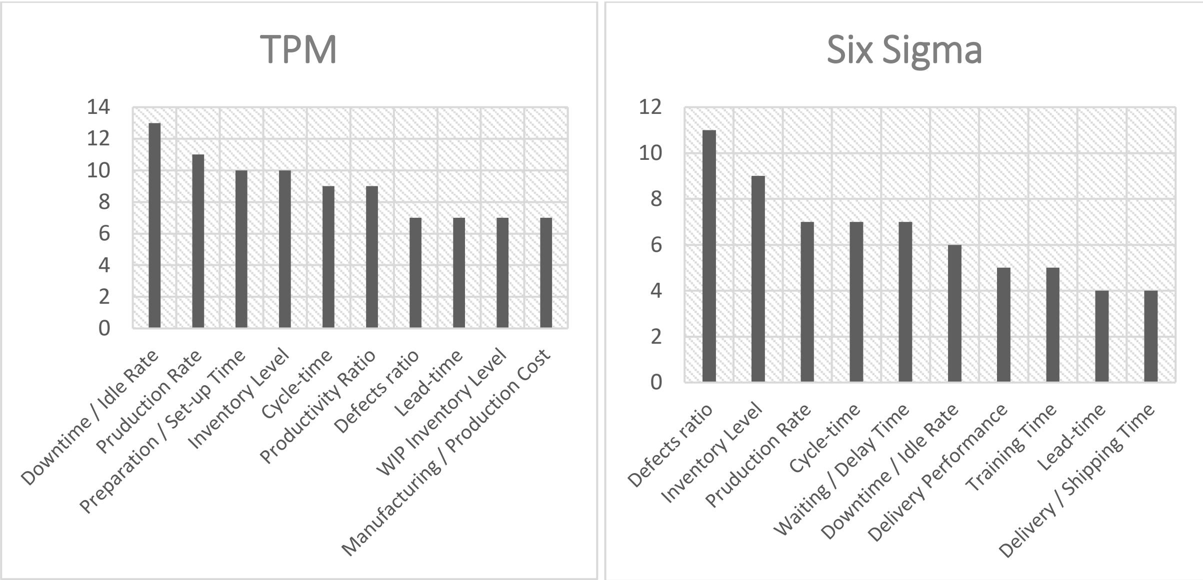


Figure 10 - Usage of indicators per Lean tool or philosophy

Source: Author

Figure 10 represents the frequency of each indicator per Lean tools, work techniques or philosophies.

Value-stream Mapping was the most used lean tool out of those analyzed. It showed the highest number of interactions and the largest usage rate of tools. On Figure 10 is possible to notice the ten most used indicators by this tool. Cycle time and lead time appear at the top, while technological capability (not shown in Figure 10) was the least used.

Regarding 5S, in congruence with the tools' goals, inventory level shows at the top, followed by lead time, while demand variability (not shown in Figure 10) was the least used.

On *Kanban*, inventory level once again appeared as the most used tool, followed by cycle time, while competitive cost (not shown) was the least used.

Regarding *Kaizen*, in accordance with this philosophy's goals of continuous improvement, inventory level and defects ratio appear as the most used, while environmental performance (not shown) was the least used. However, this is due to its specificity to environmental issues.

For SMED, unsurprisingly, set-up time and inventory level appear at the top, while customer quality expectation (not shown) was the least used.

Considering layout redesign, lead time and cycle time appear most frequently, while skill level (not shown) was the least used.

For JIT, inventory levels appear most frequently, in accordance with the philosophy's goals, followed by cycle time, while insurance costs (not shown) was the least used.

Regarding TPM, downtime and production rate appear most frequently, while new product development success rate (not shown) appeared less frequently.

On standardization, once again, cycle time and lead time appear most frequently, while environmental cost (not shown) appeared less frequently.

Finally, on Six Sigma, defects ratio appeared most frequently, followed by inventory level, while employee capability (not shown) appeared less frequently.

Considering the objectives and goals of the tools, philosophies and work techniques presented above, the indicators presented on the analysis are in accordance with the expectations.

5. Proposed Performance Measurement System to fit Lean

This chapter will formally present the proposed framework. It begins with a graphical representation of the framework, followed by a more detailed graphic representation with most important KPI's within their respective clusters and categories. It then shows the possible relations between the proposed frameworks and other performance measurement systems and possible adaptations that would allow the integration of the proposed framework with existing systems.

Finally, the chapter closes with recommendations for implementations of the framework in real-life contexts and some proposed tools, philosophies and work techniques reach the objectives of KPI's.

5.1. Framework and Structure, and KPI's

Due to how extensive the framework is, not all the KPI's will be presented only the overall top four used KPI's will be shown on the graphic representation (Figure 12 and Figure 13), on Appendix C it is possible to see the detailed categories and clusters with the respective KPI's ordered by their overall usage. Firstly, however, the structure of the framework is presented in Figure 11, on the next page.

This framework paints a general picture of KPIs and their usage. However, organizations must adapt and choose KPIs according to their reality and organizational goals, eliminating or adding new KPIs according to their needs. Furthermore, the same KPI might fit more than one cluster or category, and the framework represents that accordingly.

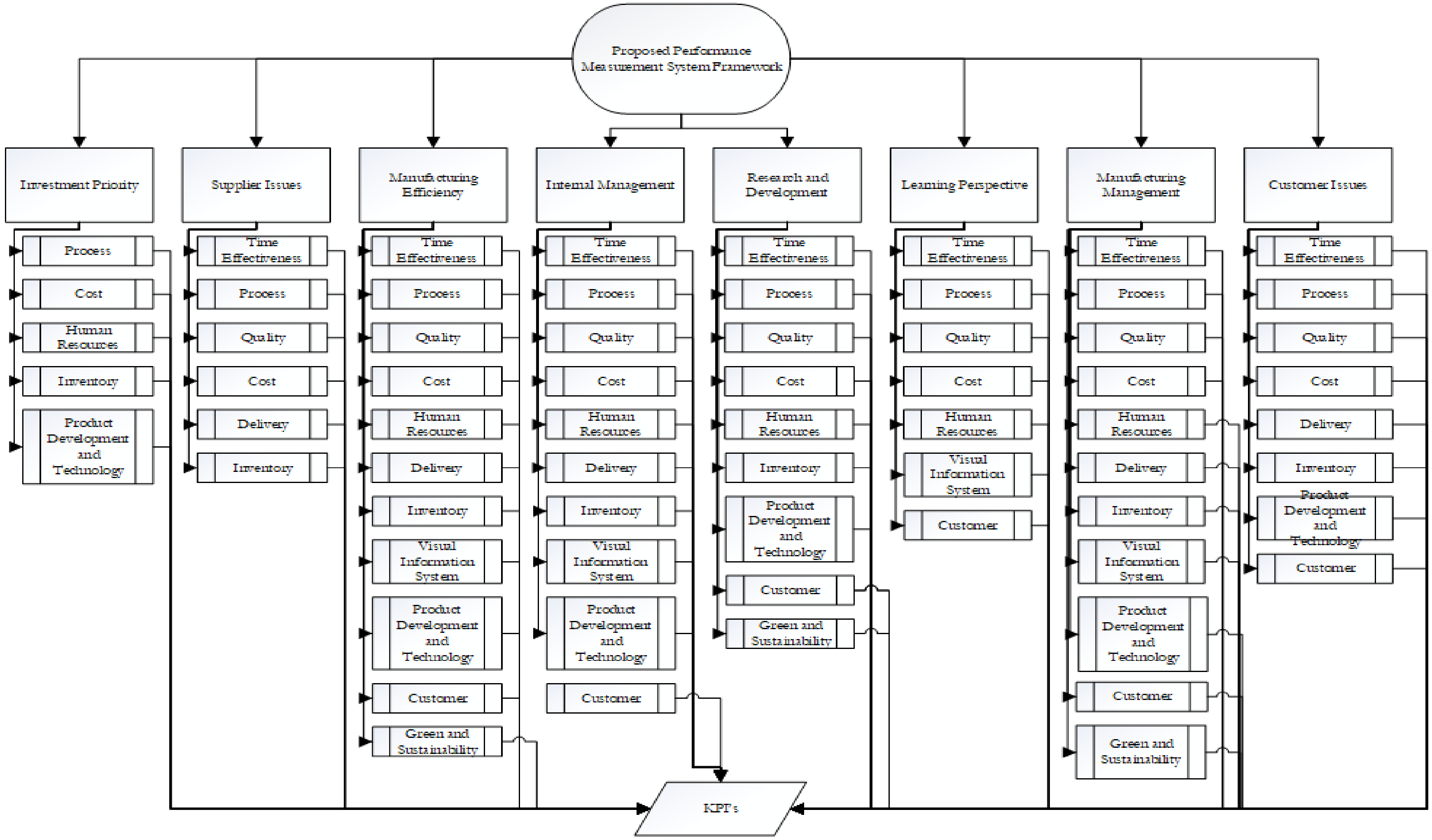


Figure 11 - Proposed Performance Measurement System Framework

Source: Author

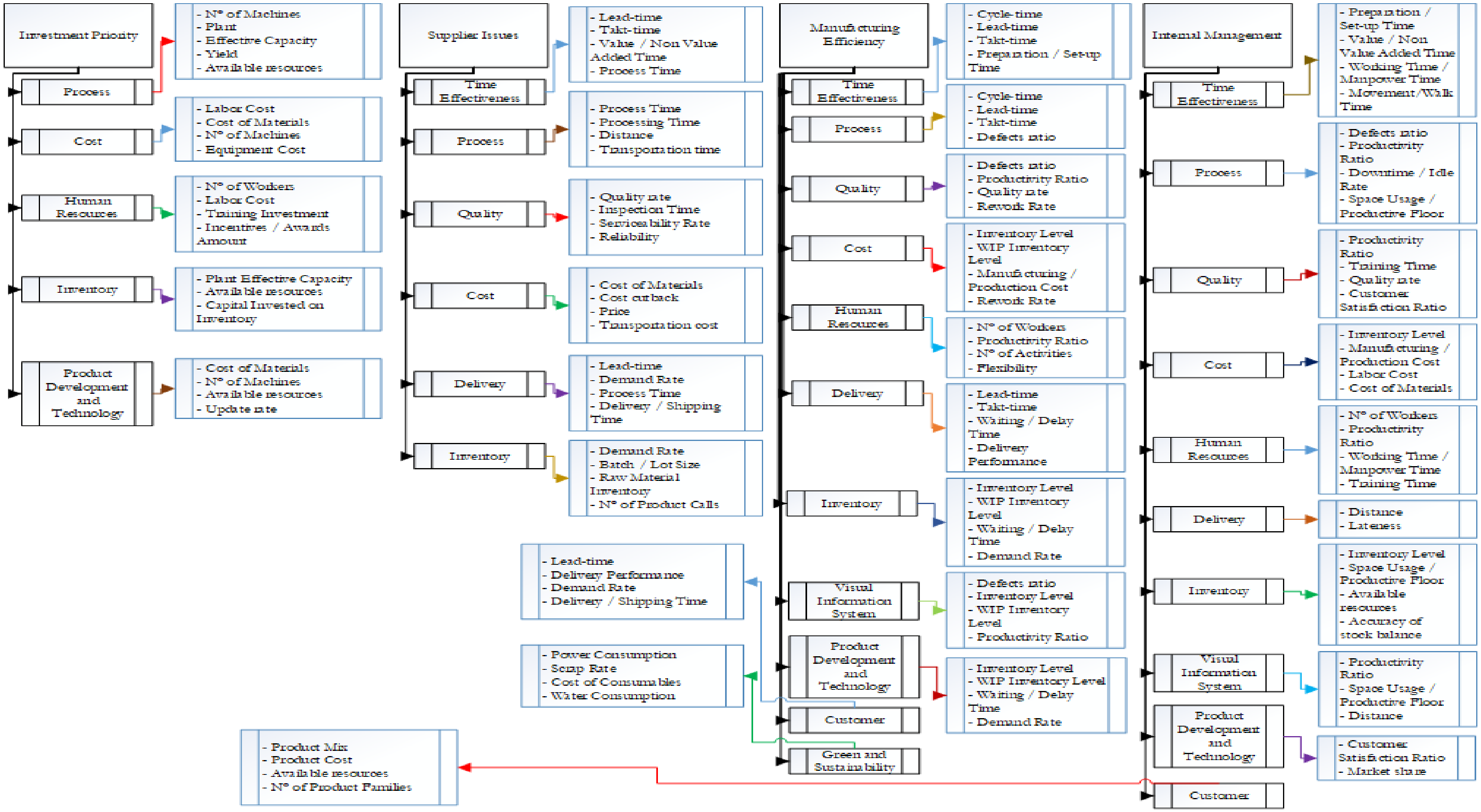


Figure 12 - Proposed Performance Measurement System Framework - Detailed 1

Source: Author

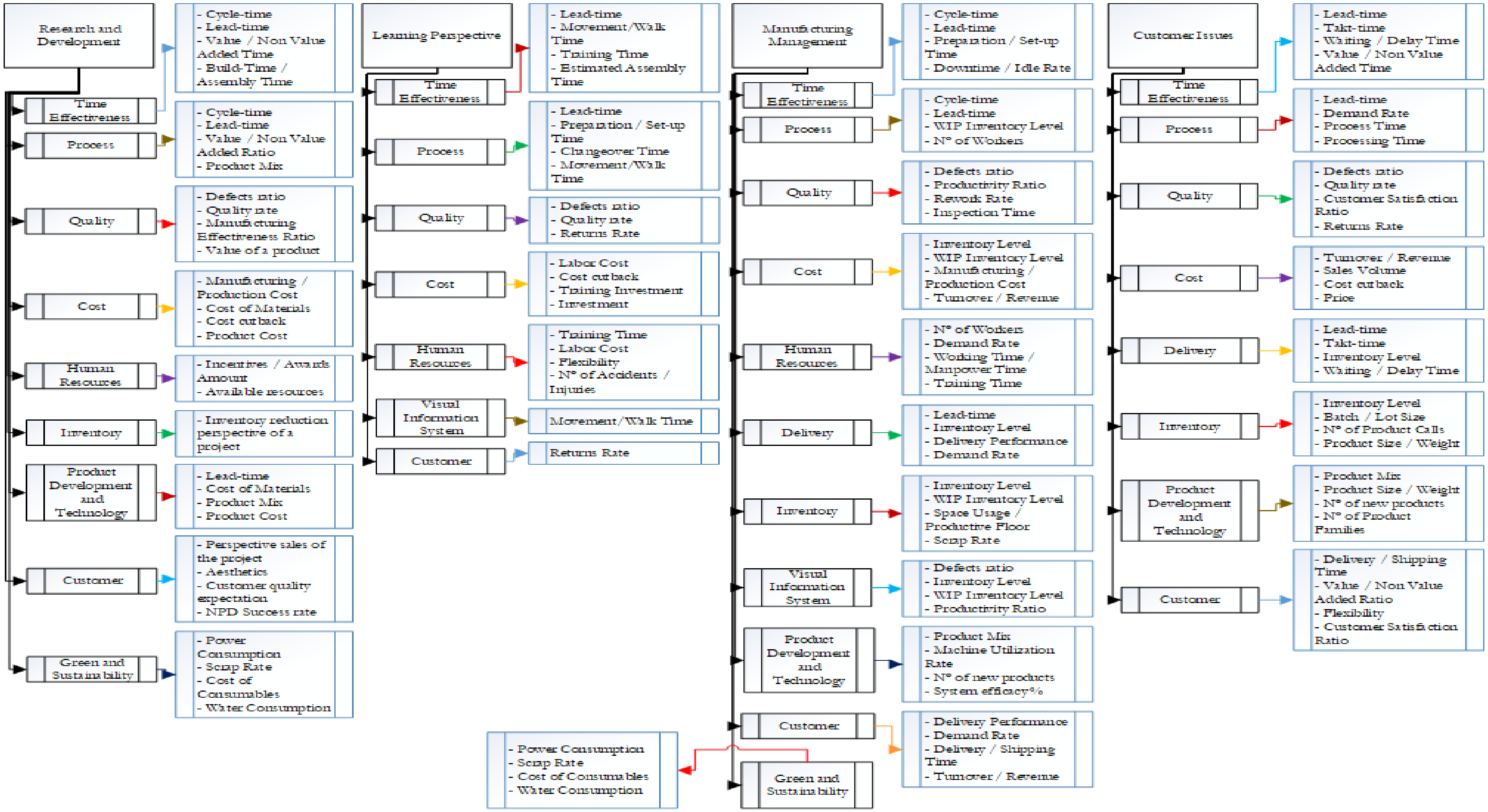


Figure 13 - Proposed Performance Measurement System Framework - Detailed 2

Source: Author

5.2. Relations with others Performance Measure Systems

The framework built by this research aims to be integrated and dynamic. Due to these characteristics, it is possible to correlate it with other performance systems, such as BSC or DMP.

What that means, practically, is that the categories present in the framework are flexible, and can be integrated into the BSC perspectives (innovation and learning, financial, customer, internal business) or DMP dimensions (financial, customer, process, people, future).

For example, if one of the company's goals in the BSC is to improve production process time, they can easily refer to the manufacturing efficiency category of the proposed framework, go to the "process" cluster and transport it to the correlated BSC perspective (in this case, internal business). This gives the BSC a new continuous improvement characteristic, which it did not have thus far.

The same can be applied to DMP. Using the same choice process as the example above, the company could transport the cluster needed to the correlated DMP dimension (in this case, process).

Finally, it is known that the BSC is the most used framework for companies at the moment, due to the possibility of integration between an organization's vision and its actions. However, it lacks the ability to view performance at a manufacturing level. By integrating the proposed framework into this model, it can overcome its shortcomings, providing managers with manufacturing-level performance information and a multi-level performance framework.

5.3. Implementation Recommendations

Although this research builds a proposed framework, it is inherently generic and conceptual, which means that it requires certain adaptations for reality. In spite of the use of successful case studies, and its proximity to reality, the fact that cases conducted in multiple manufacturing sector areas were used (e.g. automobile, automotive component manufacturer, electronic manufacturing etc.), makes it too generalized for company-specific objectives. Thus, in order to adapt it, the researcher makes the following recommendations:

The company's objectives must be carefully delineated. That way, pilot studies can be conducted to find how to best adapt the proposed framework to fit these objectives and properly measure its effects.

The proposed framework can be integrated into existing performance measurement systems, such as the BSC or the DMP. As highlighted in section 5.2, the proposed framework is flexible enough to fit into the perspectives or dimensions of other frameworks.

Goals are also essential to measure the KPIs. Pre-defined targets help easily identify key problematic areas and outline new strategies for improvement.

However, goals must also change. Given the flexible and dynamic characteristics of the framework, both the organizational goals and the KPIs must be reviewed and adapted accordingly.

Even adapted, maintaining the integrity, or the essence, of the proposed framework is important. In order to do that, companies should assign knowledgeable managers with the skills required to analyze and interpret the data offered by the framework.

The dynamic factor of the proposed framework makes it an ideal tool for continuous improvement, and that is the recommended usage for this proposed framework, rather than just examination.

Finally, the frequency analyses conducted in this research produced information regarding the existence of some relationships between indicators and Lean tools. Considering the frequency that some indicators were used with some tools, philosophies and work techniques, the researcher compiled annex D, which presents the KPIs present in the document. Table 17 shows a condensed version of these KPIs. It proposes that some tools are used with specific indicators. For example, the researcher proposes that, in order to reduce lead times, managers should employ the 5W1H tool.

Table 16 - Proposed tools, philosophies and work techniques for KPI's

Key Performance Indicators	**Proposed Lean Tool, Philosophy and Work Techniques**
Capital Invested on Inventory	JIT
Update rate	*Kanban*
Lead-time	5W1H
Value / Non Value Added Time	VA/NVA Analysis
Process Time	Cyclical schedules
Processing Time	7 Quality Tools
Transportation time	Operation Times Chart
Inspection Time	5W1H
Rework Rate	A3 Report
Downtime / Idle Rate	MDT (Downtime analysis)
Nº of Product Families	Pareto Analysis
Nº of Accidents / Injuries	LEMS (Lean Ergonomic Manufacturing Systems)

Source: Author

6. Final Considerations

The present research aimed to construct and propose a new performance measurement framework to fit Lean organizations. In order to do that, an extensive literature review was conducted, as to define the basis upon which the research stands. This review provided key information on the backgrounds of Lean philosophy and its characteristics, existing performance measurement systems, categories and dimensions.

The backbone of the research depended on choosing the proper base model for the proposed framework. IPMS was chosen because its multilevel, dynamic integrated system that allows its users to oversee performance at a manufacturing level and is malleable. Adapting this to fit detailed categories and specific clusters was the second step.

A conceptual literature review was used to define the categories according to those found in literature. The same is true for the clusters. Eight categories, divided according to different areas within companies, were defined according to the information found in literature reviews. Eleven clusters were also defined. However, only ten of the clusters were taken from existing literature, while the eleventh was created due to a need perceived by the researcher.

Key performance indicators were then gathered from an analysis of successful case studies. Following the proposed conceptual literature review methodology, a total of 889 performance indicators were found in this analysis, but only 421 of those were considered key performance indicators.

Once these were gathered and screened, the KPIs were divided amongst the different clusters and categories, and the proposed framework was completed. However, the researcher highlights its conceptual character, and the importance of further adaptations and pilot studies to validate its usage in real world companies.

The innovative character of this framework lies on the fact that it takes Lean tools, philosophies, work techniques and principles into account. Besides, it is also adaptable and its usage is compatible with existing performance measurement systems. Existing frameworks either do not take into account all aspects of Lean, or take Lean out of the equation entirely. From the researched studies, Gama and Cavenagha (2009) propose a visual model for performance, restricting it to production only, as opposed to a framework or an adaptable model. Sanjay (2008) proposes a dynamic measurement performance framework, but only includes five dimensions and is forced to use smaller, multidimensional metrics. Susilawati et al. (2013) doesn't take into account all of the lean dimensions or the relationships between indicators and lean tools. Belekoukias et al. (2014) only considers five lean methods to measure performance, while the proposed framework in this research considers eighty-eight.

By seeking out papers that applied both performance indicators and Lean, and conducting an extensive frequency analysis, this research was able to build a more complete framework. Additionally, by compiling more detailed lists of categories and clusters, this framework further specifies the usage of KPIs. This research, thus, proposes a more intuitive organization for performance measurement frameworks, that allows for adaptation and is compatible with existing performance measurement systems.

Furthermore, this research recognizes its own limitations, and recommends further studies regarding the application of the proposed framework and its adaptation to fit preexisting performance measurement models as to improve them.

From the analysis conducted in this study, it was also possible to demonstrate some of the correlations found between the usage of performance indicators, lean tools, philosophies, work techniques and principles. These provided insights such as the fact that cycle-time, lead-time, production rate, defects ratio, takt time and inventory level were the most frequently used measurements in case studies.

Frequency, however, cannot define the importance of these indicators, but merely their flexibility, as they were used as performance indicators in the wide array of settings found in different studies.

From the lean tools, philosophies and work techniques, the most frequent were VSM, 5S, Kanban, Kaizen and SMED. Amongst Lean principles, work to perfection stood out as the most frequently followed principle, in spite of lean philosophy's recommendations that all principles should be equally applied. Overall, a certain level of congruence was found between the objectives of lean tools, philosophies and work techniques, and the indicators used in relation to them.

6.1. Theoretical contributions of the study

This research contributes to existing literature on lean and performance by proposing an innovative performance measurement framework, specifically created to fit lean companies. Such work is undoubtedly important as lean management gains increasing attention within the field of management.

The proposed framework can help future researchers to overcome the shortcomings of existing performance frameworks, and is malleable enough to fit a myriad of manufacturing settings. In spite of its conceptual nature, it also creates a basis upon which further research, such as empirical studies and case studies, can be conducted, thus widening the theoretical offer existent.

6.2. Practical Contributions of the study

The proposal of this framework can highly benefit managers and contributes to the practical field of management by creating a new performance measurement system to fit lean companies. The outcomes of this research are malleable enough to be adapted to an array of companies and can fit preexistent measurement systems, improving them and providing managers with real-time monitoring, and the possibility to view performance at a manufacturing level.

Additionally, the researcher has also proposed a series of applications of lean tools according to which KPI managers aim to affect, according to the frequency analyses conducted.

6.3. Research Implications and Limitations

In this dissertation, an integrated performance measurement framework to fit lean organizations has been proposed. By exploring existing literature on lean and performance, the researcher sought to use existing models, categories and subcategories (i.e. clusters) to build a new proposed framework that overcame the shortcomings of preexistent frameworks and fit Lean philosophy and tools.

This implicates the creation of a dynamic framework that has the ability for continuous improvement, both basic needs of Lean. Furthermore, this dissertation aimed to best represent reality, by using successful case studies as the basis for gathering KPIs. Through a frequency analysis of successful case studies, a list of KPIs was compiled.

Amongst the implications, the researcher found that KPIs should be holistically measurable, as all KPIs are essential and interdependent, as it comes to Lean manufacturing. Furthermore, they should provide basis for continuous improvement.

By utilizing an existing model (IPMS) as a basis, the researcher was able to overcome its inadequacies, and propose a model that is not only dynamic and flexible, but also fits lean organizations, provides basis for continuous improvements and can be adapted to fit preexisting frameworks within other companies, such as BSC.

However, the research did have some limitations. The proposed framework is still conceptual, and further empirical studies or case studies are needed to validate its applicability. Although case studies from multiple countries were analyzed, the researcher did not compile a list of where the studies came from or of which countries they analyzed. Likewise, the reliability of the KPIs and its congruence with clusters and categories must undergo further empirical tests. Furthermore, the proposed framework is generalized, and must be adapted for company-specific objectives. Future research can also fit KPIs within the dimensions outlined by (Iuga et al., 2015), in order to facilitate visualization and management of KPIs. Finally, the lack of time and resources made running a pilot test unfeasible.

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Appendix

Appendix a *- Case Studies*

Authors	#	Subject
(Araújo, Amaral, & Varela, 2017)	1	Improve productivity and standard time on shop floor of a manufacture
(Benavides-Peña, Garza-Amaya, Garza-Madero, & Villarreal, 2017)	2	Improve on-time delivery on Logistics of a manufacturing company
(Belhadi, Touriki, & Fezazi, 2017)	3	Lean implementation on manufacturing SME shop floor
(Chaple & Narkhede, 2017)	4	Implement VSM on a manufacturing organization
(Amrina & Lubis, 2017)	5	Minimize waste on manufacturing shop floor
(Cannas, Pero, Pozzi, & Rossi, 2018)	6	Low complexity of manufacturing production
(Dhiravidamani, Ramkumar, Ponnambalam, & Subramanian, 2017)	7	Lean implementation shop floor on auto parts manufacturing sector
(Garza-Reyes, Torres Romero, Govindan, Cherrafi, & Ramanathan, 2018)	8	Manufacturing Mining consumables - Enhance environmental sustainability
(Hill, Thomas, Mason-Jones, & El-Kateb, 2018)	9	Implementation of lean six sigma to improve operational performance
(Solke & Singh, 2018)	10	Application of a structure model for lean manufacturing shop floor
(Kurilova-Palisaitiene, Sundin, & Poksinska, 2018)	11	Remanufacturing challenges
(Leonardo et al., 2017)	12	Implementation of Kanban shop floor
(Masood, Gonzalez, & Lim, 2017)	13	Offsite manufacturing using lean to reduce housing short hall
(Panwar, Nepal, Jain, Rathore, & Lyons, 2017)	14	5S to improve manufacturing process
(Roriz, Nunes, & Sousa, 2017)	15	Implement lean on a carton factory in the operational process
(Rose, Ab Rashid, Nik Mohamed, & Ahmad, 2016)	16	Multi case study in SME's in automotive component industry
(Sartal & Vázquez, 2017)	17	Lean Implementation on IT offices of a manufacturing company
(Shou, Wang, Wu, Wang, & Song, 2017)	18	Implement flow and pull and work to perfection
(Srinivasa Rao & Niraj, 2016a)	19	Implement lean ergonomic manufacturing systems
(Thomas, Francis, Fisher, & Byard, 2016)	20	Implementing Lean Six-Sigma to overcome the production challenges
(Zakaria, Mohamed, Rahid, & Rose, 2016)	21	Reduce waste on electronic assembly line
(Deffense & Cachadinha, 2011)	22	Applying lean thinking and Lean Production
(Louw, 2012)	23	Implementation of a supermarket-based scheduling
(Gunawan, 2009)	24	Implementation of lean manufacturing for labor forecast
(S. Kumar, Dhingra, & Singh, 2018)	25	Process improvement through Lean-Kaizen using value stream
(Helleno, de Moraes, & Simon, 2017)	26	Integrating sustainability indicators and Lean Manufacturing to assess manufacturing processes
(Pei, Li, Lin, & Wang, 2009)	27	Integrating Line balancing
(Diah, Parkhan, & Sugarindra, 2018)	28	Productivity improvement in the production line with lean
(Santosa & Sugarindra, 2018)	29	Implementation of lean manufacturing to reduce waste in production line with value stream mapping approach and Kaizen

(Seyedhosseini, Taleghani, Makui, & Ghoreyshi, 2013)	30	Fuzzy value stream mapping in multiple production streams
(Siregar et al., 2018)	31	Lean manufacturing analysis to reduce waste
(De Sousa Jabbour, Omodei, & Jabbour, 2014)	32	Extending of lean manufacturing practices between a manufacturer firm and its supplier
(Arya & Jain, 2014)	33	Deals with Kaizen implementation
(Wu & Wee, 2009)	34	Lean Supply Chain Effects Product Cost and Quality
(Dinis-Carvalho, Ratnayake, & Ferrete, 2018)	35	Implementation of Lean Principles for Performance Improvement
(Sukdeo, 2018)	36	Application of 6S Methodology as a Lean Improvement Tool
(Nee, Juin, Yan, Theng, & Kamaruddin, 2012)	37	Lean improvement project
(Bin Che Ani & Abdul Hamid, 2014)	38	Analysis and reduction of the waste in the work process using time study analysis
(Suárez-Barraza & Miguel-Dávila, 2011)	39	Implementation of Kaizen automotive manufacture
(Puvanasvaran, Megat, Hong, Razali, & Magid, 2010)	40	Implement problem solving capabilities on people development on lean company
(Suresh Kumar & Syath Abuthakeer, 2012)	41	Implementation of SMED
(Deros, Jun, & Rahman, 2012)	42	Benchmarking Technique in lean manufacturing (5S)
(Romano, Santillo, & Zoppoli, 2009)	43	Transformation of a production/assembly washing machine lines into a lean manufacturing system
(Simmons, Holt, Dennis, & Walden, 2010)	44	Lean Implementation in low volume manufacturing
(Štefanić, Tošanović, & Hegedić, 2012)	45	Kaizen Workshop
(Shalahim, 2010)	46	Adopting Lean Principles
(Afonso & Cabrita, 2015)	47	Lean Performance in SME
(Al-Ashaab et al., 2013)	48	Lean Product development
(Alsmadi, Almani, & Khan, 2014)	49	Implementing an integrated ABC and TOC approach to enhance decision making in a Lean context
(Anand & Kodali, 2009)	50	VSM in auto-material manufacturing
(Andersson, Hilletofth, Manfredsson, & Hilmola, 2014)	51	Lean Six Sigma strategy in telecom manufacturing
(F. Garcia & Ball, 2004)	52	Applying Lean Concepts in a Warehouse Operations
(Duran, Cetindere, & Aksu, 2015)	53	Productivity Improvement by Work and Time Study Technique for Earth Energy-glass Manufacturing Company
(Arkader, 2001)	54	Comprehensive case study of buyer supplier relationship involving car manufacturers
(Arkan & Van Landeghem, 2013)	55	Evaluating the performance of a discrete manufacturing process using RFID-Kanban
(Bai, Xia, & Zeng, 2014)	56	Case study in a typical NC job shop from a part fabrication manufacturer
(Azevedo, Govindan, Carvalho, & Cruz-Machado, 2012)	57	A single SC research design concerned with the Portuguese automotive
(Bae, Evans, & Summers, 2017)	58	Milk-run delivery system in an automobile emissions system manufacturing facility
(Akbulut-Bailey, Motwani, & Smedley, 2012)	59	A case study of a successful implementation of Lean Six Sigma
(Barua, Chaporkar, Nagarajan, & Malairajan, 2010)	60	Application of 5S and Kaizen for waste minimization

(Behnam, Ayough, & Mirghaderi, 2018)	61	Value stream mapping approach and analytical network process to identify and prioritize production system's Mudas
(Ben Ruben, Vinodh, & Asokan, 2017)	62	Implementation of Lean Six Sigma framework with environmental considerations
(Bevilacqua, Ciarapica, & Paciarotti, 2015)	63	Application of lean thinking in the field of information management in the areas of manufacturing and production
(Bhamu, Kumar, & Sangwan, 2012)	64	Productivity and quality improvement through value stream mapping
(Bhamu, Khandelwal, & Sangwan, 2013)	65	Lean manufacturing implementation in an automated production line
(Božičković, Radošević, Ćosić, Soković, & Rikalović, 2012)	66	Influence of certain lean tools as well as application of statistical analyses, simulation and graphics tools for achieving greater effectiveness and efficiency of production
(Bon & Kee, 2015)	67	Explore the key success factors and process of lean implementation
(Botti, Mora, & Regattieri, 2017)	68	Integrating ergonomics and lean manufacturing principles in a hybrid assembly line
(Braglia, Frosolini, & Gallo, 2017)	69	SMED enhanced with 5-Whys Analysis to improve set-up reduction programs: the SWAN approach
(A. Brown, Amundson, & Badurdeen, 2014)	70	Sustainable value stream mapping (Sus-VSM) in different manufacturing system configurations
(Buzby, Gerstenfeld, Voss, & Zeng, 2002)	71	Using lean principles to streamline the quotation process
(Büyüközkan, Kayakutlu, & Karakadilar, 2015)	72	Assessment of lean manufacturing effect on business performance using Bayesian Belief Networks
(Romano, Murino, Asta, & Costagliola, 2013)	73	Lean Maintenance model to reduce scraps and WIP in manufacturing system
(Sousa, Nunes, & Antunes, 2014)	74	Lean Six Sigma in Internal logistics
(Chen & Chen, 2014)	75	Application of ORFPM system for lean implementation
(Chen, Li, & Shady, 2010)	76	From value stream mapping toward a lean/sigma continuous improvement process
(Chiarini, 2012)	77	Lean production: mistakes and limitations of accounting systems inside the SME sector
(Chiarini, 2015)	78	Improvement of OEE performance using a Lean Six Sigma approach
(Ching, Hoe, Hong, Ghobakhloo, & Pin, 2015)	79	Case study of lean manufacturing application in a die casting manufacturing company
(Cochran, Eversheim, Kubin, & Sesterhenn, 2000)	80	Application of axiomatic design and lean management principles in the scope of production system segmentation
(Prida & Grijalvo, 2011)	81	Implementing lean manufacturing by means action research
(Hunter, Bullard, & Steele, 2004)	82	Lean production in the furniture industry
(Corbett, 2011)	83	Examine how quality award-winning organizations have used lean Six Sigma to assist their efforts to improve their business excellence scores
(Cuatrecasas-Arbos, Fortuny-Santos, & Vintro-Sanchez, 2011)	84	The Operations-Time Chart: A graphical tool to evaluate the performance of production systems – From batch-and-queue to lean manufacturing
(I. B. Da Silva, Miyake, Batocchio, & Agostinho, 2011)	85	Integrating the promotion of lean manufacturing and Six Sigma methodologies in search of productivity and quality
(Dadashnejad & Valmohammadi, 2017)	86	Investigating the effect of value stream mapping on overall equipment effectiveness
(De Araujo & De Queiroz, 2010)	87	A conceptual model for production leveling (Heijunka) implementation in batch production systems

(De Carlo, Arleo, Borgia, & Tucci, 2013)	88	Layout design for a low capacity manufacturing line
(Dem, Pretorius, & Kruger, 2012)	89	Application of lean product development
(Björnfot, Bildsten, Erikshammar, Haller, & Simonsson, 2011)	90	Lessons learned from successful value stream mapping
(Dwivedi & Attarwala, 2012)	91	Design for manufacture and assembly lean and product development
(Ebrahim, Muhamad, & Truong, 2015)	92	Fit manufacturing: Production waste index and its effect on production profitability
(Faulkner & Badurdeen, 2014)	93	Methodology to visualize and assess manufacturing sustainability performance
(Finnsgård, Wänströ, Medbo, & Neumann, 2011)	94	Impact of materials exposure on assembly workstation performance
(Franchetti & Yanik, 2011)	95	Continuous improvement and value stream analysis through the lean DMAIC Six Sigma approach
(M. P. Garcia, Santos, Arcelus, & Viles, 2012)	96	A framework based on OEE and wireless technology for improving overall manufacturing operations
(Gholap & Desai, 2012)	97	Reduction of rework the Six Sigma way
(Gnanaguru et al., 2011)	98	Toyota's A3 reports for improving 6-S activities
(Gudem, Steinert, Welo, & Leifer, 2013)	99	Redefining customer value in lean product development design projects
(Gupta & Jain, 2015)	100	An application of 5S concept to organize the workplace
(Haque & James-Moore, 2004)	101	Applying lean thinking to new product introduction
(Håkansson, Dellve, Waldenström, & Holden, 2017)	102	Sustained lean transformation of working conditions
(Naga Vamsi Krishna & Aditya, 2014)	103	Lean manufacturing implementation using value stream mapping as a tool

(D. S. Nallusamy, V Punna Rao, & Rajaram Narayanan, 2017)	104	Implementation of total productive maintenance lean tool to reduce lead time
(Chanarungruengkij, Saenthon, & Kaitwanidvilai, 2017)	105	Application of lean manufacturing system
(Jeyaraj, Muralidharan, Mahalingam, & Deshmukh, 2013)	106	Applying value stream mapping technique for production improvement
(John, Selladurai, & Ranganathan, 2012)	107	Machine tool component manufacturing – a lean approach
(Katayama & Bennett, 1996)	108	Lean production in a changing competitive world
(Kristensen & Israelsen, 2014)	109	Performance effects of multiple control forms in a Lean organization
(S. Kumar, Choe, & Venkataramani, 2013)	110	Achieving customer service excellence using Lean Pull Replenishment
(M. Kumar & Antony, 2009)	111	Multiple case-study analysis of quality management practices
(M. K. Kumar, Rajan, Navas, & Rubinson, 2014)	112	Application of lean manufacturing in mass production system
(Štefanić, Gjeldim, & Mikac, 2010)	113	Lean concept application in production business
(K. L. Lee & Wei, 2010)	114	Reducing mold changing time by implementing lean Six Sigma
(S. S. Lee, Dugger, & Chen, 1999)	115	Kaizen: An essential tool for inclusion in industrial technology curricula
(Lewis, 2000)	116	Lean production and sustainable competitive advantage
(Li, Bao, & Li, 2014)	117	Applications of lean logistics
(Liu & Yang, 2017)	118	Lean implementation through value stream mapping
(Losonci, Demeter, & Jenei, 2011)	119	Factors influencing employee perceptions in lean transformations

(Álvarez, Calvo, Peña, & Domingo, 2009)	120	Redesigning an assembly line through lean manufacturing tools
(Maginness, Shehab, & Beadle, 2011)	121	Value stream analysis of manufacturing engineering new product introduction processes
(Majava & Ojanperä, 2017)	122	Lean production development in SME's
(Mane & Jayadeva, 2015)	123	5S implementation in Indian SME
(P. J. Martínez-Jurado, Moyano-Fuentes, & Gómez, 2013)	124	HR management during lean production adoption
(Maxwell, Briscoe, Schenk, & Rothenberg, 1998)	125	Can lean production practices increase environmental performance
(Medeiros, Seibel, Jorge, & Fernandes, 2009)	126	Lean thinking and product innovation
(Miller, Pawloski, & Standridge, 2010)	127	A case study of lean, sustainable manufacturing
(Mirehei, Kuriger, Wan, & Chen, 2011)	128	Enhancing lean training for the office environment
(Mohanraj, Sakthivel, & Vinodh, 2011)	129	QFD integrated value stream mapping: An enabler of lean manufacturing
(Motwani, 2003)	130	A business process change framework for examining lean manufacturing
(Muruganantham, Navaneetha Krishnan, & Arun, 2013)	131	Performance improvement and cost minimization by the application of Lean with TRIZ principles
(Muruganantham, Navaneetha Krishnan, & Arun, 2014)	132	Integrated application of TRIZ with lean in the manufacturing process in a machine shop for the productivity improvement
(R. Muslimen, S. Mohd Yusof, & A. S. Z. Abidin, 2013)	133	A case study of lean manufacturing implementation approach
(S. Nallusamy, Dinagaraj, Balakannan, & Satheesh, 2015)	134	Sustainable green lean manufacturing practices in small scale industries
(S. Nallusamy & Adil Ahamed, 2017)	135	Implementation of lean tools for productivity enhancement
(Adnan, Jaffar, Yusoff, & Halim, 2013)	136	Implementation of continuous flow system in manufacturing operation
(Naveen & Ganesh Kumar, 2012)	137	Quality improvements by implementing lean manufacturing principles
(Nepal, Yadav, & Solanki, 2011)	138	Improving the NPD process by applying lean principles
(Ng, Goh, & Eze, 2012)	139	Barriers in total productive maintenance implementation
(Ng, Lim, Chong, & Goh, 2014)	140	Elimination of waste through value add/non value add process analysis to improve cost productivity
(Ng, Chong, & Goh, 2014)	141	Improving overall equipment effectiveness through the Six Sigma methodology
(Niepce & Molleman, 1996)	142	Characteristics of work organization in lean production and sociotechnical systems
(Panat, Dimitrova, Selvamuniandy, Ishiko, & Sun, 2014)	143	The application of Lean Six Sigma to the configuration control in Intel's manufacturing R&D environment
(Panizzolo, 1998)	144	Applying the lessons learned from 27 lean manufacturers. The relevance of relationships management
(Panizzolo, Garengo, Sharma, & Gore, 2012)	145	Lean manufacturing in developing countries
(Pattanaik & Sharma, 2009)	146	Implementing lean manufacturing with cellular layout
(Pool, Wijngaard, & Van Der Zee, 2011)	147	Lean planning in the semi-process industry
(Prakash & Chin, 2014)	148	Implementation of hybrid parallel Kanban-CONWIP system
(Prates & Bandeira, 2011)	149	Increased efficiency through production stream mapping and application of Index of Global Operating Income in the manufacturing process

(Pullan, Bhasi, & Madhu, 2013)	150	Decision support tool for lean product and process development
(Shams, Tritos, & Amrik, 2010)	151	Impact of lean strategy on operational performance
(Rahman, 2015)	152	Assessment of total productive maintenance implementation
(Ramdass, 2015)	153	Integrating 5S principles with process improvement
(Rane, Sudhakar, Sunnapwar, & Rane, 2015)	154	Improving the performance of assembly line
(Ruiz-De-Arbulo-Lopez, Fortuny-Santos, & Cuatrecasas-Arbós, 2013)	155	Lean manufacturing: costing the value stream
(Sahwan, Rahman, & Deros, 2014)	156	Case studies on the implementation of lean manufacturing
(Saleeshya, Sneha, Karthikeyan, Sreenu, & Rohith, 2015)	157	Lean practices in machinery manufacturing industries
(Salgado, Mello, Da Silva, Da Silva Oliveira, & De Almeida, 2009)	158	Analysis of the application of mapping the value stream in the identification of product development process waste
(Mat Salleh & Zain, 2012)	159	The study of lean layout in an automotive parts manufacturer
(Sarka, 2017)	160	Cost reduction of manufacturing and assembly
(Saunders, Gao, & Shah, 2014)	161	A case study to evaluate lean product development practices
(Saurin, Marodin, & Ribeiro, 2011)	162	A framework for assessing the use of lean production practices
(Schaeffer, Cadavid, & Backström, 2010)	163	Spatial design for continuous improvement
(Shahada & Alsyouf, 2012)	164	Design and implementation of a lean Six Sigma Framework for process improvement

(B. Singh, Garg, Sharma, & Grewal, 2010)	165	Lean implementation and its benefits to production industry
(J. Singh, Singh, Singh, & Singh, 2017)	166	Evaluating lean thinking using value stream mapping
(Slomp, Bokhorst, & Germs, 2009)	167	A lean production control system for high variety/low-volume environments
(Smith & Synowka, 2014)	168	Lean operations and SCM practices in manufacturing firms
(Soares, Bastos, Gavazzo, Pereira, & Baptista, 2013)	169	Lean management methods in product development
(Söderquist & Motwani, 1999)	170	Quality issues in lean production implementation
(Sohal, 1996)	171	Developing a lean production organization
(Stewart, Danford, Richardson, & Pulignano, 2010)	172	Workers' experiences of skill, training and participation in lean and high performance workplaces
(Stratton & Warburton, 2003)	173	The strategic integration of agile and lean supply
(Stump & Badurdeen, 2012)	174	Integrating lean and other strategies for mass customization manufacturing
(Domingo & Aguado, 2015)	175	Overall environmental equipment effectiveness as a metric of a lean and green manufacturing system
(Sutari, 2015)	176	Process improvement using lean principles
(Taylor, 2009)	177	An application of value stream management to the improvement of a global supply chain
(Thirunavukkarasu et al., 2013)	178	Lean implementation through value stream mapping

(Timans, Antony, Ahaus, & Van Solingen, 2012)	179	Implementation of lean Six Sigma
(Tortorella & Fogliatto, 2014)	180	Method for assessing human resources management practices and organizational learning factors in a company under lean manufacturing implementation
(Tuli & Shankar, 2015)	181	Collaborative and lean new product development approach
(Wen, Remus, & Mills, 2011)	182	Understanding and addressing user resistance to implementation in a lean context
(Verma & Sharma, 2017)	183	Sustainable competitive advantage by implementing lean manufacturing
(Vinodh & Kumar Chintha, 2011)	184	Application of fuzzy QFD for enabling leanness in a manufacturing organization
(Vinodh, Arvind, & Somanaathan, 2010)	185	Application of value stream mapping
(Vinodh, Gautham, & Ramiya R, 2011)	186	Implementing lean sigma framework
(Viswanath, 2014)	187	Lean transformation: How lean helped to achieve quality, cost and schedule
(Jaffar, Halim, & Yusoff, 2012)	188	Effective data collection and analysis for efficient implementation of standardized work
(Wasim et al., 2013)	189	An innovative cost modelling system to support lean product and process development
(R. Muslimen, S. M. Yusof, & A. S. Z. Abidin, 2013)	190	Lean manufacturing implementation
(Antunes, Sousa, & Nunes, 2013)	191	Using project Six Sigma and lean concepts in internal logistics
(Wee & Simon, 2009)	192	Lean supply chain and its effect on product cost and quality
(Westin, Chronéer, & Segerstedt, 2013)	193	Lean assemble-to-order manufacturing
(Yesmin, Masuduzzaman, & Zaheer, 2012)	194	Productivity improvement in plastic bag manufacturing through lean manufacturing concepts
(Zakuan & Saman, 2009)	195	Lean manufacturing concept: The main factor in improving manufacturing performance
(A. Zhang, 2010)	196	Wireless devices enabled information system design Poka-Yokes: A case study with a manufacturing logistics process
(Y. Zhang, He, Chen, & Zhang, 2013)	197	Assembly process improvement in company S: A lean Six Sigma case study
(Zhuravskaya, Michajlec, & Mach, 2011)	198	Success case–study of lean production
(Badgujar, Kanungo, & Thakar, 2016)	199	Identification of factors affecting lean manufacturing implementation
(M. P. da Silva, Tortorella, & Amaral, 2016)	200	Psychophysical demands and perceived workload—An ergonomics standpoint for lean production
(Che Ani & Chin, 2016)	201	Self-reinforcing mechanisms for cellularisation
(Ben Fredj-Ben Alaya, 2016)	202	VSM a powerful diagnostic
(Ali Naqvi, Fahad, Atir, Zubair, & Shehzad, 2016)	203	Productivity improvement of a manufacturing facility using systematic layout planning
(Srinivasa Rao & Niraj, 2016b)	205	Measurement degree of performance of an industry by using lean score technique
(Alaskari et al., 2016)	206	Development of a methodology to assist manufacturing SMEs in the selection of appropriate lean tools

(Ali & Deif, 2016)	207	Assessing leanness level with demand dynamics in a multi-stage production system
(Andrade, Pereira, & Del Conte, 2016)	208	Value stream mapping and lean simulation
(Atieh, Kaylani, Almuhtady, & Al-Tamimi, 2016)	209	A value stream mapping and simulation hybrid approach
(Birkie & Trucco, 2016)	210	Understanding dynamism and complexity factors in engineer-to-order and their influence on lean implementation strategy
(Boscari, Danese, & Romano, 2016)	211	Implementation of lean production in multinational corporations
(Caggiano, Marzano, & Teti, 2016)	212	Resource efficient configuration of an aircraft assembly line
(Chauhan, 2016)	213	An analysis of the status of resource flexibility and lean manufacturing
(Chong, Ng, & Goh, 2016)	214	Improving overall equipment effectiveness (OEE) through integration of maintenance Failure Mode and effect analysis
(Elnadi & Shehab, 2016)	215	A multiple-case assessment of product service system leanness
(Hansen & Møller, 2016)	216	Conceptualizing dynamic capabilities in lean production
(R. Kumar & Kumar, 2016)	217	Operational performance improvement by implementation of value stream mapping
(Lacerda, Xambre, & Alvelos, 2016)	218	Applying value stream mapping to eliminate waste
(Lolli, Gamberini, Rimini, & Pulga, 2016)	219	A revised FMEA with application to a blow molding process
(Maasouman & Demirli, 2016)	220	Development of a lean maturity model for operational level planning

(Nguyen & Do, 2016)	221	Re-engineering assembly line with lean techniques
(En-Nhaili, Meddaoui, & Bouami, 2016)	222	Effectiveness improvement approach basing on OEE and lean maintenance tools
(Pereira et al., 2016)	223	Reconfigurable standardized work in a lean company
(Perera, 2016)	224	Productivity Improvement Through Lean Tools
(Seleem, Attia, & El-Assal, 2016)	226	Managing performance improvement initiatives using DEMATEL method
(Sodkomkham & Chutima, 2016)	227	Lean Six Sigma application
(Tang, Ng, Chong, & Chen, 2016)	228	Case study on lean manufacturing system implementation
(Utami, 2016)	229	Predicting level of waste and cost reduction using integration of dynamic and agent based model
(Vinodh, Ben Ruben, & Asokan, 2016)	230	Life cycle assessment integrated value stream mapping framework to ensure sustainable manufacturing
(Saurin & Ferreira, 2008b)	232	Qualitative evaluation of the implementation of lean production practices
(Horbal, Kagan, & Koch, 2008)	233	Implementing lean manufacturing in high-mix production environment
(Marinescu & Toma, 2008)	234	Implementing lean management
(Van Goubergen, 2008)	235	Set-up reduction for lean cells and multi machine situations
(Lasa, Laburu, & De Castro Vila, 2008)	236	An evaluation of the value stream mapping tool
(Joe & Andrew, 2008)	237	The challenges of supply strategy selection in a project environment

(Yang & Su, 2007)	238	Application of Hoshin Kanri for productivity improvement
(Achanga, Shehab, Roy, & Nelder, 2006)	239	Critical success factors for lean implementation within SMEs
(Anand & Kodali, 2008)	240	Development of a Conceptual Framework for Lean New Product Development Process
(Aulakh & Gill, 2008)	241	Lean manufacturing- A practitioner's perspective
(Baines, Williams, Lightfoot, & Evans, 2007)	242	Beyond theory: An examination of lean new product introduction
(Bayou & de Korvin, 2008)	243	Measuring the leanness of manufacturing systems
(Braglia, Carmignani, & Zammori, 2006)	244	A new value stream mapping approach for complex production systems
(C. B. Brown, Collins, & McCombs, 2006)	245	Transformation from batch to lean manufacturing: The performance issues
(G. D. Brown & O'Rourke, 2007)	246	Lean manufacturing comes to China: A case study of its impact on workplace health and safety
(Domingo, Alvarez, Peña, & Calvo, 2007)	247	Materials flow improvement in a lean assembly line
(Doolen, Traxler, & McBride, 2006)	248	Using scorecards for supplier performance improvement: Case application in a lean manufacturing organization
(Gati-Wechsler & Torres Jr, 2008)	249	The influence of lean concepts on the product innovation process
(Gautam & Singh, 2008)	250	Lean product development: Maximizing the customer perceived value through design change
(Gibbons, 2008)	251	Introducing a lean resource mapping framework
(Hu, Wang, Fetch, & Bidanda, 2008)	252	A multi-objective model for project portfolio selection to implement lean and Six Sigma concepts
(Hunter & Black, 2007)	253	Lean manufacturing: A cellular case study
(Jin, Curran, Butterfield, & Burke, 2008)	254	A quantitative metric for workstation design for aircraft assembly
(Khan, Bali, & Wickramasinghe, 2008)	255	A business process improvement framework to facilitate superior SME operations
(B. H. Lee & Jo, 2007)	256	The mutation of the Toyota Production System
(Curry, 2007)	257	A lean analysis methodology
(Mitropoulos, Cupido, & Namboodiri, 2007)	258	Safety as an emergent property of the production system: How lean practices reduce the likelihood of accidents
(Modarress, Ansari, & Lockwood, 2005)	259	Kaizen costing for lean manufacturing
(Mothersell, L. Moore, & Strolle, 2008)	260	A brownfield lean conversion
(Östlin & Ekholm, 2007)	261	Lean production principles in remanufacturing
(Ozelkan, Teng, Johnson, Benson, & Nestvogel, 2007)	262	Building lean supply chain and manufacturing skills through an interactive case study
(Pickrell, Lyons, & Shaver, 2005)	263	Lean Six Sigma implementation case studies
(Pil & Fujimoto, 2007)	264	Lean and reflective production: the dynamic nature of production models
(Reichhart & Holweg, 2007)	265	Lean distribution: concepts, contributions, conflicts
(Saurin & Ferreira, 2008a)	266	Guidelines to evaluate the impacts of lean production on working conditions
(Serrano, Ochoa, & De Castro, 2008)	267	Evaluation of value stream mapping in manufacturing system redesign

(R. K. Singh, Choudhury, Tiwari, & Maull, 2006)	268	An integrated fuzzy-based decision support system for the selection of lean tools
(Torres Jr, Wechsler, & Favaro, 2007)	269	Innovation and organizational trajectories
(Yang & Su, 2007)	270	Application of Hoshin Kanri for productivity improvement
(Grisales & Gaitan, 2017)	271	Strategic and operational objectives and decisions as support for lean manufacturing
(Cheung, Leong, & Vichare, 2017)	273	Incorporating lean thinking and life cycle assessment to reduce environmental impacts
(Rohac & Januska, 2015)	274	Value stream mapping Demonstration
(Fu, Guo, & Niu, 2017)	275	Applying the green Embedded lean production model in developing countries
(Huang & Tomizuka, 2017)	276	Production flow analysis through environmental value stream mapping
(Omogbai & Salonitis, 2017)	277	The implementation of 5S lean tool using system dynamics approach
(Mourtzis, Fotia, Vlachou, & Koutoupes, 2018)	279	A Lean PSS design and evaluation framework supported by KPI monitoring and context sensitivity tools
(Dogan, 2015)	280	Analyzing the supplier selection process of a lean manufacturing firm
(Olah, Szolnok, Nagy, Lengyel, & Popp, 2017)	281	The impact of lean thinking on workforce motivation
(Venanzi, Faustino, da Silva, & Hasegawa, 2017)	282	Lean Six Sigma – Multiple case study
(Stadnicka & Litwin, 2017)	283	VSM based system dynamics analysis to determine manufacturing process performance
(Kareem, Al Askari, & Muhammad, 2017)	286	Critical issues in lean manufacturing programs
(Seth, Seth, & Dhariwal, 2017)	287	Application of value stream mapping (VSM) for lean and cycle time reduction in complex production environments
(Bharathi, Vinodh, Devarapu, & Siddhamshetty, 2017)	288	Application of lean approach for reducing weld defects
(Duarte & Machado, 2017)	289	Green and lean implementation
(Losonci, Kasa, Demeter, Heidrich, & Jenei, 2017)	290	The impact of shop floor culture and subculture on lean production practices
(Prashar, 2017)	291	Integration of Taguchi and Shainin DOE for Six Sigma improvement
(Lu & Yang, 2015)	295	Implementing lean standard work to solve a low work-in-process buffer problem in a highly automated manufacturing environment
(Ben Ruben, Asokan, & Vinodh, 2017)	297	Performance evaluation of lean sustainable systems using adaptive neuro fuzzy inference system
(Aviles-Gonzalez, Smith, & Sawhney, 2016)	298	Decision making method to select team members applying personnel behavior based lean model
(Ghalayini et al., 1997)	301	An integrated dynamic performance measurement system for improving manufacturing competitiveness
(Pedro José Martínez-Jurado, Moyano-Fuentes, & Jerez-Gómez, 2014)	302	Human resource management in Lean Production adoption and implementation processes
(Kurdve, Zackrisson, Wiktorsson, & Harlin, 2014)	225	Lean and green integration into production system models
(Chiesa, Frattini, Lazzarotti, & Manzini, 2007)	272	Measuring Performance in New Product Development Projects
(Christer & Pär, 1996)	294	Assessing changes towards lean production
(Toni & Tonchia, 1996)	299	Lean organization, management by process and performance measurement

(Arawati & Mohd Shukri, 2012)	204	Lean production supply chain management as driver towards enhancing product quality and business performance
(Karim & Arif-Uz-Zaman, 2013)	285	A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations
(Mohammadi, 2010)	278	Lean product development - Performance measurement system
(Shivdasini Singh, Rakesh, Ankur, & Boby, 2014)	284	Lean machine manufacturing
(M. Kumar, Antony, Singh, Tiwari, & Perry, 2006)	292	Implementing the Lean Sigma framework in an Indian SME
(Hudson, Lean, & Smart, 2001)	293	Improving control through effective performance measurement in SMEs
(Jaca, Viles, Paipa-Galeano, Santos, & Mateo, 2014)	296	Learning 5S principles from Japanese best practitioners
(Karakulin, 2015)	300	Lean innovation in large companies; A case of implementation in R&D
(Longoni, Pagell, Johnston, & Veltri, 2013)	231	Exploration of lean practices and worker health and safety outcomes

Source: Author based

Appendix b - *Key Performance Indicators*

Standard Time	Added value €	Nº of Product Families	Update rate	Departure time
Preparation / Set-up Time	Searching Time	Delivery / Shipping Time	Cycle speed	Manual time
Nº of units on the order	Cleanness Ratio	Production / Manufacturing Time	Item arrival rate	Pitch (h/pallet)
Delivery Performance	Cash-flow ratio	Operation Time	Utilization Rate	Cost of marketing process
Working Time / Manpower Time	Job quitting frequency	Raw Material Inventory	Equipment capacity	Cost of design and development
Production Rate	Employee Morale Index	Product Quality	Workload	Cost of accounting and IT process
Stop / Break Time	Employee Discourage Index	in-line Productivity	Resource purchase orders	Cost of supply chain management
Nº of Workers	Motivation Level	Labor Rate	Agilean Index	Cost of quality management
Defects ratio	Incentives / Awards Amount	Cost per m2	Nº of workstations	Cost of shipping and warehouse management
Uptime Rate	Plant Effective Capacity	Dock to Dock time	Supermarket pick-up time	Cost of service and post-sales process
Downtime / Idle Rate	Manufacturing Effectiveness Ratio	Value / Non Value Added Ratio	Supermarket drop-off time	Cost of the cell
Takt-time	Availability	Transportation effort	Unload time	Plant amortization share
Cycle-time	Attendance / Absenteeism	System efficacy %	Nº of inspection points	Sigma level
Movement/Walk Time	Demand Rate	WIP Time	Production / Manufacturing capacity	Budget of project
Waiting / Delay Time	Labor Cost	Smoothness index	Reliability	Cost of project
Inspection Time	Equipment Cost	Process Improvement	Rejection Cost	Inventory costs
Changeover Time	Product Cost	Working environment	Process capability index	Nº of re-inspections
Lead-time	Customer Satisfaction Ratio	Conveyor speed	Scrap cost	Outsourcing costs
Nº of items needed	Build-Time / Assembly Time	Bottleneck time	Rework cost	Quality rate
Inventory Level	Production Target	Maintenance Time	Raw material consumption	Investment in working materials
Processing Time	Capital Invested on Inventory	Product Size / Weight	Environmental impact index	Budget
Estimated Assembly Time	Inventory Time	Scrap Rate	Time spent to acquire information	Duration of the project
Nº of Tasks / Operations	Fuel / Oil Consumption	Nº of Parts	Time spent to identify information	nº of workers on the project
% travel of workers	Vehicle Maintenance	Process Cost	Time spent to verify information	Perspective sales of the project
Nº of Machines	Power Consumption	Supplier evaluation	Cost cutback	Inventory reduction perspective of a project
Cost of Materials	Work Efficiency	Resource utilization %	% of vehicles that not meet delivery times	Cost reduction perspective of a project
Machine Utilization Rate	Satisfaction Ratio	Batch / Lot Size	Available resources	% defects reduced by the project
Material Usage Rate	Financial Investment	Price	% of vehicles that delivery in advance	Performance rate

WIP Inventory Level	nº of shifts	Set-up labor hours	% of vehicles that delivery in time	Development costs
Nº of Activities	Demand Volume	Nº of Invoices	% of vehicles that delivery in late	Production waste index
Distance	Rate of learning %	Nº of customers contacts	Misunderstanding between operators	Profit margin
Nº of Product Calls	Throughput rate	Nº of vendors	Value / Non Value Added Time	Profitability
Order to Receive Time	Lateness	Sales Volume	Non-productive time	Maintenance Costs
Training Time	Equipment Usage Rate	Pretax income	Nº of Inputs	Indirect labor costs
Nº of Inspected Items	Water Consumption	Nº of inspectors	Waste returning time	Consumables reuse rate
Maintenance Effort	Harmful Gases Release	Travel time	Polluting reduction degree	Ratio of recycled scraps
Machine Productivity	Waste Segregation %	Shift change time	Safety time	Ratio of use of renewable energy
Product Mix	Waste with Traceable Treatment %	Rework Time	Value of a product	% of potential harmful piking activities
Rework Rate	Green Production Rate	Overtime	Nº of setup activities	Nº of sold units
Process Time	Level of Environmental Sustainability	Warranty costs	Raw material cost	Cost of movement
Turnover / Revenue	Noise Level	Schedule effectiveness	% of time allocation	% travel savings
Returns Rate	Level of Social Sustainability	Nº of new products	Flexibility	% of cost cutback
Transportation time	Operation Cost	Training Investment	OEE	Cost savings
Productivity Ratio	Effective Cost	Compliance rate	Nº of hours of extra time	Net profit
Manufacturing / Production Cost	Stock Cost	Manufacturability rate	WIP Cost	Internal rate of return
First Pass Yield	Takt Cost	Serviceability Rate	Total time spent to solve a problem	Labor utilization
Space Usage / Productive Floor	Cost Cycle Efficiency %	Safety Ratio	Quality of supply service	Communication level
Nº of Accidents / Injuries	Total line time	Material handling time	Nº of units not produced due to failures	Response rate
Cost of Consumables	Station Time	Truck loading time	Product Loss	Price
Frequency of Movements	Product time	Time spent checking inventory age	Arrival Time	Quality-cost-ratio index
Service costs	Nº of employee suggestions	Employee dependency	Employment security	Goal congruence index
Value retention	Manual demand	Nº of errors	Responsibility level	Nº of Safety stock
Aesthetics	Tool demand	Delivery quality	Work effort	% Ship to promise
Handling capability	Cost of recycling	Time to lunch a new product	Creativity	Yield
Brand image	Delivery cost	Nº of shipping errors	Climate change	Customer complaints
Competitors brand image	Customer quality expectation	Perceived workload level	Human toxicity	Nº of employee complaints
Quality of materials	Quantity of parts shipped	Coverage rate by stocks	Environmental toxicity	Raw material stock accuracy
Audit score	Operator fatigue index	Bonus	NPV	Nº of sales order defects
Saved time	Overproduction rate	Speed Loss	IRR	Setup cost
Completion time	Waiting inventory	Orders delivered late	ToR	Savings on WIP

% pre-processing time	Process cycle efficiency	Dispatch time	DToR	WIP Inventory (hours)
% analysis time	Total time	Lean Production index / score	Technological capability	Transportation cost
% post-processing time	Market share	Quality control level	Co-worker relation	Commitment level
% of waste	Payback potential	Quality Control output level	Nº of items delivered before time	Belief effect
Cleaning time	Project performance index	Sense giving index	Lean Sustainability index	Communication effect
Accuracy of stock balance	Equipment effectiveness	Pressure Index	Incentives	Work method effect
% of Conflicts	Supplier total cost	Adaptive Index	Employee capability	Automated time
Health rate	R&D cost	Investment in Social Capital	Investment in technology	Inventory turnover
Burnout rate	Inventory rotation index	Leadership average performance	Environmental cost	Accessibility
Stress rate	Slack time	Waste costs	Environmental performance	Skill level
Recognition / Nº of rewards	Planning time	Value / Non Value added cost	Prototype cost	Available space between machines
Process Inventory level	IGOI (Index of Global Operating Income)	Physical load index	Operation Income	Available storage space
Line Speed	Cost per department	Work environment risk	Return on Equity	Cost of control
Personnel efficiency	Workers compensation cost	Air acidification	Travel costs	Delay of supply
Fixed costs	Lost time	Carbon footprint	Overall Process efficiency	Nº of incomplete orders
CM-ratio 3 Index	Delay capacity	Customer willing to pay	Meeting time	Manufacturing investment cost
Wage-ratio Index	Other costs	Downtime cost	Insurance costs	Investment
Forecast accuracy	Material Recovery rate	Failure costs	Variable cost	
Logistics cost	Order fill rate	ROI	Risk cost	
OEEE (Environmental)	Overhead work	% reused parts	Perceived value index	
Demand variability	Perceived cost	Temperature level	Durability index	
Cost of emergency shipping	Engineering cost	Customer response time	Project potential benefit index	
Customer moment of truth	Yield rate satisfying level	Disruption ratio	Project benefit : cost ratio	
Time to market	Labor savings	Direct labor turnover	Overhead costs	
Market risk	Target Cost	Autonomy	Completed sequential production ratio	
Decision making capability	NPD Success rate	Variability	Product development time	

Source: Author based

Appendix c - *Detailed Framework Categories and Clusters*

Investment Priority

Process	Cost	Human Resources	Inventory	Product development and technology
Nº of Machines	Labor Cost	Nº of Workers	Plant Effective Capacity	Cost of Materials
Plant Effective Capacity	Cost of Materials	Labor Cost	Available resources	Nº of Machines
Yield	Nº of Machines	Training Investment	Capital Invested on Inventory	Available resources
Available resources	Equipment Cost	Incentives / Awards Amount		Update rate
Forecast accuracy	Investment	Investment in Social Capital		Investment in technology
ROI	Budget of project			
Investment in working materials	Cost of project			
Goal congruence index	Budget			
Payback potential	Cash-flow ratio			
Project performance index	Incentives / Awards Amount			
IGOI (Index of Global Operating Income)	ROI			
Investment in Social Capital	Capital Invested on Inventory			
Investment in technology	Financial Investment			
	Investment in working materials			
	Manufacturing investment cost			
	Investment in Social Capital			
	Investment in technology			

Supplier Issues

Time effectiveness	Process	Quality	Cost	Delivery	Inventory
Lead-time	Process Time	Quality rate	Cost of Materials	Lead-time	Demand Rate
Takt-time	Processing Time	Inspection Time	Cost cutback	Demand Rate	Batch / Lot Size
Value / Non Value Added Time	Distance	Serviceability Rate	Price	Process Time	Raw Material Inventory
Process Time	Transportation time	Reliability	Transportation cost	Delivery / Shipping Time	Nº of Product Calls

Delivery / Shipping Time	Flexibility	Product Quality	Cost of Consumables	Processing Time	Raw material cost
Processing Time	Nº of Product Calls	Supplier evaluation	Inventory costs	Distance	Waiting inventory
Transportation time	Order to Receive Time	Compliance rate	Raw material cost	Transportation time	Cost per m2
Dock to Dock time	Response rate	Value of a product	Delivery cost	Flexibility	
Order to Receive Time	Transportation effort	Quality of supply service	Overhead costs	Nº of Product Calls	
Travel time	Nº of Invoices	Quality of materials	Warranty costs	Dock to Dock time	
Time spent to acquire information	Item arrival rate	Quality-cost-ratio index	Cost of supply chain management	Order to Receive Time	
Arrival Time	Resource purchase orders	Delivery quality	Outsourcing costs	Travel time	
Delay of supply	% travel savings		Service costs	Arrival Time	
Truck loading time	Performance rate (OEE)		Fixed costs	Delivery cost	
Unload time			Quality-cost-ratio index	Transportation effort	
Time spent to identify information			Setup cost	Resource purchase orders	
Time spent to verify information			Supplier total cost	% of vehicles that not meet delivery times	
Departure time			Cost of control	% of vehicles that delivery in advance	
% pre-processing time			Travel costs	% of vehicles that delivery in time	
% analysis time			Logistics cost	% of vehicles that delivery in late	
% post-processing time			Cost of emergency shipping	Departure time	
Total time			Rejection Cost	Cost of supply chain management	
Dispatch time				% Ship to promise	
				Delivery quality	
				Nº of shipping errors	
				Orders delivered late	
				Nº of items needed (Overproduction)	

Manufacturing Efficiency

Time effectiveness	**Process**	**Quality**	**Cost**	**Human Resources**	**Delivery**
Cycle-time	Cycle-time	Defects ratio	Inventory Level	Nº of Workers	Lead-time
Lead-time	Lead-time	Productivity Ratio	WIP Inventory Level	Productivity Ratio	Takt-time

Takt-time	Takt-time	Quality rate	Manufacturing / Production Cost	Nº of Activities	Waiting / Delay Time
Preparation / Set-up Time	Defects ratio	Rework Rate	Rework Rate	Flexibility	Delivery Performance
Waiting / Delay Time	WIP Inventory Level	Inspection Time	Cost cutback	Frequency of Movements	Demand Rate
Downtime / Idle Rate	Nº of Workers	Reliability	Cost cutback	nº of shifts	Process Time
Value / Non Value Added Time	Waiting / Delay Time	Product Quality	Product Cost	Overtime	Delivery / Shipping Time
Working Time / Manpower Time	Productivity Ratio	Nº of Inspected Items	Rework cost	Serviceability Rate	Processing Time
Changeover Time	Downtime / Idle Rate	Manufacturing Effectiveness Ratio	Transportation cost	Nº of Tasks / Operations	Distance
Process Time	Demand Rate	Nº of inspectors	Cost of Consumables	Maintenance Effort	Transportation time
Movement/Walk Time	Changeover Time	Safety time	Operation Cost	Labor Rate	First Pass Yield
Delivery / Shipping Time	Process Time	Quality of supply service	Scrap cost	Personnel efficiency	Flexibility
Processing Time	Movement/Walk Time	Quality of materials	Inventory costs	Commitment level	Nº of Product Calls
Inspection Time	Rework Rate	Quality-cost-ratio index	Process Cost	Available resources	Dock to Dock time
Uptime Rate	Processing Time	Quality control level	Maintenance Costs	Communication effect	Order to Receive Time
Production / Manufacturing Time	Space Usage / Productive Floor	Quality Control output level	Effective Cost	in-line Productivity	Travel time
Stop / Break Time	Inspection Time		Raw material cost	Working environment	Lateness
Transportation time	Uptime Rate		WIP Cost	Nº of inspectors	Arrival Time
First Pass Yield	Distance		Inventory Time	Shift change time	Transportation effort
Standard Time	Stop / Break Time		Value / Non Value added cost	Compliance rate	Truck loading time
Operation Time	Throughput rate		Overhead costs	% of time allocation	% of vehicles that not meet delivery times
Searching Time	Power Consumption		Added value €	Nº of hours of extra time	% of vehicles that delivery in advance
Maintenance Time	Value / Non Value Added Ratio		Stock Cost	% of potential harmful piking activities	% of vehicles that delivery in time
Rework Time	Nº of Activities		Takt Cost	Labor utilization	% of vehicles that delivery in late
Returns Rate	Transportation time		Cost per m2	% of Conflicts	Departure time

Overtime	Scrap Rate		Cost of quality management	Belief effect	Cost of service and post-sales process
Maintenance Effort	First Pass Yield		Cost of the cell	Work effort	% Ship to promise
Build-Time / Assembly Time	Flexibility		Indirect labor costs	Work Efficiency	Quantity of parts shipped
Station Time	Frequency of Movements		Cost of movement		Nº of items delivered before time
Travel time	Nº of Machines		Service costs		Orders delivered late
Manual time	Material Usage Rate		Fixed costs		Failure costs
Pitch (h/pallet)	nº of shifts		Wage-ratio Index		Nº of items needed (Overproduction)
Inventory Time	Utilization Rate		Quality-cost-ratio index		Fuel / Oil Consumption
WIP Time	Production / Manufacturing capacity		Setup cost		
Bottleneck time	Raw Material Inventory		Other costs		
Material handling time	Serviceability Rate		Cost of control		
Time spent to acquire information	Overproduction rate		Travel costs		
Non-productive time	Nº of Product Calls		Logistics cost		
Arrival Time	Workload		Waste costs		
Saved time	Nº of Tasks / Operations		Downtime cost		
Completion time	Maintenance Effort		Variable cost		
Cleaning time	Machine Productivity		Risk cost		
WIP Inventory (hours)	Variability		Target Cost		
Lost time	Machine Utilization Rate		Perceived cost		
Delay of supply	Order to Receive Time		Rejection Cost		
Estimated Assembly Time	Plant Effective Capacity				
Total line time	Conveyor speed				
Product time	Process capability index				
Shift change time	Raw material consumption				
Time spent checking inventory age	Pitch (h/pallet)				
Supermarket pick-up time	Sigma level				
Supermarket drop-off time	Response rate				

Unload time	% of waste				
Time spent to identify information	Personnel efficiency				
Time spent to verify information	Nº of errors				
% of time allocation	Nº of Inspected Items				
Departure time	Lateness				
% pre-processing time	Equipment Usage Rate				
% analysis time	Equipment capacity				
% post-processing time	Nº of workstations				
Automated time	Available resources				
Total time	Nº of Inputs				
Dispatch time	Product Loss				
	Line Speed				
	Communication effect				
	Speed Loss				
	Estimated Assembly Time				
	Added value €				
	Manufacturing Effectiveness Ratio				
	in-line Productivity				
	Cost per m2				
	Transportation effort				
	Smoothness index				
	Resource utilization %				
	Nº of inspectors				
	Schedule effectiveness				
	Cycle speed				
	Item arrival rate				
	Nº of inspection points				
	Nº of setup activities				

	% of time allocation				
	Nº of units not produced due to failures				
	Nº of re-inspections				
	Production waste index				
	% travel savings				
	Labor utilization				
	Process Inventory level				
	Available space between machines				
	Manual demand				
	Tool demand				
	Process cycle efficiency				
	Equipment effectiveness				
	Delay capacity				
	Nº of incomplete orders				
	Customer willing to pay				
	Quality control level				
	Quality Control output level				
	% reused parts				
	Disruption ratio				
	Completed sequential production ratio				
	Material Recovery rate				
	Order fill rate				
	Overhead work				
	Lean Sustainability index				
	Overall Process efficiency				
	Nº of units on the order (On-time Delivery)				
	Production Rate				

	Work Efficiency				
	No. of handled lots				
	Performance rate (OEE)				

Inventory	**Visual Information System**	**Product development and technology**	**Customer**	**Green and Sustainability**
Inventory Level	Defects ratio	Inventory Level	Lead-time	Power Consumption
WIP Inventory Level	Inventory Level	WIP Inventory Level	Delivery Performance	Scrap Rate
Waiting / Delay Time	WIP Inventory Level	Waiting / Delay Time	Demand Rate	Cost of Consumables
Demand Rate	Productivity Ratio	Demand Rate	Delivery / Shipping Time	Water Consumption
Processing Time	Delivery Performance	Processing Time	Distance	Noise Level
Space Usage / Productive Floor	Quality rate	Space Usage / Productive Floor	Nº of Product Calls	Environmental impact index
Scrap Rate	Space Usage / Productive Floor	Scrap Rate	Order to Receive Time	% of waste
Batch / Lot Size	OEE	Material Usage Rate	Nº of units on the order (On-time Delivery)	Harmful Gases Release
Skill level	Distance	Raw Material Inventory		Waste Segregation %
Material Usage Rate	Pitch (h/pallet)	Nº of Product Calls		Level of Environmental Sustainability
Utilization Rate	Nº of units not produced due to failures	Plant Effective Capacity		Level of Social Sustainability
Raw Material Inventory	Completed sequential production ratio	Product Size / Weight		Waste with Traceable Treatment %
Nº of Product Calls	Production Rate	Inventory Time		Green Production Rate
Workload	Nº of items needed (Overproduction)	WIP Time		Process Improvement
Inventory costs	Performance rate (OEE)	Stock Cost		Waste returning time
Plant Effective Capacity		Cost per m2		Polluting reduction degree
Product Size / Weight		Nº of units on the order (On-time Delivery)		Production waste index
Nº of Parts		Production Rate		Consumables reuse rate
Raw material consumption		Nº of items needed (Overproduction)		Ratio of recycled scraps
Inventory turnover				Ratio of use of renewable energy
Inventory Time				Cost of recycling

WIP Time				OEEE (Environmental)
Available resources				Waste costs
Nº of Inputs				Air acidification
Raw material cost				Carbon footprint
WIP Cost				Temperature level
Product Loss				Material Recovery rate
WIP Inventory (hours)				Climate change
Waiting inventory				Human toxicity
Stock Cost				Environmental toxicity
Cost per m2				Environmental cost
Time spent checking inventory age				Environmental performance
Nº of sold units				Fuel / Oil Consumption
Accuracy of stock balance				
Process Inventory level				
Nº of Safety stock				
Raw material stock accuracy				
Accessibility				
Available storage space				
Inventory rotation index				
Coverage rate by stocks				
Nº of units on the order (On-time Delivery)				
Production Rate				
Nº of items needed (Overproduction)				

Internal Management

Time effectiveness	**Process**	**Quality**	**Cost**	**Human Resources**	**Delivery**
Preparation / Set-up Time	Defects ratio	Productivity Ratio	Inventory Level	Nº of Workers	Distance

Value / Non Value Added Time	Productivity Ratio	Training Time	Manufacturing / Production Cost	Productivity Ratio	Lateness
Working Time / Manpower Time	Downtime / Idle Rate	Quality rate	Labor Cost	Working Time / Manpower Time	
Movement/Walk Time	Space Usage / Productive Floor	Customer Satisfaction Ratio	Cost of Materials	Training Time	
Stop / Break Time	Availability	Safety time	Cost cutback	Availability	
Standard Time	Distance	Work environment risk	Cost cutback	Labor Cost	
Searching Time	Uptime Rate		Profitability	Stop / Break Time	
Maintenance Time	Flexibility		Equipment Cost	Nº of Activities	
Overtime	Frequency of Movements		Product Cost	Flexibility	
Production Target	Skill level		Cost of Consumables	Nº of Accidents / Injuries	
Station Time	Product Mix		Incentives / Awards Amount	Frequency of Movements	
Manual time	nº of shifts		Vehicle Maintenance	Skill level	
Non-productive time	Motivation Level		Cost of service and post-sales process	nº of shifts	
Vehicle Maintenance	Serviceability Rate		Cost of movement	Motivation Level	
Shift change time	Safety Ratio		Internal rate of return	Overtime	
Safety time	Workload		Service costs	Serviceability Rate	
% of time allocation	Recognition / Nº of rewards		Fixed costs	Safety Ratio	
Nº of hours of extra time	Maintenance Effort		Workers compensation cost	Workload	
Total time spent to solve a problem	Employee Morale Index		Cost of control	Recognition / Nº of rewards	
Planning time	Market share		Labor savings	Nº of Tasks / Operations	
	Sigma level		Bonus	Maintenance Effort	
	Stress rate		Risk cost	Employee Morale Index	
	Personnel efficiency			Satisfaction Ratio	
	Commitment level			Labor Rate	
	Autonomy			Response rate	
	Nº of errors			Stress rate	
	Cleanness Ratio			Personnel efficiency	
	Lateness			Commitment level	
	Equipment Usage Rate			Autonomy	
	Nº of workstations			Incentives / Awards Amount	

	Available resources			Available resources	
	Communication effect			Communication effect	
	Nº of employee suggestions			Nº of employee suggestions	
	Job quitting frequency			Job quitting frequency	
	Employee Discourage Index			Employee Discourage Index	
	Nº of Product Families			Stock Cost	
	in-line Productivity			Cost per m2	
	Smoothness index			Working environment	
	Schedule effectiveness			Set-up labor hours	
	Nº of inspection points			Nº of vendors	
	Nº of setup activities			Nº of inspectors	
	% of time allocation			Shift change time	
	Internal rate of return			Compliance rate	
	Labor utilization			Misunderstanding between operators	
	Value retention			% of time allocation	
	Handling capability			Nº of hours of extra time	
	Audit score			% of potential harmful piking activities	
	% of Conflicts			Labor utilization	
	Health rate			Communication level	
	Burnout rate			Value retention	
	Wage-ratio Index			Handling capability	
	Nº of employee complaints			% of Conflicts	
	Belief effect			Health rate	
	Accessibility			Burnout rate	
	Operator fatigue index			Wage-ratio Index	
	Employee capability			Nº of employee complaints	
	Decision making capability			Belief effect	
	Employee dependency			Work method effect	
	Perceived workload level			Accessibility	

	Bonus			Operator fatigue index	
	Sense giving index			Employee capability	
	Pressure Index			Decision making capability	
	Adaptive Index			Employee dependency	
	Leadership average performance			Perceived workload level	
	Physical load index			Sense giving index	
	Work environment risk			Pressure Index	
	Direct labor turnover			Adaptive Index	
	Employment security			Leadership average performance	
	Responsibility level			Physical load index	
	Work effort			Direct labor turnover	
	Creativity			Employment security	
	Co-worker relation			Responsibility level	
	Attendance / Absenteeism			Work effort	
	Work Efficiency			Creativity	
	Performance rate (OEE)			Co-worker relation	
				Attendance / Absenteeism	
				Work Efficiency	

Inventory	**Visual Information System**	**Product development and technology**	**Customer**
Inventory Level	Productivity Ratio	Product Mix	Customer Satisfaction Ratio
Space Usage / Productive Floor	Space Usage / Productive Floor	Product Cost	Market share
Available resources	Distance	Available resources	
Accuracy of stock balance		Nº of Product Families	
Nº of Safety stock			
Production Rate			

Research and development

Time effectiveness	Process	Quality	Cost	Human Resources	Inventory
Cycle-time	Cycle-time	Defects ratio	Manufacturing / Production Cost	Incentives / Awards Amount	Inventory reduction perspective of a project
Lead-time	Lead-time	Quality rate	Cost of Materials	Available resources	
Value / Non Value Added Time	Value / Non Value Added Ratio	Manufacturing Effectiveness Ratio	Cost cutback		
Build-Time / Assembly Time	Product Mix	Value of a product	Product Cost		
Product development time	Utilization Rate	% defects reduced by the project	Cost of Consumables		
Total time spent to solve a problem	Product Cost	Customer quality expectation	Operation Cost		
Duration of the project	Production / Manufacturing capacity		Budget of project		
Total time	Machine Productivity		Cost of design and development		
Slack time	Budget of project		Cost of project		
Planning time	Conveyor speed		Budget		
Meeting time	Nº of new products		Development costs		
Time to lunch a new product	Budget		Value of a product		
	System efficacy %		Outsourcing costs		
	Available resources		Cost reduction perspective of a project		
	Nº of Product Families		Fixed costs		
	Process Improvement		R&D cost		
	Manufacturability rate		Cost of control		
	Update rate		Meeting time		
	nº of workers on the project		Waste costs		
	Perspective sales of the project		Engineering cost		
	Inventory reduction perspective of a project		Target Cost		
	Aesthetics		Prototype cost		
	Payback potential				

	Project performance index				
	Equipment effectiveness				
	NPD Success rate				
	Project potential benefit index				
	Target Cost				
	Performance rate (OEE)				

Product development and technology	**Customer**	**Green and Sustainability**
Lead-time	Perspective sales of the project	Power Consumption
Cost of Materials	Aesthetics	Scrap Rate
Product Mix	Customer quality expectation	Cost of Consumables
Product Cost	NPD Success rate	Water Consumption
Machine Productivity		Noise Level
Conveyor speed		Environmental impact index
Nº of new products		% of waste
Equipment capacity		Harmful Gases Release
Available resources		Waste Segregation %
Completion time		Level of Environmental Sustainability
Technological capability		Level of Social Sustainability
Nº of Product Families		Waste with Traceable Treatment %
Process Improvement		Green Production Rate
Manufacturability rate		Process Improvement
		Waste returning time
		Polluting reduction degree
		Production waste index
		Consumables reuse rate
		Ratio of recycled scraps
		Ratio of use of renewable energy
		Cost of recycling

		OEEE (Environmental)
		Waste costs
		Air acidification
		Carbon footprint
		Temperature level
		Material Recovery rate
		Climate change
		Human toxicity
		Environmental toxicity
		Environmental cost
		Environmental performance
		Fuel / Oil Consumption

Learning perspective

Time effectiveness	Process	Quality	Cost	Human Resources	Visual Information System	Customer
Lead-time	Lead-time	Defects ratio	Labor Cost	Training Time	Movement/Walk Time	Returns Rate
Movement/Walk Time	Preparation / Set-up Time	Quality rate	Cost cutback	Labor Cost		
Training Time	Changeover Time	Returns Rate	Training Investment	Flexibility		
Estimated Assembly Time	Movement/Walk Time		Investment	Nº of Accidents / Injuries		
Total time spent to solve a problem	Training Time		Cost of Consumables	Skill level		
Planning time	Flexibility		Fixed costs	Motivation Level		
Meeting time	Skill level		Cost of control	Safety Ratio		
	Safety Ratio			Training Investment		
	Training Investment			Employee Morale Index		
	Satisfaction Ratio			Satisfaction Ratio		
	Labor Rate			Labor Rate		
	Commitment level			Response rate		
	Autonomy			Commitment level		

	Nº of employee suggestions			Autonomy		
	Rate of learning %			Nº of employee suggestions		
	Process Improvement			Job quitting frequency		
	Update rate			Employee Discourage Index		
	Value retention			Rate of learning %		
	Handling capability			Working environment		
	Belief effect			Communication level		
	Work method effect			Value retention		
	Employee capability			Handling capability		
	Decision making capability			Belief effect		
	Employee dependency			Work method effect		
	Pressure Index			Employee capability		
	Adaptive Index			Decision making capability		
	Creativity			Employee dependency		
	Work Efficiency			Sense giving index		
				Pressure Index		
				Adaptive Index		
				Creativity		
				Work Efficiency		

Manufacturing Management

Time effectiveness	Process	Quality	Cost	Human Resources	Delivery
Cycle-time	Cycle-time	Defects ratio	Inventory Level	Nº of Workers	Lead-time
Lead-time	Lead-time	Productivity Ratio	WIP Inventory Level	Demand Rate	Inventory Level
Preparation / Set-up Time	WIP Inventory Level	Rework Rate	Manufacturing / Production Cost	Working Time / Manpower Time	Delivery Performance
Downtime / Idle Rate	Nº of Workers	Inspection Time	Turnover / Revenue	Training Time	Demand Rate
Value / Non Value Added Time	Productivity Ratio	Customer Satisfaction Ratio	Labor Cost	Availability	Process Time

Working Time / Manpower Time	Downtime / Idle Rate	Returns Rate	Sales Volume	Labor Cost	Delivery / Shipping Time
Changeover Time	Changeover Time	Nº of Inspected Items	Cost of Materials	Nº of Activities	Distance
Process Time	Process Time	Manufacturing Effectiveness Ratio	Cost cutback	Flexibility	Transportation time
Delivery / Shipping Time	Rework Rate		Price	Nº of Accidents / Injuries	First Pass Yield
Inspection Time	Space Usage / Productive Floor		Nº of Machines	Skill level	Flexibility
Uptime Rate	Inspection Time		Returns Rate	nº of shifts	Nº of Product Calls
Production / Manufacturing Time	Uptime Rate		Equipment Cost	Motivation Level	Dock to Dock time
Stop / Break Time	Distance		Product Cost	Overtime	Order to Receive Time
Transportation time	Stop / Break Time		Training Investment	Serviceability Rate	Travel time
First Pass Yield	Throughput rate		Rework cost	Safety Ratio	Lateness
Standard Time	Power Consumption		Transportation cost	Training Investment	Arrival Time
Operation Time	Value / Non Value Added Ratio		Investment	Workload	Delivery cost
Rework Time	Nº of Activities		Cost of Consumables	Recognition / Nº of rewards	Transportation effort
Overtime	Transportation time		Operation Cost	Nº of Tasks / Operations	Truck loading time
Production Target	Scrap Rate		Scrap cost	Maintenance Effort	Unload time
Dock to Dock time	First Pass Yield		Inventory costs	Employee Morale Index	% of vehicles that not meet delivery times
Time to market	Flexibility		Profit margin	Satisfaction Ratio	% of vehicles that delivery in advance
Order to Receive Time	Nº of Machines		Process Cost	Noise Level	% of vehicles that delivery in time
Station Time	Material Usage Rate		Cost of project	Labor Rate	% of vehicles that delivery in late
Travel time	Product Mix		Maintenance Costs	Response rate	Departure time
Pitch (h/pallet)	nº of shifts		Inventory turnover	Stress rate	Cost of shipping and warehouse management
Inventory Time	Utilization Rate		Cash-flow ratio	Commitment level	Nº of sold units
WIP Time	Profitability		Effective Cost	Autonomy	% Ship to promise
Bottleneck time	Production / Manufacturing capacity		Raw material cost	Incentives / Awards Amount	Nº of items delivered before time
Material handling time	Serviceability Rate		WIP Cost	Available resources	Delivery quality

Time spent to acquire information	Overproduction rate		Development costs	Communication effect	Nº of shipping errors
Non-productive time	Nº of Product Calls		Delivery cost	Nº of employee suggestions	Orders delivered late
Saved time	Workload		Value / Non Value added cost	Job quitting frequency	Fuel / Oil Consumption
Completion time	Nº of Tasks / Operations		ROI	Employee Discourage Index	
Cleaning time	Maintenance Effort		Overhead costs	Rate of learning %	
WIP Inventory (hours)	Profit margin		Added value €	in-line Productivity	
Lost time	Market share		Capital Invested on Inventory	Working environment	
Delay of supply	Variability		Vehicle Maintenance	Set-up labor hours	
Vehicle Maintenance	Machine Utilization Rate		Financial Investment	Nº of vendors	
Total line time	Order to Receive Time		Stock Cost	Nº of inspectors	
Product time	Plant Effective Capacity		Takt Cost	Shift change time	
Shift change time	Nº of Parts		Cost per m2	Compliance rate	
Time spent checking inventory age	Process capability index		Nº of Invoices	Misunderstanding between operators	
Supermarket pick-up time	Raw material consumption		Pretax income	% of time allocation	
Supermarket drop-off time	Pitch (h/pallet)		Warranty costs	Nº of hours of extra time	
Time spent to identify information	Sigma level		Value of a product	% of potential harmful piking activities	
Time spent to verify information	Response rate		Cost of marketing process	Labor utilization	
Safety time	% of waste		Cost of accounting and IT process	Communication level	
% of time allocation	Yield		Cost of supply chain management	Value retention	
Nº of hours of extra time	Inventory turnover		Cost of quality management	% of Conflicts	
% pre-processing time	Nº of errors		Cost of shipping and warehouse management	Health rate	
% analysis time	Cleanness Ratio		Cost of service and post-sales process	Burnout rate	
% post-processing time	Lateness		Cost of the cell	Wage-ratio Index	
Automated time	Equipment Usage Rate		Plant amortization share	Nº of employee complaints	
Total time	System efficacy %		Outsourcing costs	Belief effect	
Planning time	Equipment capacity		Investment in working materials	Work method effect	

Meeting time	Nº of workstations		Indirect labor costs	Accessibility	
Dispatch time	Available resources		Cost of movement	Operator fatigue index	
	Nº of Inputs		Net profit	Employee capability	
	Product Loss		Internal rate of return	Labor savings	
	Arrival Time		Service costs	Decision making capability	
	Line Speed		Fixed costs	Employee dependency	
	Nº of employee suggestions		CM-ratio 3 Index	Perceived workload level	
	Forecast accuracy		Wage-ratio Index	Bonus	
	Demand variability		Quality-cost-ratio index	Sense giving index	
	ROI		Setup cost	Pressure Index	
	Added value €		Savings on WIP	Adaptive Index	
	Manufacturing Effectiveness Ratio		Cost of recycling	Investment in Social Capital	
	Nº of Product Families		Supplier total cost	Leadership average performance	
	in-line Productivity		R&D cost	Physical load index	
	Transportation effort		IGOI (Index of Global Operating Income)	Work environment risk	
	Smoothness index		Cost per department	Direct labor turnover	
	Process Improvement		Workers compensation cost	Employment security	
	Resource utilization %		Other costs	Responsibility level	
	Nº of Invoices		Cost of control	Work effort	
	Pretax income		Manufacturing investment cost	Creativity	
	Nº of inspectors		Travel costs	Co-worker relation	
	Schedule effectiveness		Labor savings	Attendance / Absenteeism	
	Manufacturability rate		Logistics cost		
	Cycle speed		Cost of emergency shipping		
	Item arrival rate		Bonus		
	Resource purchase orders		Investment in Social Capital		
	Agilean Index		Waste costs		
	Nº of inspection points		Downtime cost		

	Nº of setup activities		Failure costs		
	% of time allocation		Engineering cost		
	Nº of units not produced due to failures		Variable cost		
	Departure time		Risk cost		
	Nº of re-inspections		Target Cost		
	Production waste index		Perceived cost		
	Nº of sold units		NPV		
	Net profit		IRR		
	Internal rate of return		ToR		
	Labor utilization		DToR		
	Value retention		Investment in technology		
	Brand image		Environmental cost		
	Audit score		Operation Income		
	Process Inventory level		Return on Equity		
	CM-ratio 3 Index		Insurance costs		
	Goal congruence index		Rejection Cost		
	Nº of sales order defects				
	Savings on WIP				
	Work method effect				
	Available space between machines				
	Manual demand				
	Tool demand				
	Quantity of parts shipped				
	Payback potential				
	Equipment effectiveness				
	IGOI (Index of Global Operating Income)				
	Delay capacity				
	Nº of incomplete orders				

	Market risk				
	Customer willing to pay				
	Quality control level				
	Quality Control output level				
	Leadership average performance				
	Work environment risk				
	% reused parts				
	Disruption ratio				
	Completed sequential production ratio				
	Target Cost				
	Perceived cost				
	Material Recovery rate				
	Order fill rate				
	Overhead work				
	NPV				
	IRR				
	ToR				
	DToR				
	Lean Sustainability index				
	Operation Income				
	Return on Equity				
	Production Rate				
	Nº of items needed (Overproduction)				
	No. of handled lots				
	Performance rate (OEE)				

Inventory	Visual Information System	Product development and technology	Customer	Green and Sustainability
Inventory Level	Defects ratio	Product Mix	Delivery Performance	Power Consumption
WIP Inventory Level	Inventory Level	Machine Utilization Rate	Demand Rate	Scrap Rate
Space Usage / Productive Floor	WIP Inventory Level	Nº of new products	Delivery / Shipping Time	Cost of Consumables
Scrap Rate	Productivity Ratio	System efficacy %	Turnover / Revenue	Water Consumption
Batch / Lot Size	Quality rate	Equipment capacity	Distance	Noise Level
Material Usage Rate	Space Usage / Productive Floor	Available resources	Sales Volume	Environmental impact index
Utilization Rate	% of waste	Technological capability	Transportation time	% of waste
Raw Material Inventory	Pitch (h/pallet)	Nº of Product Families	Customer Satisfaction Ratio	Harmful Gases Release
Nº of Product Calls	Nº of units not produced due to failures	Process Improvement	Price	Waste Segregation %
Inventory costs	Nº of items needed (Overproduction)	Manufacturability rate	Returns Rate	Level of Environmental Sustainability
Plant Effective Capacity	Performance rate (OEE)	Update rate	Product Cost	Level of Social Sustainability
Nº of Parts		Automated time	Nº of Product Calls	Waste with Traceable Treatment %
Raw material consumption		Equipment effectiveness	Profit margin	Green Production Rate
Inventory turnover			Customer complaints	Process Improvement
Inventory Time			Market share	Waste returning time
WIP Time			Order to Receive Time	Polluting reduction degree
Available resources			Forecast accuracy	Production waste index
Nº of Inputs			Demand variability	Consumables reuse rate
Raw material cost			Nº of customers contacts	Ratio of recycled scraps
WIP Cost			Nº of vendors	Ratio of use of renewable energy
Product Loss			Pretax income	Cost of recycling
WIP Inventory (hours)			Value of a product	OEEE (Environmental)
Waiting inventory			Aesthetics	Waste costs
Capital Invested on Inventory			Brand image	Air acidification
Stock Cost			Competitors brand image	Carbon footprint
Cost per m2			CM-ratio 3 Index	Temperature level
Time spent checking inventory age			Nº of sales order defects	Material Recovery rate
Nº of sold units			Customer quality expectation	Climate change

Accuracy of stock balance			Customer moment of truth	Human toxicity
Process Inventory level			Market risk	Environmental toxicity
Nº of Safety stock			Yield rate satisfying level	Environmental cost
Raw material stock accuracy			Customer willing to pay	Environmental performance
Available storage space			Customer response time	Fuel / Oil Consumption
Inventory rotation index			Perceived value index	
Coverage rate by stocks			Durability index	
Production Rate				
Nº of items needed (Overproduction)				

Consumer issues

Time effectiveness	Process	Quality	Cost	Delivery
Lead-time	Lead-time	Defects ratio	Turnover / Revenue	Lead-time
Takt-time	Demand Rate	Quality rate	Sales Volume	Takt-time
Waiting / Delay Time	Process Time	Customer Satisfaction Ratio	Cost cutback	Inventory Level
Value / Non Value Added Time	Processing Time	Returns Rate	Price	Waiting / Delay Time
Process Time	Distance	Serviceability Rate	Returns Rate	Delivery Performance
Delivery / Shipping Time	Sales Volume	Reliability	Product Cost	Demand Rate
Processing Time	Distance	Product Quality	Transportation cost	Process Time
Transportation time	Transportation time	Compliance rate	Inventory turnover	Delivery / Shipping Time
Dock to Dock time	Flexibility	Value of a product	Cash-flow ratio	Processing Time
Time to market	Profitability	Quality of materials	Delivery cost	Distance
Order to Receive Time	Nº of Product Calls	Nº of sales order defects	Added value €	Transportation time
Travel time	Inventory costs	Customer quality expectation	Pretax income	Flexibility
Time spent to acquire information	Customer complaints	Delivery quality	Warranty costs	Nº of Product Calls
Inventory Time	Market share	Perceived value index	Value of a product	Dock to Dock time
Truck loading time	Order to Receive Time	Durability index	Cost of marketing process	Order to Receive Time
Unload time	Response rate		Cost of supply chain management	Travel time

Time spent to identify information	Product Loss		Cost of shipping and warehouse management	Arrival Time
Time spent to verify information	Arrival Time		Cost of service and post-sales process	Delivery cost
% pre-processing time	Demand variability		Service costs	Transportation effort
% analysis time	Forecast accuracy		Fixed costs	Truck loading time
% post-processing time	Transportation effort		CM-ratio 3 Index	% of vehicles that not meet delivery times
Total time	Nº of Invoices		Cost of control	% of vehicles that delivery in advance
Dispatch time	Nº of customers contacts		Travel costs	% of vehicles that delivery in time
Disruption ratio	Nº of vendors		Logistics cost	% of vehicles that delivery in late
	Item arrival rate		Service costs	Departure time
	Departure time		Delivery quality	Cost of supply chain management
	Nº of sold units		Perceived cost	Cost of shipping and warehouse management
	% travel savings			% Ship to promise
	Communication level			Quantity of parts shipped
	Value retention			Nº of items delivered before time
	Brand image			Nº of shipping errors
	Competitors brand image			Orders delivered late
	CM-ratio 3 Index			Nº of units on the order (On-time Delivery)
	Nº of sales order defects			Nº of items needed (Overproduction)
	Customer quality expectation			Fuel / Oil Consumption
	Quantity of parts shipped			
	Payback potential			
	Nº of incomplete orders			
	Customer moment of truth			
	Market risk			
	Yield rate satisfying level			
	Customer willing to pay			
	Customer response time			
	Nº of units on the order (On-time Delivery)			

Inventory	Product development and technology	Customer
Inventory Level	Product Mix	Delivery / Shipping Time
Batch / Lot Size	Product Size / Weight	Value / Non Value Added Ratio
Nº of Product Calls	Nº of new products	Flexibility
Product Size / Weight	Nº of Product Families	Customer Satisfaction Ratio
Inventory turnover	Durability index	Price
Product Loss		Returns Rate
Inventory Time		Product Quality
Waiting inventory		Customer complaints
Cost per m2		Added value €
Nº of sold units		Nº of customers contacts
Nº of Safety stock		Value of a product
Coverage rate by stocks		Aesthetics
Nº of units on the order (On-time Delivery)		Brand image
Nº of items needed (Overproduction)		Competitors brand image

Source: Author based

Appendix d - *Proposed Lean Tool, Philosophy and Work Techniques*

Key Performance Indicators	Proposed Lean Tool, Philosophy and Work Techniques
Nº of Machines	TISM
Plant Effective Capacity	ANOVA
Yield	CONWIP
Available resources	IDEF0 (Integrated definition language 0)
Labor Cost	VSC (Value Stream Costing)
Cost of Materials	VSC (Value Stream Costing)
Equipment Cost	VSC (Value Stream Costing)
Nº of Workers	CFS (Continuous Flow System)
Training Investment	BSC
Incentives / Awards Amount	Team Improvement
Capital Invested on Inventory	JIT
Update rate	Kanban
Lead-time	5W1H
Takt-time	DFMA
Value / Non Value Added Time	VA/NVA Analysis
Process Time	Cyclical schedules
Processing Time	7 Quality Tools
Distance	VASA Model
Transportation time	Operation Times Chart
Quality rate	Plug & Lean CiMo Framework
Inspection Time	5W1H
Serviceability Rate	SBCE (Set based concurrent engineering)
Reliability	Bayesian Belief Networks
Cost cutback	Bayesian Belief Networks
Price	LPD (Lean Product development)
Transportation cost	TRIZ
Demand Rate	7MP Tools
Delivery / Shipping Time	Axiomatic design
Batch / Lot Size	ILP Model
Raw Material Inventory	ANOVA
Nº of Product Calls	SIPOC
Cycle-time	Power Model - Learning Curve
Preparation / Set-up Time	MMSUR (Multiple Machines Setup Reduction
Waiting / Delay Time	Cross-functional Flow Chart
Defects ratio	QIP(Quality Improvement Project)

WIP Inventory Level	CFS (Continuous Flow System)
Productivity Ratio	LEMS (Lean Ergonomic Manufacturing Systems)
Rework Rate	A3 Report
Inventory Level	A3 Report
Manufacturing / Production Cost	DFMA
Nº of Activities	SWAN
Flexibility	Bayesian Belief Networks
Frequency of Movements	Lean ABC-TOC
Delivery Performance	Gap Analysis
Power Consumption	(LCA) Life Cycle Assessment
Scrap Rate	Spiderman
Cost of Consumables	5 Why's
Water Consumption	VSM
Noise Level	JIT
Working Time / Manpower Time	House of Quality
Movement/Walk Time	7 Quality Tools
Downtime / Idle Rate	MDT (Downtime analysis)
Space Usage / Productive Floor	VASA Model
Training Time	Team Improvement
Customer Satisfaction Ratio	KANO
Lateness	ILP Model
Accuracy of stock balance	Standardization
Product Mix	TISM
Product Cost	KANO
Nº of Product Families	Pareto Analysis
Market share	Heijunka
Build-Time / Assembly Time	DOE (Design of Experiment
Value / Non Value Added Ratio	VASA Model
Manufacturing Effectiveness Ratio	Kanban
Value of a product	ILP Model
Inventory reduction perspective of a project	Six Sigma
Perspective sales of the project	Six Sigma
Aesthetics	LPD (Lean Product development)
Customer quality expectation	Shingo Assessment
NPD Success rate	TPM
Estimated Assembly Time	Standardization
Changeover Time	Cyclical schedules
Returns Rate	SIPOC

Nº of Accidents / Injuries	LEMS (Lean Ergonomic Manufacturing Systems)
Performance rate (OEE)	Plug & Lean CiMo Framework
Turnover / Revenue	DFMA
Machine Utilization Rate	TISM
Nº of new products	BSC
System efficacy %	SBCE (Set based concurrent engineering)
Sales Volume	Hoshin Karin
Product Size / Weight	SBCE (Set based concurrent engineering)
OEE	MDT (Downtime analysis)
Availability	VA/NVA Analysis
Uptime Rate	Automation

Source: Author based