WIND POWER SUPPLY CHAIN: RELEVANT ASPECTS RELATED TO MANUFACTURING AND QUALITY MANAGEMENT

Jordi Castelló i Dalmau

Universitat de Girona

Doctoral Thesis

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Relevant aspects related to Manufacturing and Quality Management

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CERFITY

*That **Jordi Castelló i Dalmau** carried out the dissertation entitled "Wind Power Supply Chain: relevant aspects related to Manufacturing and Quality Management" under my supervision and that it fulfils the requirements for the degree of Doctor (University of Girona)*

I hereby sign this certificate:

PhD Rodolfo de Castro i Vila

Director

Als meus pares el Pere i la Mª Carme, gràcies pel sacrifici fet durant tots aquests anys. Sense vosaltres, aquest treball no hauria estat possible.

"Si he vist més enllà és perquè estava damunt les espatlles de gegants"

Isaac Newton

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".. *em sembla que he estat només com un nen que juga a la vora del mar, i que es diverteix buscant de tant en tant una pedra més polida i una conquilla més bonica del normal, mentre que el gran oceà de la veritat s'exposava davant meu completament desconegut.*"

Isaac Newton

A thesis by publications

This is a thesis by publications. The papers included in this thesis have been either published in international journals or are under review.

Additionally the information from the papers have been presented in international conferences and incorporated in research books.

International Journals (Published)

- **Castello, J., De Castro, R. and Gimenez, G. (2016).** *"ISO 9001 Aspects Related to Performance and Their Level of Implementation"*. Journal of Industrial Engineering and Management JIEM, 2016 - 9 (5): 1090-1106 - Online ISSN: 2013-0953. **Q2 (138/423), SJR (0,247, year 2016).** DOI: 10.3926/jiem.2072

- **Castello, J., De Castro, R. and Llach, J. (2016).** *"Evidence for quality management systems being instrumental in improving supplier performance: the case of the wind power sector"*. International Journal Productivity and Quality Management Vol. 22, Nº4; 2017. **Q2 (90/291), SJR (0,380, year 2016).** DOI pendent.

International Journals (On going)

- **Castello, J., De Castro, R., and Marimon, F. (2017).** *"Use of quality tools and techniques and their integration in to ISO 9001 (A wind power supply Chain case)"*. Business Process Management Journal (Under peer reviewers).

- **Castello, J., De Castro, R., and Vall-llosera, L. (2017).** *"Lean manufacturing and their impact in the "competitive priorities": A wind power supply chain study"*. International Journal of Production Research. (Under peer reviewers).

Research books:

- **Castello, J., De Castro, R., and Bikfalvi, A. (2016). "**Supply Chain Strategies and the Engineer to Order Approach (IGI Global) ISBN 9781522500216. Chapter

10. *"Hybrid Supply Chain Strategies in Wind Business"*. **Q2 (116/258).** DOI: 10.4018/978-1-5225-0021-6.ch010

International Conferences:

- **Castello, J., De Castro, R. (2014)**. 8th International Conference on Industrial Engineering and Industrial Management XX International Conference on Industrial Engineering and Operations Management International IIE Conference 2014 Malaga, Spain. July 23-25, 2014 *"Supply Chain Sourcing Strategies in Wind Business".*
- **Castello, J., De Castro, R. and Gimenez, G. (2016).** Congress International Joint Conference - CIO-ICIEOM-IIE-AIM (IJC 2016) San Sebastian, Spain, July 13-15, 2016" *"ISO 9001 aspects related to performance and their level of implementation".*
- **Castello, J., De Castro, R., and Marimon, F. (2016).** "2nd International Conference on Quality Engineering and Management (ICQEM), Guimarães, Portugal, 2016 *"Assessing Quality Tools Use in the Wind Power Sector".*

List abbreviations

AC: Alternating Current

APQP: Advanced Quality Plan

AQP: Advanced Quality Plan

AS 9000: Aerospace Basic Quality System Standard

ATO: Assembly To Order

AVE: Average Variance Extracted

A3: Problem solving format (Toyota)

BPM: Business Process Management

BTM (consulting): Wind Energy magazine

CAPEX: Capital expenditure

CFA: Confirmatory Factor Analysis

CFI: Comparative Fit Index

COPQ: Cost of Poor Quality

DC: Direct Current

DMAIC: Define – Measure – Analyse – Improvement – Control

DOE: Design of Experiments

EDF: Electric Company (France)

EDP: Electric Company (Portugal)

EFA: Exploratory Factor Analysis

EFQM: European Foundation for Quality Management

EON: Electric Company (Germany)

ETO: Engineer To Order

EWEA: European Wind Energy Association

FDA: Food & Drug Administration

FMEA (AMFE): Failure Mode and Effects Analysis

Formel Q: Quality Capability Suppliers Assessment Guidelines. (Requirements for the Companies of the VOLKSWAGEN GROUP, to Assure the Quality of Processes and also the Components in the Procurement and Supply Chain.)

GAS: Global Audit Score

GHG: Greenhouse gas

GLP: Good Laboratory Practice regulations

GMP: Good Manufacturing Practice

HAW: Horizontal- axis wind turbine

HRM: Human Resources

IATF: International Automotive Task Force

IEC 61400- 22: International Electrotechnical Commission Wind turbines - Part 22: Conformity testing and certification

IPP: Independent Power Producers

ISO: International Organization for Standardization

ISO 9000: Quality management systems - Fundamentals and vocabulary

ISO 9001: Quality management systems - Requirements

ISO/TS16949: Quality management systems - Particular requirements for the application of ISO 9001:2000 for automotive production and relevant service part organizations

IT: Information technologies

JIT: Just in Time

KMO: Kaiser- Meyer- Olkin (index)

Kw: Kilowatts

LM: Lean Manufacturing

MAKE (consulting): Wind Energy magazine

MBNQA: Malcom Baldrige National Quality Award

MI: Modification Index

MPS: Master Plan Scheduling

MTS: Make To Stock

MTO: Make To Order

MW: Megawatts

MWh: Megawatt hours

ODP: Order Decoupling Point

OEM: Original Equipment Manufacturer

PAC: Principal Component Analysis

PC: Expected Parameters Change

PDCA: Plan Do Check Action

PPAP: Production Part Approval Process

PS 9000: Pharmaceutical Quality Group

QFD: Quality Function Deployment

QM: Quality Management

QMS: Quality Management System

QS 9000: A company level certification based on quality system requirements related specifically to the automotive industry. (These standards were developed by the larger automotive companies including Ford, General Motors and DaimlerChrysler).

QT&T: Quality Tools and Techniques

RBV: Resource Based View

R&D: Research and Development

RQ: Research Question

Run & Rate: The purpose of a Run & Rate is to verify: the supplier's actual manufacturing process is capable of producing components that meet GM's on-going quality requirements, as stated in the Production Part Approval Process (PPAP), at quoted tooling capacity for a specified period of time.

RMS: Root Mean Residual

RMSEA: Root Mean Square Error of Approximation

SC: Supply Chain

SCM: Supply Chain Management

SME: Small and Medium Enterprises

SMED: Single-Minute Exchange of Die

SOP: Start of Production

SPA: Second-party Audit

SPC: Statistical Process Control

SPSS: Statistical Package for the Social Sciences (software)

SQA: Supplier Quality Assurance

SQAE: Supplier Quality Assurance Engineer

STO: Source To Order

TE 9000: Quality System Requirements Tooling & Equipment, (referred to as TE supplement, was developed by Chrysler, Ford General Motors)

TL 9000: Quality Management System for the Telecommunication industry

TLI: Turkey and Lewis Index

TPA: Third-party Audit

TPM: Total Productive Maintenance

TQM: Total Quality Management

TS 16949: Quality management systems - Particular requirements for the application of ISO 9001:2000 for automotive production and relevant service part organizations

VDA: German Association of the Automotive Industry

VSM: Value Stream Map

WB: Wind Business

WF: Wind Farm

WP: Wind Power

WPP: Wind Power Plants

WPSC: Wind Power Supply Chain

WT: Wind Turbine

WTM: Wind Turbine Manufacturer

2DP: Two Days Production

8D: The Eight Disciplines of problem solving (methodology)

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Resum

El concepte de la gestió de la cadena de subministrament (SCM) ha anat guanyant importància en els darrers anys, donat que actualment ja no són les empreses les que competeixen entre elles, sinó que són les cadenes de subministrament les que competeixen entre si.

El principal objectiu d'aquesta tesi, realitzada sota la modalitat de tesi doctoral per articles, és analitzar per mitjà de dades reals (dades de camp) i empíriques, alguns aspectes rellevants, relacionats amb la fabricació i la gestió de la qualitat, en la cadena de subministrament del sector eòlic.

Els resultats d'aquest estudi mostren que la cadena de subministrament del sector eòlic, és una cadena "híbrida", on coexisteixen diferents paradigmes de fabricació (lean, agile, leagile i la gestió per projectes); amb diferents punts de penetració de comanda. Alhora en aquesta tesi, s´analitza el paradigma "lean manufacturing" des de la perspectiva del sector eòlic i ens posa de manifest les dificultats que troben els proveïdors i tecnòlegs del sector a l´hora d'implementar aquest paradigma.

També en els resultats d´aquesta tesi es demostra que el popular estàndard de gestió de la qualitat ISO 9001, vàlid per a la majoria de sectors, és un estàndard insuficient quan es tracta d'implementar la gestió de la qualitat en sectors amb una alta complexitat tecnològica. Finalment també aquest treball demostra l'elevat ús de les eines i tècniques de qualitat en el sector eòlic, comparat amb altres sectors industrials.

Finalment podem afirmar que aquesta tesi, constitueix un punt de partida per l'anàlisi de cadenes de subministrament en sectors d´alta tecnologia, on la demanda és incerta, amb baixos volums de fabricació i un alt grau de personalització en el "mix" de productes.

Summary

In recent years, supply chain management (SCM) has become of great importance as nowadays not only are businesses competing with each other, but so too are suppliers.

The main objective of this thesis is to analyse some of the relevant aspects of SCM found in the manufacturing processes and quality control methods of the supply chain in the wind power sector. This is done through a collection of articles which present and analyse real data collected in the field as well as empirical data.

The subsequent results reveal that supply chains in the wind power sector are hybrids, where various manufacturing paradigms are in play (lean, agile, leagile and project management) at specific points of the purchasing and manufacturing process.

This thesis analyses the lean manufacturing concept inside the wind power sector, revealing the extent to which the lean tools and techniques are applied and the impact they subsequently have on competing priorities. It also examines the difficulties encountered by service providers when attempting to implement lean concepts as well as those resulting from the complex technology required by this highly specialised sector.

The thesis also highlights the fact that the widely-used ISO 9001 standard, valid in so many industrial sectors, falls short in sectors dealing with high technological complexity. Furthermore, it sheds light on the perception clients have concerning third-party audits. Lastly, the thesis demonstrates the wind sector's extensive use of quality tools and techniques when compared to other industrial sectors.

This thesis provides the starting point for analysing aspects related to manufacturing and quality management systems in the supply chains of sectors handling high technological complexity, where there is low volume manufacture, high levels of customised and mixed products and irregular demand.

Resumen

El concepto de la gestión de la cadena de suministro (SCM), ha ido ganando protagonismo en las últimas décadas; de la forma que ya no son las empresas las que compiten entre sí, sino que son las propias cadenas de suministro las que compiten entre sí.

El principal objetivo de esta tesis, realizada bajo la modalidad de tesis doctoral por artículos, es analizar con datos reales (obtenidos en campo) y empíricos, algunos aspectos relevantes relacionados con la fabricación y la gestión de la calidad en la cadena de suministro del sector eólico.

Los resultados obtenidos en el estudio, revelan que la cadena de suministro del sector eólico, es una cadena de suministro “hibrida”, donde coexisten distintos paradigmas de fabricación (lean, agile, leagile y la gestión por proyectos) con distintos puntos de penetración de pedido.

Igualmente en esta tesis se analiza el paradigma “lean manufacturing” desde la perspectiva del sector eólico, y pone de manifiesto la intensidad del uso de las herramientas y técnicas “lean” en el sector y su impacto en las prioridades competitivas. Así como dificultades que encuentran los proveedores y tecnólogos del sector, cuando tratan de implementar el mismo.

Además, en esta tesis también se pone en evidencia, que el popular estándar de gestión de calidad ISO 9001, valido y suficiente para muchos sectores; es un estándar insuficiente cuando se trata de abordar sectores con alta complejidad tecnológica. De la misma forma, esta tesis pone de manifiesto la percepción que tienen los clientes sobre las auditorias de certificación por terceras partes.

Finalmente, en esta tesis también se pone en evidencia el alto uso de las herramientas y técnicas de calidad del sector con respecto a otros sectores.

Esta tesis constituye el punto de partida para el análisis de aspectos relacionados con la fabricación y la gestión de la calidad en cadenas de suministro en sectores de alta complejidad tecnología, donde la demanda es incierta, y los volúmenes de fabricación son bajos y existe un alto grado de customización en el “mix” de los productos.

Part I

Wind Power Supply Chain Introduction

Motivation and Research Objectives

Chapter №1

Wind Power Introduction and Research Objectives

1. Wind Power introduction and research objectives

1.1. Introduction

The wind energy is a relatively new industry; its premises date back from the 1970's in Western Europe. On average, the global wind energy market has grown over 25% annually over the last ten years. Despite this relative infancy, it has experienced a steady annual growth rate of 25% globally between 2007 and 2012 (BTM consultant 2013). Nowadays, wind energy represents a major trend as countries are trying to establish renewable energy technologies and diversify their energy mix.

The Kyoto protocol in 1997 which made the reduction of greenhouse gases a legal obligation for the signatories was a first event signalling countries to take initiative and search for alternative energy sources in order to decrease their dependence on traditional sources, mainly fossil fuels.

In order to reach Kyoto's objectives, governments of the countries responsible for the higher rates of greenhouse gas (GHG) emissions have launched incentives such as tax reductions to foster investments in wind energy. Indeed, investments required for the installation of wind farms are massive: the cost of an onshore 2MW turbine is estimated to be 1.3 - 1.5 Million euros per MW. Besides the determination of governments to rely less on fossil fuels for sustainability considerations, a reason why wind energy future's bright is because the input of wind energy (wind) is free and unlimited, as long as wind farms are located strategically on strong wind regions.

Wind energy offers significant potential for near-term (2020) and long-term (2050) greenhouse gas (GHG) emissions reductions. A number of different wind energy technologies are available across a range of applications, but the primary use of wind energy of relevance to climate change mitigation is to generate electricity from larger, grid-connected wind turbines, deployed either onshore or offshore.

Wind energy is a mature renewable energy source that has been successfully deployed in many countries. It is technically and economically capable of significant continued expansion, and its further exploitation may be a crucial aspect of global GHG reduction strategies. Though average wind speeds vary considerably by location, the world's technical potential for wind energy exceeds global electricity production, and ample technical potential exists in most regions of the world to enable significant wind energy deployment.

Wind energy relies, indirectly, on the energy of the sun. A small proportion of the solar radiation received by the Earth is converted into kinetic energy (Hubbert, 1971), the main cause of which is the imbalance between the net outgoing radiation at high latitudes and the net incoming radiation at low latitudes. The Earth's rotation, geographic features and temperature gradients affect the location and nature of the resulting winds (Burton et al., 2001).

The use of wind energy requires that the kinetic energy of moving air be converted to useful energy. As a result, the economics of using wind for electricity supply are highly sensitive to local wind conditions and the ability of wind turbines to reliably extract energy over a wide range of typical wind speeds.

Wind energy has been used for millennia (for historical overviews, see, e.g., Ackermann and Soder, 2002; Pasqualetti et al., 2004; Musgrove, 2010). Sailing vessels relied on the wind from before 3,000 BC, with mechanical applications of wind energy in grinding grain, pumping water and powering factory machinery following, first with vertical axis devices and subsequently with horizontal axis turbines. By 200 BC, for example, simple windmills in China were pumping water, while vertical axis windmills were grinding grain in Persia and the Middle East. By the 11th century, windmills were used in food production in the Middle East; returning merchants and crusaders carried this idea back to Europe.
The Dutch and others refined the windmill and adapted it further for industrial applications such as sawing wood, making paper and draining lakes and marshes. When settlers took this technology to the New World in the late 19th century, they began using windmills to pump water for farms and ranches. Industrialization and rural electrification, first in Europe and later in the USA, led to a gradual decline in the use of windmills for mechanical applications.

The first successful experiments with the use of wind to generate electricity are often credited to James Blyth (1887), Charles Brush (1887), and Poul la Cour (1891). The use of wind electricity in rural areas and, experimentally, in larger-scale applications, continued throughout the mid-1900s.

However, the use of wind to generate electricity at a commercial scale became viable only in the 1970s as a result of technical advances and government support, first in Denmark at a relatively small scale, then at a much larger scale in California (1980s), and then in Denmark, Germany and Spain (1990s).

The primary use of wind energy of relevance to climate change mitigation is to generate electricity from larger, grid-connected wind turbines, deployed either in a great number of smaller wind power plants or a smaller number of much larger plants. As of 2010, such turbines often stand on tubular towers exceeding 80 m in height, with three-bladed rotors that often exceed 80 m in diameter; commercial machines with rotor diameters and tower heights in excess of 125 m are operating, and even larger machines are under development.

Wind “Power Plants” are commonly sited on land “onshore”. By the end of 2009, wind power plants sited in sea or freshwater were a relatively small proportion of global wind power installations. Nonetheless, as wind energy deployment expands and as the technology advances, offshore wind energy is expected to become a more significant source of overall wind energy supply.

Today, the lessons learned from more than a decade of operating wind power plants, along with continuing R&D, have made wind-generated electricity very close in cost to the power from conventional utility generation in some locations. Wind energy is the world's fastest-growing energy source and will power industry, businesses and homes with clean, renewable electricity for many years to come.

1.2. How wind turbines work

Wind turbines produce electricity by using the natural power of the wind to drive a generator. The wind is a clean and sustainable fuel source, it does not create emissions and it will never run out as it is constantly replenished by energy from the sun. Wind turbines generate electrical power in the same way as all other generation technologies. The only difference is in the source of the mechanical power supplied to the electrical generator: wind, rather than a diesel engine or steam turbine, provides the energy.

Blades capture energy in the wind and turn the turbines. Control mechanisms point the blades into the wind (yaw control) and, on large wind turbines, adjust the pitch of the blades (blade angle) as wind speeds change. Typically, a gearbox connects the shaft from the blades (rotor) to the electrical generator.

The electrical generators used on wind turbines may either be induction generators or synchronous generators. The electrical power from the generator is typical 60 Hz, AC power with 600V output for large wind turbines. A transformer may be required to increase or decrease the voltage so it is compatible with the end-use, distribution or transmission voltage, depending on the type of interconnection.

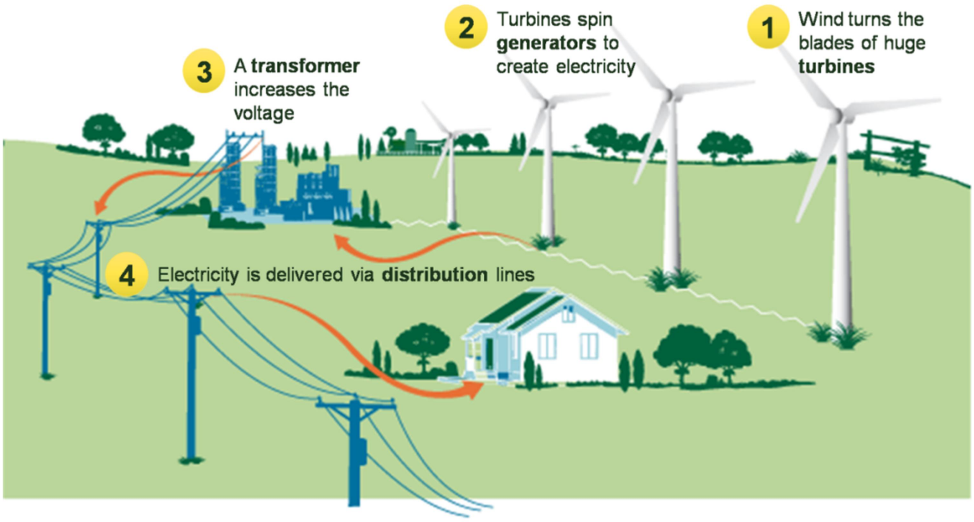

Figure 1.2-1 How Wind Turbines work

The amount of power produced by a wind turbine depends on three variables:

- The density of the air surrounding the turbine (in kilograms per unit volume of air), which tends to decrease a little bit with elevation and as the air gets colder.

- The area covered by the turbine blades, in square meters. If you think of drawing a circle around the tips of the turbine blades, this would approximately give you the area over which the turbine is capturing the energy in the wind.

- The velocity of the wind, in meters per second. This changes with time (windy versus non-windy periods) and with elevation. Generally, the wind blows more strongly the higher you get off the ground. This is why wind turbines are so tall. Typically, 80 to 100 meters is the norm, though advances in tower materials and construction could enable taller turbines.

All of this can be summed up in the **wind power equation**:

$$\text{Wind Power (WP)} = \frac{1}{2} \cdot \rho \cdot \text{Cp} \cdot \text{A} \cdot \text{v}^3$$

$Air\ density\ (\rho) = \left[\frac{kg}{m^3}\right]$
$Frontal\ Area\ (A) = m^2$
$Velocity\ of\ the\ wind\ (v) = \frac{m}{s}$

The maximum theoretical coefficient of performance or Betz limit is defined as 16/27 or 0.59 although in practice this would not be achievable and a lower value should be used. The coefficient of performance will typically vary with wind speed. An efficient horizontal axis wind turbine might achieve a value of 0.35

Energy produced by wind turbines

The nameplate rating of a wind turbine should indicate the capacity or maximum power output of the turbine in kilowatts (kW). This usually occurs at very high wind speeds and is not representative of the average power production over time. Energy production is commonly estimated as the annual average energy or the amount of energy produced over the course of one year. The power produced by a wind turbine at any moment is related to the wind speed at that moment. A power curve for a wind turbine indicates the power produced across the entire operating range of the wind turbine.

Most wind turbines start generating electricity at wind speeds of around 3-4 meters per second (m/s), (8 miles per hour); generate maximum 'rated' power at around 15 m/s (30mph); and shut down to prevent storm damage at 25 m/s or above (50mph) (Figure 1.2-1).

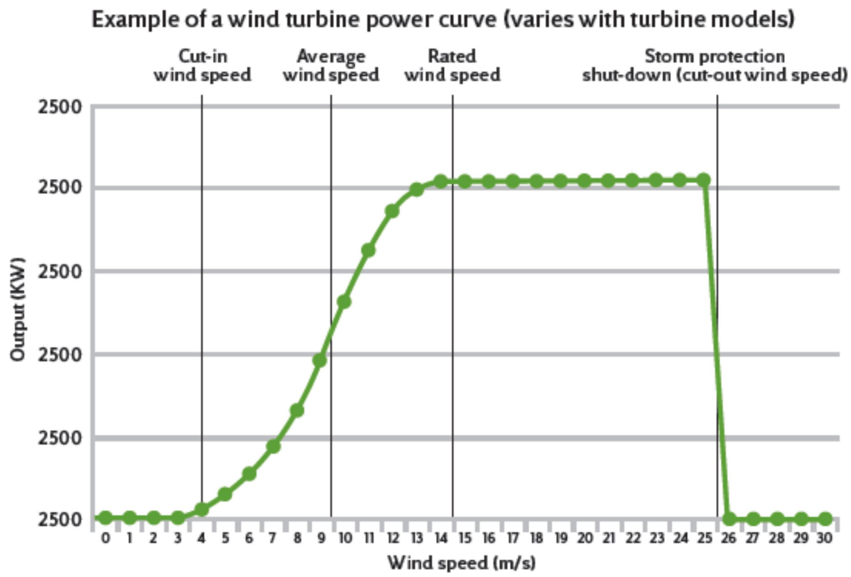

Figure 1.2-2 Example of a wind turbine power curve

Energy production is estimated from the wind turbine power curve together with an estimation of the amount of time in a year that the wind will be blowing at each specified speed. The wind speed distribution is a function of location. Good wind sites have high and steady wind speed while others have low average wind speed with considerable variability over the course of a day, month and year. The capacity factor (CF) is a single number that is used to estimate annual average energy production from a wind turbine as a percentage of its maximum capacity.

$$\text{Capacity Factor (CF)} = \frac{\text{Annual Energy Production (kWh)}}{\text{WT name plate capacity (kW)} \cdot 8760 \text{ hours}} \cdot 100\%$$

Large turbines located at good wind sites can achieve capacity factors of 40% or more. Small wind turbines located at poor sites can have capacity factors of 20% or less.

The rated power is a property of the wind turbine, while the capacity factor is a property of the location of the wind turbine (a measure of the available wind energy at this location).

1.3. Wind power basics: components and description

The Wind is the fuel for the wind power station. Small changes in wind seep produce greater changes in the commercial value of wind farm.

Wind power technologies transform the kinetic energy of the wind into useful mechanical power. The kinetic energy of the air flow provides the motive force that turns the wind turbine blades that, via a drive shaft, provide the mechanical energy to power the generator in the wind turbine.

The modern era of wind power began in 1979 with the mass production of wind turbines by Danish manufacturers as Nec Micon, Vestas, Nordex and Bonus. These early wind turbines typically had small capacities (10 kW to 30 kW) by today's standards, but pioneered the development of the modern wind power industry that we see today.

The current average size of grid-connected wind turbines is around 3 MW (BTM Consult; 2011), while most new projects use wind turbines between 5 MW and 7 MW.

Many different design concepts of the horizontal-axis wind turbine are in use. The most common is a three bladed, stall- or pitch-regulated, horizontal axis machine operating at near-fixed rotational speed. However, other concepts for generation are available, notably gearless "direct drive" turbines with variable speed generator designs have a significant market share.

Wind turbines consist of three principal components (Wilburn; 2011), (1) the nacelle, (2) rotor, (3) and tower.

The **nacelle** contains much of the equipment required for energy conversion and generation and typically accounts for 25 to 40 percent of the weight of the wind turbine (Ancona, McVeigh; 2001). The nacelle case contains the drivetrain components (bearings, coupling, gears, generator, and shafts) and the analytical and auxiliary equipment (anemometer, brakes, controller, and converter, cooling system, sensors, and yaw drive system). Materials used for these components consist primarily of aluminium, cast iron, copper, plastic, stainless steel, and steel alloys.

The **rotor** typically makes up 10 to 14 percent of the weight of the wind turbine (Ancona, McVeigh; 2001). The rotor of a wind turbine consists of four principal components—the blades, the blade extender, the hub, and the pitch drive system. Rotor blades are constructed primarily of fiberglass-reinforced plastic mixed with epoxy adhesive and lightweight core materials, such as balsa wood or polymer foam. A steel blade extender is used to provide additional blade support and to attach the blade to the hub. The hub, constructed primarily of cast iron, serves as a base for the rotor blades and extenders and as a housing for pitch control systems. The pitch drive, constructed primarily of stainless and alloy steels, controls blade angle for optimum energy recovery and enables adjustment for wind speed and other weather conditions that may affect wind turbine operation.

The **tower** provides the support system for the turbine blades and the nacelle and serves as the conduit for electrical and electronic transmission and grounding. The most widely used tower configuration in the United States comprises steel sections with a concrete foundation custom designed for local site conditions. A tower, including the concrete base, typically accounts for 30 to 65 percent of the total weight of the wind turbine. Tower height is selected to optimize wind energy capture.

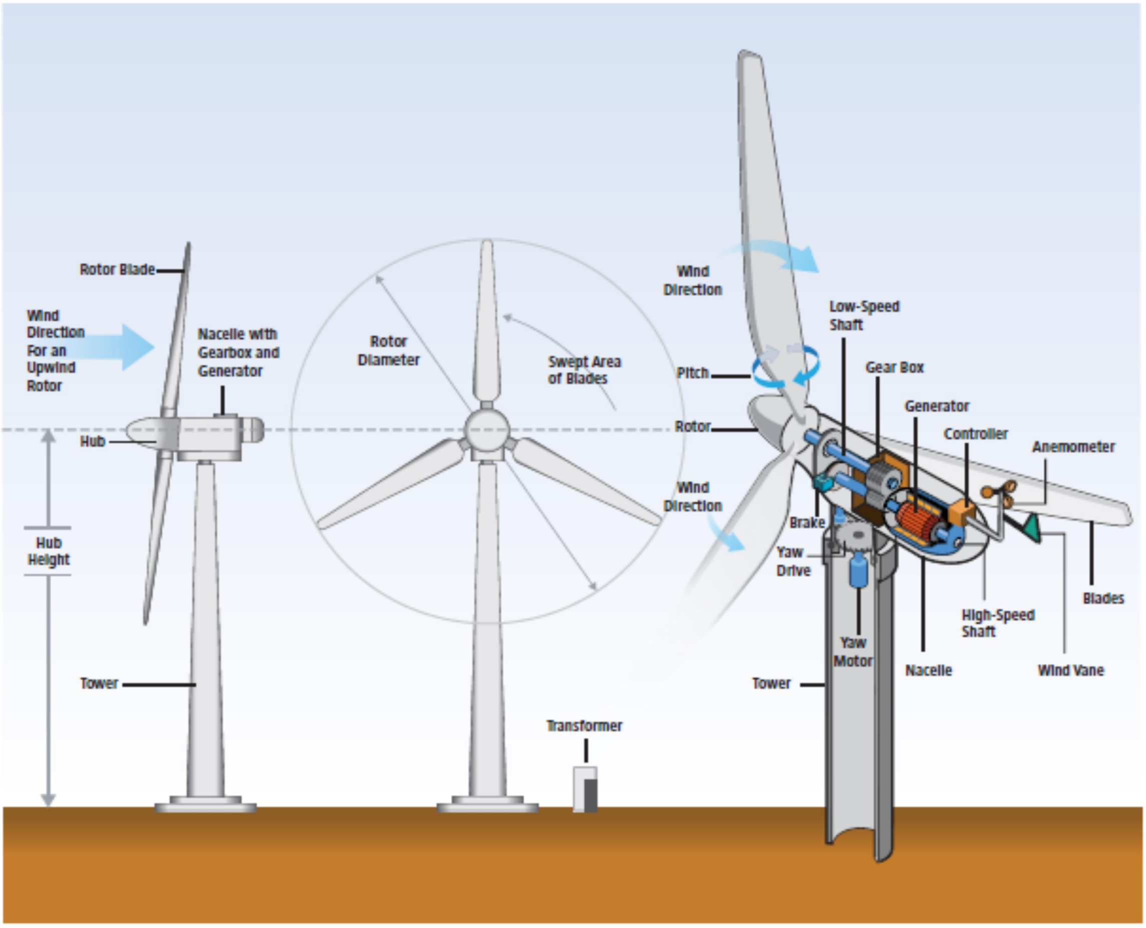

Figure 1.3-1 Wind Turbine layout (Source NREL)

A typical wind turbine will contain up to 8.000 different components (Aubrey, 2007). The cost of the turbine itself accounts for 76% of the total capital cost of a wind energy project (EWEA; 2009).

A typical wind turbine is reported to contain 89.1 percent steel, 5.8 percent fiberglass, 1.6 percent copper, 1.3 percent concrete (primarily cement, water, aggregates, and steel reinforcement), 1.1 percent adhesives, 0.8 percent aluminium, and 0.4 percent core materials (primarily foam, plastic, and wood) by weight (Wilburn et al., 2011).

1.4. Principal parts and major components of wind turbines (Wilburn et al., 2011)

1.4.1. Nacelle

Cover: Encloses mechanical components of the wind turbine. Primary materials are fiberglass and steel-reinforced the plastic.

Frame: Inner casing of the nacelle. Primarily, materials are cast iron and steel.

Anemometer: Meteorological instrumentation to provide wind velocity data to yaw controls.

Brakes: Mechanical brakes are used as auxiliary devices to stop machinery during maintenance and inclement weather. Prevent undesired rotation or turbine fatigue.

Controller: Electronic and fiber optic monitoring equipment that report performance to the central controller.

Converter: Converts direct current (DC) electricity from the generator to alternating current (AC) to achieve compatibility with the electrical grid.

Cooling system: Axial fans convectively cool machinery and exhaust waste heat from nacelle.

Sensors: Instrumentation relays information to controllers, which automatically adjust components to address changing conditions.

Yaw drive: Turns the turbine into the wind to generate maximum power. Typically four drives are used.

Shafts: Low- and high-speed shafts are the mechanisms for conversion from low-speed rotation of the rotor (kinetic energy) to high-speed rotation of the gearbox (electrical energy).

Bearings: Bearings are required for the shafts, gearbox, yaw mechanism, generator, and other rotating parts. The nacelle and tower are connected by a contact ball bearing, allowing the nacelle to rotate.

Couplings: The flexible coupling is attached to the high-speed shaft to dampen out oscillating loads introduced by the gearbox, improving electricity quality produced by the generator.

Gear Boxes: A gearbox is used to convert low-speed rotation of the input shaft from the rotor to high-speed rotation. The high speed is necessary to drive the generator.

Generator: Generator produces electrical energy by spinning the rotor around a magnetic stator using electromagnetism to produce AC electricity. Alternatively, permanent magnet materials may be used to generate electricity.

1.4.2. Rotor

Blade: Rotor blades convert wind energy to mechanical energy. Blades are manufactured in specially designed molds from composite materials, usually a combination of glass fiber and epoxy resin. Options include polyester instead of epoxy and the addition of carbon fiber to add strength and stiffness.

Blade extender: Steel components that support blades and secure them to the hub. Typically is more than 1 metric ton in weight.

Hub: Hub serves as a base for rotor blades and blade extenders, and as a housing for pitch control systems. Attaches to the shaft, by means of a shaft bearing assembly. Material is typically cast iron.

Pitch drive: Controls blade angle to achieve optimum angle for wind speed and desired rotation speed. Typically three motors, one for each blade.

1.4.3. Tower

Tower: Primarily made of steel (or concrete), built in sections because of size. Oversize-load issues often constrain transportation to the site.

Tower flange: Ductile iron fittings that join tower segments.

Power electronics: Transformer and other DC to AC power-conversion apparatus, except for electronic circuitry.

Screws: Hold the main components in place, must be designed for extreme loads.

Cables: Link individual's turbines in a wind farm to an electricity sub-station.

1.5. Wind Power Supply Chain

The wind power (WP) energy sector encompasses developers, manufacturers and operators. Wind turbine manufactures (WTMs) generally embrace a range of activities including development, design, production, wind farm construction and erection, operation and maintenance, technical service and, finally, distribution.

The wind power supply chain (WPSC) - Figure 1 - is basically composed of five entities: second-tier suppliers (raw material component suppliers), first-tier suppliers (component and subassembly suppliers), OEMs (WTMs, assembly plant manufacturers, wind farm construction (including civil works), installation and commissioning and technical assistance), and utility companies (who are generally responsible for the operation and maintenance of WF). Note too that utility companies might also be involved in wind energy generation, transmission and distribution.

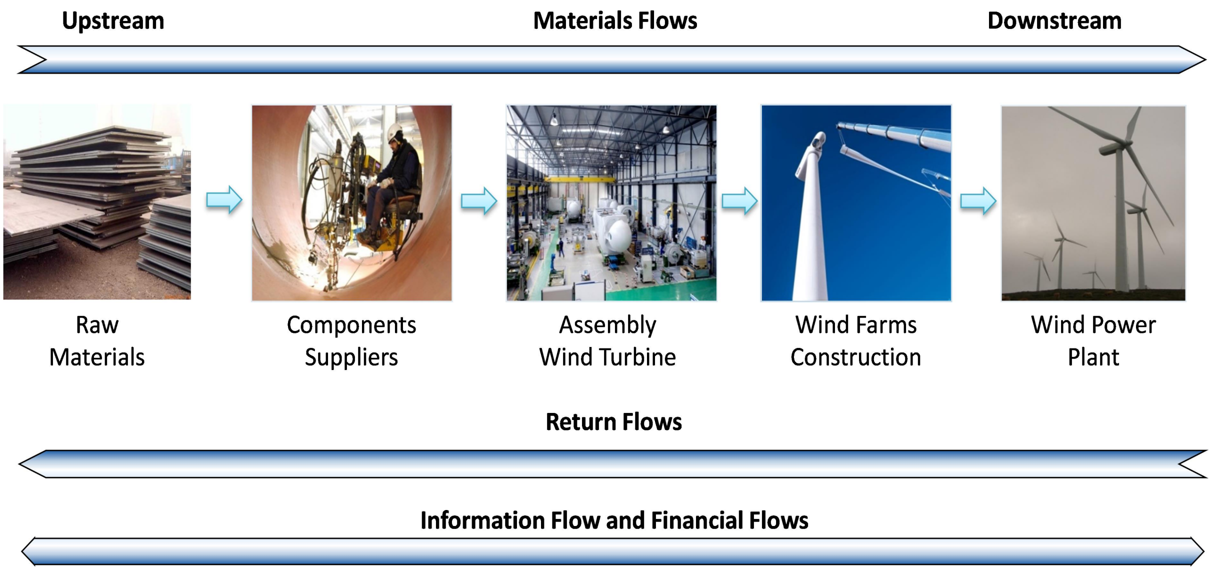

Figure 1.5-1 Wind Power Supply Chain (Source author)

In the following paragraphs, we briefly describe the main activities of the supply chain (SC) described in Figure 1.

- **Raw materials**

Raw material suppliers provide the basic materials such as steel, forges, castings, fibres, composites, etc., to the supplier's plants.

- **Components suppliers**

Component supply is a strategic key point in the SC sector since many of the components are developed in partnership with the suppliers (Aubrey, 2007; BTM Consult, 2011; MAKE Consulting, 2013), because the technology of both product and process, for example gearboxes, converters, generators, castings, welding etc., in most cases belongs to the suppliers.

- **Assembly Wind Turbines**

Assembly plants (wind turbine assembly plants) are responsible for assembling the different components that come into the plant following the master scheduling plan (MPS) and leaving the turbine (WT) ready for dispatch.

- **Wind Farms Construction**

Wind farm construction includes civil work, commissioning, erecting and installing the machine in the park (WF) in accordance with the customer's contractual requirements. In this phase of the SC, the customer closely scrutinizes the installation process as it occurs on their premises and under their supervision.

- **Wind Power Plants**

The final step in the SC is the customer, who is usually a utility company responsible for operating and maintaining the wind farms, and distribution the energy generated to the final customer. This, however, can vary depending on the type of customer or contract.

We can characterize WP from the perspective of manufacturing and operating under the following attributes: (1) low volume, (2) high variability, (3) high customization, (4) high-technology, (5) high levels of quality and (6) short WT life cycles.

1.6. Motivation and research objectives

Just as globalization and information technologies (ITs) have changed the paradigms of industry, Supply Chain Management (SCM) has changed the way business is done and understood. For this reason, the main motivation behind this doctoral thesis is to deepen the understanding of a number of aspects related to the supply chain in the wind power sector. Given the scope and complexity of the wind power supply chain, and the limitations in time and space of this doctoral thesis, we concentrate our research on some fundamental aspects of the SC sector: manufacturing and quality management.

Nowadays, there is a lot of academic literature on SCM and its different models and management paradigms, including lean practices and the thinking behind them and, of course, quality management. However, an in-depth literature review has shown us that there are almost no conceptual, theoretical, or empirical cases or studies related to SC management in this sector.

The first aspect we approach is related to the supply chain management model and the different manufacturing, purchasing and procurement strategies derived from it. The second aspect that we analyze is how the lean paradigm fits in the sector. We analyze the intensity of lean practice uses and their impact on competitive priorities. The last, and perhaps the most extensive aspect of our research is related to quality management (QM). As we have access to the data required to do so, we carry out different analyzes in which we closely examine aspects related to ISO 9001 standard implementation and use in the supply chain, as well as the uses of quality tools and techniques in the WP sector.

As a result of the technological complexity of the components and systems (mostly structural) that form part of the wind turbine, they are (in accordance with IEC 61400-22: 2010) subjected to a number of international tests, norms and standards, thus ensuring quality along all the steps of the SC is a strategic element for wind turbine manufacturers (WTMs) because, in accordance with this standard, wind turbines and their manufacturers are subject to audits from third parties throughout the life cycle of the wind turbine. On the other hand, customers demand a 20-year guarantee for the WT from WTMs as well as 97.5% function levels during its life time.

Therefore, in this thesis we plan to fulfil the following objectives:

- Analyze the behaviour of the supply chain of the sector and determine what the optimal functional paradigm is.

- Analyze how intense the use of lean manufacturing practices in the sector is, and determine the impact they have on competitive priorities.

- Study whether the ISO 9001 model is a valid model to ensure the quality of the sector's supply chain, or if the sector requires other more advanced models of quality management.

- Analyze whether ISO 9001 is a valid instrument to ensure quality and improve performance for suppliers.

- Analyze the intensity of the quality tools and techniques used in the supply chain of this sector and the impact they have.

1.7. Introduction to the papers (main objectives and research methods)

In the next section, we will make a brief introduction of the different «papers» that make up this thesis. In the same way, we will make a brief description of the different research methods used, and the main objectives that are derived from each paper, with the aim of giving greater consistency to the reader. At the same time they serve as a guiding thread for linking paper to paper.

“Paper 1” - Hybrid supply chain strategies in wind business

Nowadays, globalization and information technology (ITs) have changed the way business is done in the world today. Likewise, the Supply Chain Management (SCM) paradigm has changed the way companies approach their operations both from inside and outside. In this sense, the main aspect that we address in this paper is to determine which management paradigm the wind power supply chain works under.

Since the launch of their seminal book "The machine that changed the world" (Womack et al., 1990), and their later one "Lean thinking", the authors Womack and Jones (1996) have popularized the concept of lean, which has gone on to become one of the most important manufacturing paradigms in the last decades. According to Christopher (2000), the lean paradigm works well in environments of predictable and stable demand, with high manufacturing volumes and little variability in the mix of demand. Later, in contrast, the concept agile appeared (Nagel and Dove, 1991) to respond to environments where demand is unpredictable and uncertain, where manufacturing volumes are small, and where there is a high variability in the product mix (Christopher and Towill, 2000).

Thus, this paper analyzes what the optimal paradigm for the supply chain of the sector is. The choice of paradigm will have different consequences on companies’ bottom line, and consequently on the purchase and supply strategies that the companies in the sector will adopt to manage their own supply chains. Likewise, this decision has consequences on planning, as we will see in detail in the paper through the concepts of "postponement" and "order decoupling point" (OPD). Both are of vital importance to reduce working in process as well as working capital. On the other hand, the technological complexity of a 1.5 - 3 Mw wind turbine containing about 8000 references (Aubrey, 2007), where «lead time» can vary from several days for a commercial catalogue component or up to 7 months for a component of high technological complexity, means that wind turbine manufacturers have great difficulty in planning their supply chain, since they must keep the minimum inventory in the «pipeline» to ensure that there is no stock break.

In this paper we have proposed the "Action Research" method (Coughlan and Coghlan, 2002), to analyze how different sector players, (Ecotencia, Gamesa, Vestas, Alstom, Siemens, GE, etc.) manage and model their supply chains, with the aim of achieving greater efficiency. During our study, it became evident that given the technological complexity of the sector, the large number of components a wind turbine (WT) has, and the variability of its lead times, the sector supply chain would be best not to work with a single manufacturing paradigm, but rather conform to a "hybrid" management model and combine three paradigms, "lean", "agile" and "project management" as well as two different order decoupling points (ODP).

A first reduced version of this article was presented at:

- 8th International Conference on Industrial Engineering and Industrial Management XX International Conference on Industrial Engineering and Operations Management International IIE Conference 2014 Malaga, Spain. July 23-25, 2014 "Supply Chain Sourcing Strategies in Wind Business".

Later a more extensive version of it was published as a chapter in the book:

- Supply Chain Strategies and the Engineer to Order Approach (IGI Global) de "Hybrid Supply Chain Strategies in Wind Business".

"Paper 2" - Lean manufacturing and its impact on competitive priorities: A wind power supply chain study

Since the appearance of the seminal book "Lean Thinking" (Womack and Jones, 1996), thousands of companies around the world have tried to embrace lean thinking in an effort to reduce costs and increase efficiency and productivity. Even today, the words lean and concept lean continue to be buzzwords in manufacturing.

The goal of lean manufacturing is to reduce the waste in human effort, inventory time to market and manufacturing space to become highly responsive to customer demand while producing world class quality products in the most efficient and economical way. The basis of lean manufacturing is to eliminate waste, because waste uses resources but does not add value to the product (Ohno, 1993; Womack and Jones; 1996). According to Womack and Jones (1996), lean production is lean because it uses less of everything - compared with mass production - "half the human effort" in the factory, "half the manufacturing space", "half the investment in tools", "half the engineering hours to develop a new product" in "half the time".

The philosophy of lean and its thinking have been described in the academic literature on different levels of abstraction. Petterson (2009) identified four alternatives for lean approaches:

- operational philosophy - Leanness (Krafcik; 1988)
- strategic philosophy - Lean thinking (Womack and Jones, 1996; Liker, 2004)
- operational practice - Tool box lean (Shah and Ward, 2007)
- strategic practice - Becoming lean (Liker, 1998; Karlsson and Ahlstrom; 1996)

These different approaches, coupled with the lack of consensus among academics as to a conclusive definition of lean and the characteristics that this concept has associated to it (Shah and Ward, 2007; Pettersen, 2009), makes it confusing for the many companies and consultants to implement. According to Naylor et al. (1999), Christopher and Towill (2000), and Masson-Jones et al. (2000), lean works well in environments where *(i) demand is stable and predictable, (ii) production volumes are high and (iii) there is little variability in product mix*.

That said, the interest of our article comes from analysing the use of lean practices in environments that are completely the opposite to the ones mentioned above. In fact, we look at environments where *(i) demand is unpredictable and uncertain* because it depends on policy decisions and environmental regulations, *(ii) manufacturing* *volumes are small* due to the high costs of making a wind turbine and (iii) *a big variety in the "mix" of product*, since wind turbines are manufactured to meet the different laws and regulations of each country.

In our analysis, we take data from a survey sent out to different companies and managers belonging to the supply chain of the sector and analyse the intensity of the use of lean practices and their impact on competitive priorities. The research method used to reach our final conclusions is as follows: A descriptive analysis of the data collected shows the intensity of the use of lean practices. Subsequently, the exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) identified and validated the dimensions of lean manufacturing in the sector. Finally, the correlational analysis correlated the previous lean dimensions of our EFA with the competitive priorities.

From our study, we can affirm that there is a moderate use of lean practices in the sector. In addition, the EFA has detected various dimensions of lean manufacturing in the sector. Finally, our analysis matches with other authors in the academic literature, where the daily use of lean practices has an impact on competitive priorities.

A first version of this article was submitted to the:

- International Journal of Production Research. "Lean manufacturing and their impact in the "competitive priorities: A wind power supply chain study".

"Paper 3" - ISO 9001 aspects related to performance and their level of implementation

The search for reliable suppliers with the technological capacity needed is one of the main challenges faced by wind turbine manufacturers, since approximately 76% of the cost of a wind turbine corresponds to the cost of its components (Wind Directions, 2007), which are mostly manufactured by suppliers. At present, one of the main requirements that buyers have before starting commercial relationships with potential suppliers is that they can provide ISO 9001, or similar, certification.

International quality standards such as ISO 9001 are designed to give customers confidence that organizations (their suppliers) are able to meet customer requirements and specifications. However, since their origin in 1987, these ISO 9001 certifications have not been exempt from controversy and discussion. Some authors assert that this type of certification is merely a way to access some tenders, and that they are not really connected with the product (Curkovic and Pagell, 1999). On the other hand, other authors assert that ISO 9001 improves the performance of companies (Prajogo et al., 2012; Troung et al., 2016).

For this reason, although other work in the academic literature has used surveys it was to study the level that ISO 9001 certification had been implemented in organizations, whereas in our work, we analyse the impact this certification has had using client (second-party) audits. In this way, we our contribution will also add to another discussion in the academic literature; that of the discrepancies between efficiency, third-party audits (TPA) and second-party audits (SPA).

One of the main contributions of our work to other papers referenced in the academic literature, is that our study is based on real data, (i.e. primary data) collected in 90 audits of the main suppliers of components of the SC in the WP sector, most of whom (such as MAKE and BTM) have been referenced in prestigious magazines in the sector. Therefore, this article differs from other studies in the academic literature, where the "data" used for analysis, discussion and final conclusions were based on surveys answered by managers and technicians from the same companies surveyed. This, from the point of view of the thesis authors, allows us to see the reliability of our conclusions.

According to the literature review, authors such as Naveh and Marcus, 2004; Prajogo et al., 2012, etc. have shown different levels of ISO 9001 implementation in different countries and sectors. On the other hand, there is another point of controversy in the academic literature regarding ISO 9001 certification. This is the usefulness of certification audits by third parties (TPA) and how companies perceive them (Kluse, 2013). In our paper, we analyse this controversy from the client’s point of view, using SPA with respect to TPA. For this purpose, field data has been collected from 90 audits carried out on the main suppliers in the sector. To that aim, we have distributed the main ISO 9001: 2008 processes into (P1) management system and responsibility, (P2) resource management, (P3) Product completion, (P4) Measuring analysis and improvement and we have distributed these into 21 points.

To carry out our study, we have used an exploratory factor analysis (EFA) to analyse the different levels of implementation of ISO 9001 certification in the WP sector, and a latter confirmatory factorial analysis (CFA) to validate the data obtained. From the results of our study and through TPA, we have shown that there are different levels of ISO 9001 standards implementation in ISO certified companies. As a result of our work’s conclusions, we can affirm that SPA provides a rewarding added value, both to the quality of the final product as well as to the entire quality management system (QMS). This is because they allow any weaknesses in the QMS to be detected and/or potential areas for improvement that had not been seen previously in the TPA to be identified. Furthermore, any audited suppliers who had relaxed their management in these areas (with the product quality implications that this could have) were also able to be detected. Moreover, in the article a “road map" is proposed to better those suppliers who had been classified as having a lower level of implementation.

Finally, the paper also shows that audits performed by third parties only make it evident that the audited suppliers are simply fulfilling the standard and do not go beyond it, leaving many potential areas for improvement open, all of which can have an impact on final product quality. At the same time, the paper reveals the value and contribution of the audits performed by the SPA clients. Using the same ISO 9001 standard in audits has enabled us to compare the same QMS from different perspectives. A more commercial point of view between certification entities and their customers (in this case, suppliers in the sector) and another operational point of view, which is the final customer auditing their suppliers with the objective of solving their problems of quality day by day.

A first version of this article was presented at the:

- “The International Joint Conference - CIO-ICIEOM-IIE-AIM (IJC 2016) San Sebastian, Spain, July 13-15, 2016”

Afterwards a more extensive version of it was published in the:

- “Journal of Industrial Engineering and Management JIEM, 2016- 9 (5): 1090-1106 - Online ISSN: 2013-0953”

“Paper 4” - Evidence for quality management systems being instrumental in improving supplier performance: the case of the wind power sector

Although the concept of supply chain is implicitly referenced in ISO 9001 as *"supplier-organization-customer"* (ISO 9001: 2008), a careful revision of the standard shows that it is more focused within the organization than beyond its boundaries and the interrelationship between the agents who form part of the supply chain. With this perception in mind, we consider whether the ISO 9001 standard ensures a "positive relationship" between the wind turbine manufacturers (WTMs) and the suppliers that constitute their supply chain.

It is well known that some sectors, such as the automotive industry, OEMs or first tiers suppliers, require their suppliers to hold ISO9001/TS 16949 certification to be able to participate in tenders or projects, and then during the design and development phases of the product and the prototype phases the component manufacturers are subjected to various audits and approvals such as APQP, PPAP, etc., by the customers. Later, during the beginning of the SOP (Start of Production series), they are subjected to constant quality and capacity audits (Run & Rate or 2DP – ‘‘Two Days of Production”) to demonstrate their quality and capacity to comply with the contractual requirements.

In other sectors, such as "oil & gas", a similar thing happens. Component suppliers are also subject to continuous "witness" and "hold point" inspections, to the extent that certain processes and components are inspected by the customer who authorizes them to continue manufacturing once they have audited and inspected certain components. Obviously, all these practices only consume time and resources and make us wonder whether ISO 9001 is an adequate standard to ensure quality in certain sectors. As mentioned above a key element for wind turbine manufacturers (WTMs) is to ensure quality in the SC, as many of the developments of the components and systems that make up the wind turbine are initiated by the same suppliers.

Bearing this controversy in mind, we intend to analyse here whether the ISO 9001 standard provides enough confidence for wind turbine manufacturers to ensure supplied component quality or because of the technological complexity the manufacturers of wind turbines are required to deal with, should they also develop similar processes as the automotive and oil & gas industries have to ensure the quality of components in the SC. To carry out this research we compiled data from customer audits from 90 wind power sector suppliers certified with the ISO 9001 standard.

To start, we have classified the suppliers from the results obtained in the audits according to the ISO 9001 standard, and we have observed that there is a great dispersion among the results obtained. During our study, we detected strong and weak points in the quality management systems as well as potential areas for improvement. On the other hand, we also divided the suppliers into different manufacturing technologies to analyse which types of technologies provide greater reliability in the quality of the components for the SC.

In conclusion, we have seen that there are different levels of standard implementation within the sector, and we even observed that in some of them they do not meet the minimum ISO standard requirements. In the same study, we have also analysed the impact the standard has had by grouping the suppliers into different technologies. In doing so, we observed different levels of implementation of the standard, depending on the purpose of the technological complexity. Therefore, we affirm that our study also validates the conclusions of authors like Curkovic and Pagell (1999), Romano (2002), etc., who conclude that ISO certification does not assure quality in the supply chain and that it only assures us that the standard is implemented (Sroufe and Curkovic, 2008).

In this way, we can affirm that the standard according to ISO 9001 is a generalist model and does not assure the quality required in complex and high technology sectors. We can therefore conclude that the WP sector should adopt more advanced models of quality management las other sectors such as the automotive industry's ISO / TS, the AS 9000 for the space sector, or TL 9000 for the telecommunications sector etc.

The results of this work were published as:

- "Evidence for quality management systems being instrumental in improving supplier performance: the case of the wind power sector". International Journal Productivity and Quality Management Vol. 22, Nº4; 2017

"Paper 5" – The use of quality tools and techniques and their integration into ISO 9001: A wind power supply chain case

In the past decades, through the influence of the leaders of the quality movement the use of the following quality tools and techniques in organizations has increased: Deming's 14 points and improvement cycle (PDCA), Shewhart´s statistical process control (SPC), Juran's quality trilogy (quality planning, control and improvement), Crosby's prevention defects, zero defects and cost of quality, Garvin's quality dimensions, Ishikawa's root cause and effect diagram, and Feigenbaum's three steps to quality (quality leadership, modern quality technology and organizational commitment.).

Quality tools and techniques are usually used in the development of new products (QFD's, AMFE's, Benchmarking, AQP, etc.) during the control of manufacturing processes (control charts, data collection sheets, SPC's, etc.) and in the final inspection (sampling criteria, data records, etc.). They are also used for the analysis and resolution of problems surfacing from customer complaints (A3, 8D's, Problem solving, etc.) and continuous improvement processes (PDCA).

The use of quality tools and techniques has been the subject of different work from different authors in different countries and sectors in the academic literature. After an extensive literary review, we have verified that there are no clear conclusions regarding the use of quality tools and techniques, as the use of these varies from sector to sector and from country to country. Also in our literature review, we have clarified that there is no academic work on the use of quality tools and techniques in the wind power sector. For this reason, we were motivated to analyse the use of quality tools and techniques in this sector.

Nowadays, one of the main challenges faced by wind turbine manufacturers (WTMs) is to achieve an "availability" of wind turbines above 97.5%. This means a constant improvement in the reliability of components and systems that are part of a wind turbine throughout its life cycle, and at all stages of the value chain. This objective starts in the design phases of wind turbines (WT), in the homologation and validation of components phases, in the suppliers' facilities, during their assembly, installation and start-up and finally during the operation phases in the wind power plants (WPP).

Given the technological complexity of the sector with its constant technological challenges and the complexity of the product, it is important to integrate quality from the phases of the beginning of the product design to its operation in the wind power plants (WPP). For this reason, we were motivated to analyse the use of quality tools and techniques in all the phases of the "life cycle" of the product and its entire supply chain.

From the point of view of the author of this thesis, after 30 years of experience in the professional world in different sectors (automotive, oil and gas, wind power) the intensity of the daily use of quality tools and techniques evidences the level of quality culture of an organization versus the analysis and resolution of the daily problems of the organization and its continuous improvement. For this reason, in this article we intend to look deeper into the use of the quality tools and techniques used in the WP sector's supply chain, as well as to analyse the relationship between quality tools and techniques in the ISO 9001 environment. For that purpose, and based on an extensive literary review, we have selected a series of quality tools and techniques to carry out this study.

The data used to carry out this research is based on different surveys made of the different "agents" that make up the SC of the WP sector, from suppliers of raw materials, component suppliers, installation and start-up equipment to the wind turbine manufacturers themselves. Although from the point of view of the authors of the article, it is suitable to use "real data" verified on site, here it has not been possible to do so, therefore data from different surveys has been used.

In our research, we used different research methods. First a "descriptive analysis" of the data shows us the intensity of the use of quality tools and techniques in the sector. Subsequently, the Exploratory Factor Analysis (EFA) and then the Confirmatory Factor Analysis (CFA) grouped and validated the quality tools and techniques analysed.

Finally, we correlated the dimensions obtained in the EFA, with the different ISO 9001 processes, (management and responsibility, resource management, product completion, measurement analysis and improvement) to analyse whether or not the ISO 9001 standard provides a suitable environment for the use of quality tools and techniques.

As conclusions to our research, we have shown that there is a high use of quality tools and techniques in the WP sector unlike other sectors and the findings from previous studies in the academic literature. Also in our study, we have shown that ISO 9001 provides a favourable environment for the use of quality tools and techniques.

A first version of this article was presented at the:

- "2nd International Conference on Quality Engineering and Management (ICQEM), Guimarães, Portugal, 2016 "Assessing Quality Tools Use in the Wind Power Sector"

Afterwards, a more extensive version of it was under review in:

- Business Process Management Journal. "Use of quality tools and techniques and their integration in to ISO 9001 (A wind power supply chain case)".

1.7.1. Scope of the papers

In below figure (1.7-1), we can see the scope of the papers presented in this thesis.

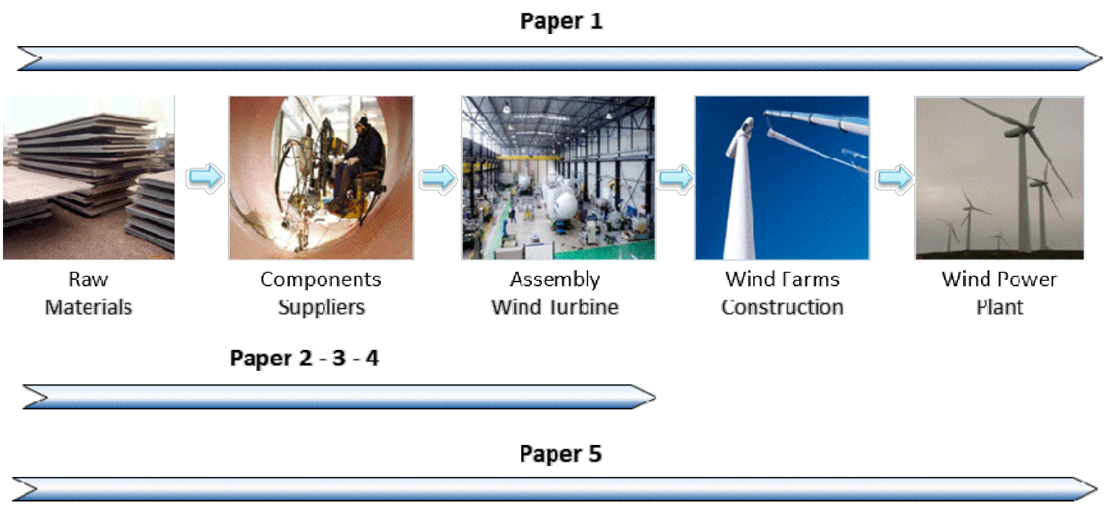

Figure 1.7.1-1 Scope papers

Part II

Wind Power Supply Chain

Aspects related to **Manufacturing**

Chapter №2

Hybrid Supply Chain Strategies in the Wind Business

2. Hybrid Supply Chain Strategies in the Wind Business

Abstract

Purpose - The present chapter aims to increase the understanding of possible supply chain models and their fit and most effective configuration in a typical engineer-to-order sector, namely the wind business.

Design/methodology/approach - We use action research methodology because we want to demonstrate that integrating the paradigms into the same supply chain is the best way to manage the supply chain. Action research consists of the deliberate implementation of a cyclical four-step process: planning, taking action, evaluating the action, which leads to further planning, taking action and so on.

Findings - Our findings suggest the pertinence of a Hybrid Supply Chain model combining elements of the Lean, Agile and Leagile paradigms “upstream” and the Project Management paradigm “downstream” in the case of a wind turbine manufacturer. We also find that, depending on the complexity of the market and supply diversity, multiple decoupling points emerge.

Practical implications – In the present case of the Wind Energy Supply Chain, we find that for effective management of a global supply chain characterized by a large number of references and multiple technologies, it is necessary to mix different manufacturing paradigms in order to provide a quick, agile and competitive response to the customer.

Research limitations / recommendations - This paper is focuses only on the wind business sector, however its findings could be extrapolated to similar sectors of high technology and high levels of complexity.

Originality /value - This wind business case opens up new opportunities for further research, to investigate broad scope of supply chain management and the variety of management paradigms (depending on the type of product, the complexity of markets and the nature of components) that can be found beyond those required in wind energy.

Keywords: Supply, Strategy, Lean, Agile, Leagile, Project Management, Wind, Business

Paper type - Action research paper

2.1. Introduction

Key enabling technologies generating smart industries and alternative sources of energy contributing to sustainable societies have become an economic priority.

The wind business (WB) is a relatively new industry and in Western Europe its origins date back to the 1970s. Despite its relative infancy, the global wind energy market has experienced a steady 25% annual growth rate over the past 10 years. Nowadays, wind energy represents a major trend as countries try to establish renewable energy technologies and diversify their energy mix. Wind energy is the world's fastest growing energy source and will power industry, businesses and homes with clean, renewable electricity for many years to come.

In terms of manufacturing and operations, the wind energy business has the following characteristics: *i) low-volume, ii) high-variability, iii) highly-customized, iv) high technology, v) high-quality and vi) short life wind turbines*. The supply chain model (SCM) becomes a powerful strategic weapon, but is also an order-winning criterion when contracts are awarded.

Currently, one of the principle challenges facing wind turbine manufacturers (WTM) is trying to balance the capacity of their supply chain with demand uncertainty and variability, while attempting to ensure supply capacity, lower working capital, reduce work in process, decrease costs, lessen the lead time for components and reduce delivery times to final customers.

It is in this complex panorama that the questions, Which manufacturing strategy best fits the manufacturer? and What are the critical elements in the supply chain? arise. The aim of the present research is to reach a better understanding as to which supply chain model is best in a complex and typically engineered-to-order sector such as the WB.

In consequence, the research questions (RQ) we formulate are:

- **RQ1**: How can a supply chain co-exist with other manufacturing paradigms e.g. Lean, Agile, Leagile and Project Management?
- **RQ2**: What are order decoupling points in the supply chain and how do they vary?
- **RQ3:** What type of strategy needs to be adopted when the product can require variable lead-times? Does a one-size-fits-all supply strategy apply?

2.2. Literature review

According to Russell and Taylor (2007), several authors assume "the challenges that organizations are facing at present are wide ranging and include: intense competition, global markets, global sourcing, global financing, global strategies, enhanced product variety, mass customization, service businesses, quality improvement, flexibility, advances in technology, employee involvement, and environmental and ethical issues. Therefore, an organization should make use of strategies and technologies to form a virtual organization, in which participants collaboratively respond in a more agile manner" to any unexpected changes in customer demand.

The present contribution focuses on developing a flexible understanding of supply chains to enable mass customization of products and services. The main idea is to use concepts which, while are not new, have either not been integrated or have not been included in the same supply chain.

The literature review is divided into two main sections. We focus first on supply chain management to explore paradigms related to the supply of components and raw materials, and second on project management because project management has become the main generator of supply orders in this complex industry. The final integration in the supply chain is monitored by project managers because of the complex business of selling power capacity rather than selling a product which generates wind energy.

2.2.1. Supply Chain Management

The field of supply chain management (SCM) has gained importance over the last two decades and there are many indications that it will continue to do so. A supply chain is a network of facilities that produce raw materials, transform them into intermediate goods and then final products, which are delivered to customers through a distribution system. However, while SCM has been around for more than 25 years, there is as yet no consensus on its definition or what it entails. Stock and Boyer (2009) provide a definition of SCM after performing a qualitative analysis of 173 individual definitions of the field. Their definition, which is the most comprehensive available, as it is based on the qualitative analysis of an extensive literature review, is as follows: "The management of a network of relationships within a firm and between interdependent organizations and business units consisting of material suppliers, purchasing, production facilities, logistics, marketing, and related systems that facilitate the forward and reverse flow of materials, services, finances and information from the original producer to final customer, with the benefits of adding value, maximizing profitability through efficiencies, and achieving customer satisfaction" (Stock, 2009:706).

Supply chain strategy requires an end-to-end focus on the integration of business processes throughout the value chain for the purpose of providing optimum value to the end-customer (Qrunfleh and Tarafdar, 2013; Green et al., 2008). However, it is possible to account for these processes using different paradigms and evolving knowledge. A number of paradigms are presented below.

2.2.2. Lean Supply Chain

The origins of Lean can be found on the shop-floors of Japanese manufacturers and, in particular, innovations at Toyota Motor Corporation (Womack and Jones, 1996; Monden, 1983). These innovations are summarized in some tools that include the just-in-time production system, the Kanban method of pull production, respect for employees and high levels of employee problem-solving / automated mistake-proofing (Hines et al, 2004).

Based on Lean principles, the Lean supply chain strategies are a logical extension to Lean Thinking. These strategies focus on waste reduction, helping firms to eliminate those activities that do not add value because they consume excess time, labour, equipment, space, and inventory across the supply chain. Christopher and Towill (2000) suggest that Lean principles are applicable in markets where demand is "*relatively stable*" and therefore "*predictable*", and where "*variety is low*" and "*volume is high*".

2.2.3. Agile Supply Chain

In a report published by the Iacocca Institute of Lehigh University and entitled "21st Century Manufacturing Enterprise Strategy", Nagel and Dove (1991), originally introduced the concept of agile manufacturing as an option for managing firms in a dynamic world. The origins of "agility" as a business concept lie partly in flexible manufacturing systems which, through automation (i.e. reduced setup times) enable rapid changeovers and, as a result, can be responsive to changes in product mix and volume (Christopher and Towill, 2000). Later, this idea of manufacturing flexibility was extended to a wider business context by Nagel and Dove (1991), and the concept of agility as a supply chain paradigm was born.

Many authors have a definition of agility. Gunasekaran (1998) defined agility as the ability to respond to market changes in a cost-efficient and profitable manner, while

Christopher and Towill (2000) define it as, “a business-wide capability that embraces organizational structures, information systems, logistics processes and in particular, mind-sets.” Agility involves the utilization of market knowledge and a responsive organization in order to exploit profitable opportunities in a volatile marketplace (Agarwal et al., 2006). Essentially, it is about being demand-driven rather than forecast-driven.

The focus of improvement efforts in the agile approach is the integration of information flow across the supply chain with the objective of creating a market responsive supply chain that reacts quickly to unpredictable demands and thereby minimize lost sales, forced markdowns and obsolescent inventory (Hoek, 2000). A market-responsive supply chain emphasizes market mediation to a greater extent than the efficient physical supply of the product (de Treville et al, 2004). An important point is that agile manufacturing implementation requires the company to be a world class manufacturer using lean manufacturing methods (Bayraktar et al., 2007).

2.2.4. Leagile Supply Chain

In recent years, one of the most interesting debates concerning supply chain strategies has centered on the relative merits of the Lean and Agile philosophies. Lean and Agile approaches are discussed as opposing paradigms, even though they share a common objective: meeting customer demand at the least total cost (Goldsby et al., 2006; Hilletofth, 2012). Therefore agility should not be confused with leanness and the main difference between the two approaches is that lean supply is associated with level scheduling, whereas agile supply reserves capacity to cope with volatile demand.

Many researchers have suggested that the Lean and Agile approaches can be integrated in a variety of ways to create so-called Leagile strategies (Aitken et al., 2003; Childerhouse et al., 2002; Christopher and Towill, 2000; Mistry, 2005). Thus, instead of focusing on a definition of a Lean or an Agile strategy, attention is directed to the selection and integration of the most appropriate aspects of these paradigms in a specific supply chain strategy (Hilletofth, 2012).

Integration of Lean and Agile concepts in “Leagile” implies the use of postponement, a practice which has been used increasingly by industry in recent years. The main idea is to use the Lean concept until the decoupling point, working to enhance efficiency indicators, and then to use the Agile concept beyond that point, seeking mass customization. Many European industrial companies are currently implementing Leagile supply chain systems (Hoek et al., 2001).

Finally, the ability to customize – by being close to the customer – means that a higher level of variety can be offered at a lower total cost, enabling strategies of "mass-customization" to be pursued. In order for Leagile supply chain systems to succeed, a reliable supplier network that can supply parts and services is essential (Feitzinger and Lee, 1997).

2.2.5. Decoupling points in a supply chain structure

One problem in supply chains is the limited visibility of real demand. A linking point between production and demand is required. This is the point where "real demand" penetrates upstream in a supply chain, and market demand "pull" meets upstream supply "push". This may be called the decoupling point, because upstream from that point real demand cannot be felt. This point has also been called the "order penetration point" by several authors (Hallgren et al., 2011; Olhager, 2003; Christopher, 2000).

The decoupling point separates that part of the supply chain which responds directly to the customer from the part of the supply chain which uses forward planning and strategic stock management to respond to any variability in the demand of the supply chain. This concept has been applied in many environments: supply chain (Christopher et al.., 2006) or manufacturing strategy (Olhager, 2003). Nevertheless, the decoupling point connects directly with characteristics of the Lean and Agile paradigms (Naylor et al., 1999). The Lean paradigm can be applied to the supply chain upstream of the decoupling point if demand is smooth and standard products flow through a number of value streams. But, downstream from the decoupling point a number of products flow through just one value stream. The Agile paradigm must be applied downstream from the decoupling point as demand is variable and product variety per value stream is increased. The decoupling point is where the two paradigms meet and the challenge of SCM is to seek to develop Lean strategies up to the decoupling point, and then Agile strategies beyond that point. By using generic or modular inventory to "postpone" final commitment to specific, customized products, it should be possible to achieve volume-oriented economies of scale through product standardization. The point of flow up to the decoupling point should be forecast driven and after the decoupling point it should be demand driven (Christopher, 2000).

However, in "real-world" supply chains there are actually two decoupling points (Mason-Jones and Towill, 1999; Mason-Jones et al., 2000). The first is the material decoupling point, where strategic inventory is held in the most generic form possible. This point should ideally lie as far downstream in the supply chain and as close to the final marketplace as possible in order to reduce delivery time. The second decoupling point is the information decoupling point. The idea here is that this should lie as far as possible upstream in the supply chain; it is, in effect, the furthest point to which information on real final demand penetrates. The penetration of the “information” decoupling point is promoted by sharing mechanisms such as design coordination, partnerships or in-depth collaborations.

2.2.6. The postponement concept

Christopher (2000) states that, “Postponement, or delayed configuration, is based on the principle of seeking to design products using common platforms, components or modules, but where the final assembly or customization does not take place until the final market destination and/or customer requirement is known”. In other words, postponement is moving the order decoupling point (ODP) to delay final definition of the product.

Several authors suggest that the combined effect of delayed configuration through “postponement” and shared information in a supply chain is a significant improvement in responsiveness. There is a strong relationship between product design and Agile supply chain performance. Product design must introduce information about which activities should be performed after orders are received and managed according to Agile principles (i.e. responsive, order-driven and customized activities) and which activities should be performed before orders are received and managed according to Lean principles (i.e. efficient, planned and standardized activities).

2.2.7. Project Management

Cicmil and Hodgson (2006) provide a clear description of the origins of this concept and practice, which emerged as a social practice in the post-World War II development of technology and infrastructure, following its development in the Manhattan Project in the 1940s. The majority of the groundwork was done in the USA defense and aeronautics industries in the 1950s, including its use in the Apollo space programs, although the US oil and chemical industry also played a major role in this period.

Bakouros and Kelessidis (2000) state that, “Project Management emerged because of the growing demand for complex, sophisticated, customized goods and services and the exponential expansion of human knowledge. It is a set of principles, methods and techniques for effective planning of objective-oriented work, thereby establishing a sound basis for effective scheduling, controlling and re-planning in the management of programs and projects. In other words, it provides an organization with powerful tools that improve the organization's ability to plan, organize, implement and control its activities and the ways it uses its people and resources".

Research into Project Management remains heavily reliant on a functionalist approach and largely ignores theoretical aspects. It main interest is the accomplishment of some finite piece of work in a specified period of time, within a certain budget, and to agreed specifications (Atkinson, 1999).

2.3. Methodology and Research Design

It was only in the late 1990s that the development of the SCM paradigm accelerated, with the majority of the theoretical and empirical investigation starting in 1997 (Lambert et al., 1998). A meta-analysis of 405 articles carried out by Giunipero et al. (2008) revealed that 70 percent of the articles published on SCM were empirical in nature, and the rest were theoretical. Carter and Ellram (2003) found that approximately 75 percent of the research in journals, including surveys and case studies, is empirical in nature.

Empirical research contributes in the context of theory building as well in validating any proposed theories. From the practitioners point of view it is easier for business executives to understand empirical research, especially if they do not have advanced training in management science or operations research (De-Margerie and Jiang, 2011; Wong et al., 2005).

According to Soni and Kodali (2012) and Voss et al. (2002) empirical methods are imperative in Operations Management and are suitable for exploring the extension and refinement of theory, for a more in-depth examination and for validating empirical results. Operations Management is a very dynamic field in which new practices are continually emerging and subsequently being applied to other fields.

In this study we use action research methodology because we want to demonstrate that integrating the paradigms into the same supply chain is the best way to manage the supply chain. A comprehensive study of the WB sector is necessary in order to explore the different behaviours along the chain. This study was conducted from the perspective of a WTM, where one of the authors was involved and participated in decisions about how to manage the supply chain.

Action research is a qualitative research technique. The researcher participates in the company where the research is developed and may influence decisions made during the case study. Moreover the same researcher can try to escape the system to obtain a broader perspective. Afterwards, the researcher can thus be described as an outside agent, building theory, while simultaneously participating as a facilitator in the firm where the case was developed. The aim is to take action, at the same time as creating knowledge or theory about action. Although action research has longer roots, it was only recently that this methodology was also applied in the supply management domain (Soni and Kodali, 2012). One example of action research in Operations Management, is the study by Karlsson and Ahlström (1996), who supported, implemented and examined lean product development in a company over a period of two years.

For the present study the researchers actively participated in component classification and establishing relationships with suppliers; who were in constant interaction with the organization. In action research the researcher can collect information which would be impossible to obtain without active participation. The authors, as participants, use observational data as well as secondary data to develop the proposed model. To ensure methodological rigor, the action research cycle described by Coughlan and Coghlan (2002), which prescribes process steps for conducting quality action research, was followed. Action research consists of the deliberate implementation of a cyclical four-step process: planning, taking action, evaluating the action, which leads to further planning, taking action and so on.

The company concerned was a global WTM firm located in Spain. The action research started in October 2008 with planning. This was followed by the initial intervention in May 2009, and then the evaluation which lead to further action that concluded in November 2009. Finally the concluding phase was completed in March 2010.

The methodology used was guided by external academic sources and based on the perspectives of both practitioners and managers. The case study itself is based on more than fifteen years' experience of decision-making in the WB field, of data acquisition, of analyzing component lead times and manufacturing capabilities, dealing with supply chain bottlenecks and so on, as well as problem solving, to attain an efficient supply chain, while keeping in touch with suppliers, assembly plants and wind farm installations. The data collected related to 1) negotiating suppliers' prices and delivery times, 2) supplier capacity audits, 3) work-in-process and working capital for different pipelines, 4) company supply strategies, 5) workshops supply strategies, 6) supplier agreements, and 7) procurement delivery lead times.

2.4. The case of the Wind Business

The wind business is a highly complex industry. Since our aim is to analyze the supply chain, we need to consider the perspective of a key agent, for which purpose we selected a WTM.

The WB is a relatively new industry and in Western Europe its origins date back to the 1970s. Despite its relative infancy, the global wind energy market has experienced a steady 25% annual growth rate over the past 10 years. Wind energy represents a major trend as countries try to establish renewable energy technologies and diversify their energy mix.

2.4.1. Sector

The investment required to install a wind farm is massive: the cost of an onshore 2MW turbine is estimated to be 1.3 million Euros per MW. Besides the determination of governments to rely less on unsustainable fossil fuels, a further reason as to why the WB future is bright is because the wind energy input is free and unlimited, so long as the wind farm is strategically located in a region with strong winds.

The lessons learned from more than a decade of operating wind power plants, along with continuing R&D, mean that wind-generated electricity is very close to being cost-competitive with conventional utility power generation in some locations. Wind energy is the world’s fastest growing energy source and will power industry, businesses and homes with clean, renewable electricity for many years to come.

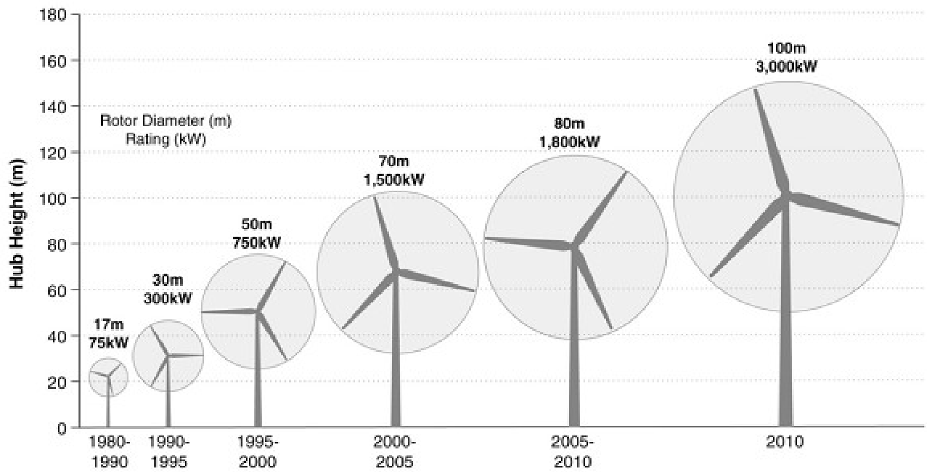

Figure 2.4.1-1 Representative turbine evolution from 1980 to 2010
Source: Lantz et al 2012 - NREL

The WB has expanded exponentially in recent years. The power of wind turbines is constantly increasing (figure 2.4.1-1). Furthermore, customers' technological specifications and product customization have also increased (Kaldellis and Zafirakis, 2011).

Most customers are large power generating "public utilities" (e.g. Iberdrola, EON, EDP, EDF), although there are also independent investors (IPPs - Independent Power Producers) who are wind farm owner-operators who sell the energy they generate to the public utilities.

One aspect of the complexity of the sector is that customers do not actually buy wind turbines; they buy energy (MWh). Moreover, demand is uncertain, not only in terms of concrete contracts, but also in terms of in executing wind farm contracts. This uncertainty may be exacerbated by administrative barriers concerned with the project licensing process. Such barriers to licensing arise from the public administration and regulation of each individual country, environmental impact, and so on, and sometimes stem from infrastructure or electric network connection problems. Consequently they can delay permits to construct wind farms for years, making it difficult to forecast demand, which makes it even more difficult to align WTM production capacity.

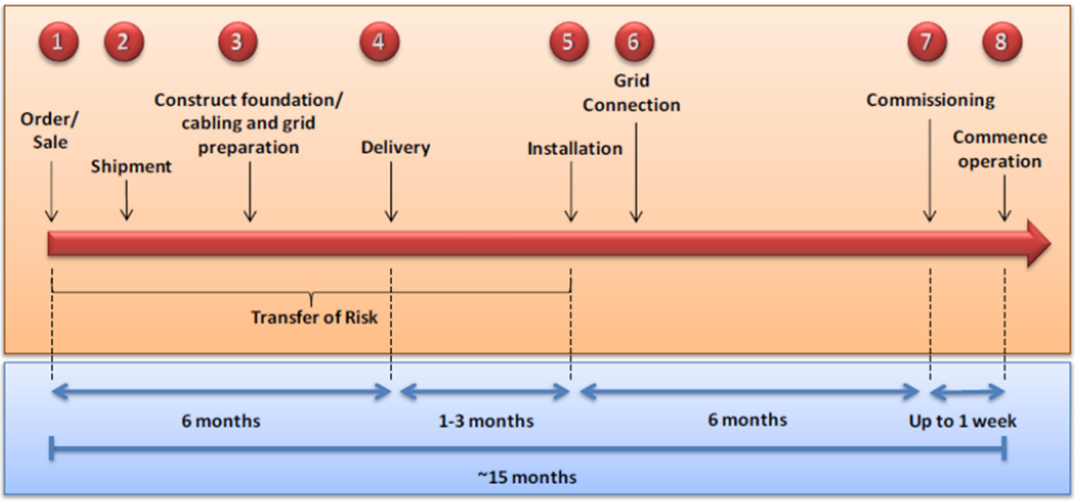

Figure 2.4.1-2 Typical onshore wind turbine development timeline
Source: BTM Consultant (2013)

One of the main challenges to meet is the high technological requirements for wind turbines, typically availability of 97.5% to 98 % of the time of the contract, although this is a median value (Wilburn et al., 2011), and a cycle life of approximately 20 years. This technological demand on the efficiency and machine cycle-life required for a wind turbine is reflected at individual component level. Developing key components can only be entrusted to a few skilled suppliers. These assumptions about risk for this technology cause a shortage of key components, which in turn creates bottlenecks in the supply chain (Aubrey, 2007; BTM Consult, 2011; MAKE Consulting, 2013).

In other words, the long lead times of these key components, along with demand uncertainty, force the WTM to slot their short-term planning work (backlogs of administrative authorizations and forecasts) in between orders. In terms of manufacturing and operations, the WB can be described as: (1) Low-volume, (2) High-variability, (3) Highly-customized, (4) High-technology, (5) High-quality and (6) Short life cycle. As a result, SCM is a powerful strategic weapon, but also an order winning criterion when contracts are awarded.

Currently, one of the principle challenges facing WTMs is trying to balance the capacity of their supply chain with demand uncertainty and variability and attempting 1) to ensure supply capacity, (2) to lower working capital, (3) to reduce work in process, (4) to decrease costs, (5) to reduce the lead time for components, and (6) to reduce delivery times to final customers.

2.4.2. Products

IRENA (2012: 4) stated that, “Wind power technologies transform the kinetic energy of the wind into useful mechanical power. The kinetic energy of the air flow provides the motive force that turns the wind turbine blades which, via a drive shaft, provide the mechanical energy to power the generator in the wind turbine”.

Historically, the era of wind power as we know today began in 1979 with the mass production of wind turbines by the Danish manufacturers Nec Micon, Vestas, Nordex, Bonus, and some others. Those wind turbines had small capacities (10 kW to 30 kW) by today’s standards. The current average size of grid-connected wind turbines is from 1.16 MW to 3 MW (BTM Consult; 2011; IRENA, 2012).

There are many configurations but horizontal-axis wind turbine (HAW) designs are more common, usually a three bladed stall or pitch-regulated machine operating at near-fixed rotational speed.

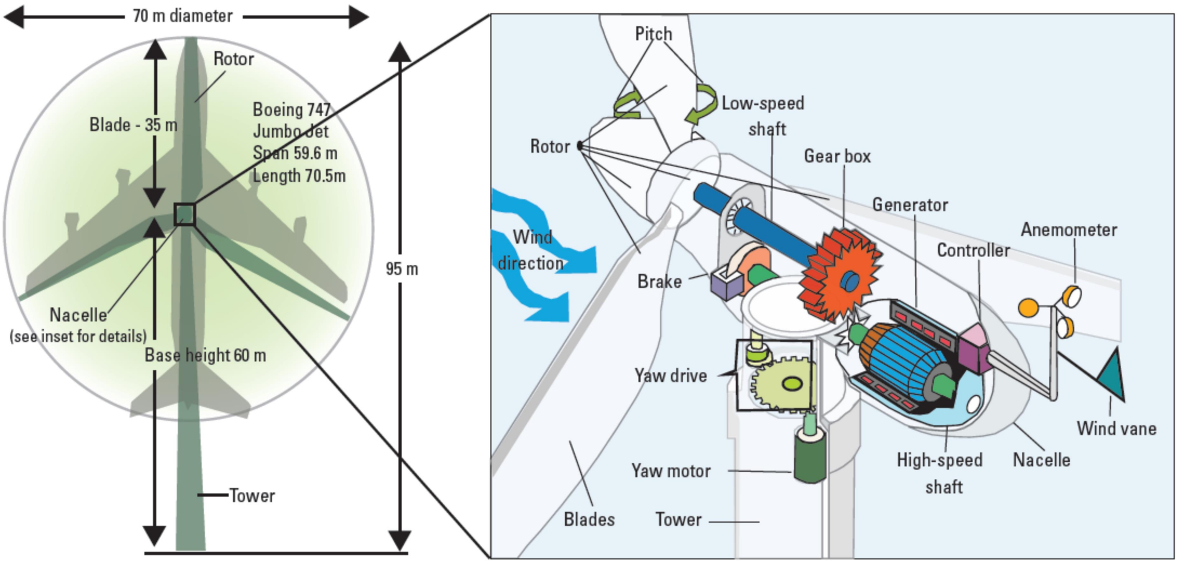

Figure 2.4.2-1 Diagrams of a typical large wind turbine and major components
Source: Wilburn (2011)

Wind turbines consist of three principal components (Wilburn et al.., 2011), (1) the nacelle, (2) the rotor, and (3) the tower (figure 2.4.2-1). Willburn et al. (2011:10-11) state that, “The nacelle contains much of the equipment required for energy generation and conversion and typically accounts for 25 to 40 percent of the weight of the wind turbine. The rotor typically makes up 10 to 14 percent of the weight of the wind turbine. The rotor of a wind turbine consists of four principal components: the blades, the blade extender, the hub, and the pitch drive system… The tower provides the support system for the turbine blades and the nacelle and serves as the conduit for electrical and electronic transmission and grounding”.

A typical wind turbine contains up to 8,000 different components (Aubrey, 2007) and is reported to contain, by weight, 89.1% steel, 5.8% fiberglass, 1.6% copper, 1.3% percent concrete (primarily cement, water, aggregates, and steel reinforcement), 1.1% adhesives, 0.8% aluminium, and 0.4% core materials (primarily foam, plastic, and wood) (Wilburn et al.., 2011). The cost of the turbine itself accounts for 76% of the total capital cost of a wind farm project (EWEA, 2009).

2.5. WTM as a Key agent in Wind Business

Our focus is on the WTM, because it is the key agent in the supply chain and also where we are carrying out our action research. The WTM is interested in selling electrical production capacity rather than just a wind turbine. The concept of ODP can be used when the product is clearly defined, but, in the case of a highly complex product, postponement must deal with uncertainty in some of the parameters defined by the final project. We therefore propose to use the ODP concept twice: firstly downstream from the WTM, when the project management determines the final requirements, and secondly in the different supply pipelines depending on the component involved.

Traditionally, companies have conducted their business according to an MTS (Make to Stock) approach. This implies that they perform all the supply chain activities, including design, sourcing, manufacturing, assembly, packaging, labelling and distribution, based on forecast and speculation. However, in the case of the WTM, suppliers have to postpone committing to specific components, depending on the available degree of definition. Manufacturing postponement by suppliers aims to maintain the product in a neutral and non-committed status in the supply chain for as long as possible (Bowersox and Closs; 1996). Customization of components for a particular project is postponed to the last possible moment. This means that suppliers delay assembly to order (ATO), make to order (MTO), and source to order (STO), and may even engineer to order (ETO) until orders have been defined and received. Moving the second ODP upstream in the supply chain depends on the classification of components and is coordinated by the WTM.

Globalization is revolutionizing the scope of the supply chain. The suppliers' relative importance and their contributions in terms of technological developments, capacity, delivery time, and cost are crucial in the WB. The capacity of the WTM conditional upon the capacity of its supply base and its capacity to supply the key components required by the WTM on time (Aubrey, 2007; BTM Consult, 2011; MAKE Consulting, 2013).

In fact, the term "delivery time" is a critical factor when the final customer awards contracts. Customers may penalize delays. There are no limitations to the WTM's assembling and installing ability, and these are currently neither a bottleneck nor a constraint. The crucial limitations are in component supply management. The current lack of component supply capacity requires the WTM to make decisions whether to make or buy some key components, in order to ensure supply, control costs, and absorb demand surges, respond quickly to customers, and improve supply chain responsiveness.

While many WTMs have chosen a vertical integration strategy for some key components, not all WTMs have, and prefer instead to ensure their responsiveness by increasing their supply base for key components, following an outsourcing strategy that allows suppliers to develop their core competence in a sector where investment in R&D and equipment (CAPEX), including blades, gearboxes, converters, and generators, is much needed. Many key suppliers use the same design platforms for different WTMs customizing their components at the end of their production process, thus making them more cost competitive and more efficient through economies of scale.

2.6. Findings

The action research methodology involves various stages during the investigation. Table 2.6-1 show these stages, which are also outlined in the following sections. The planning and taking action stage corresponds to the initial supply chain configuration and the classification of component suppliers, based on supplier attributes. This was followed by evaluation of the action, where, because of the complexity of the business and demand uncertainty, orders have to be anticipated using a mix of customer confirmed project orders and forecasting based on historical data. Finally, this led to further planning where project management was proposed to monitor wind farm construction.

Research Stage	Objective	Section in paper
Planning	Problem statement and first approximation of Wind Business Supply Chain Model.	Supply Chain configuration.
Taking action	Development of WTM sourcing model based on components attributes and determination of different manufacturing paradigms and determination of different decoupling points.	Components supplier classification based on supply attributes
Evaluating the action	Perform, managing and monitoring different pipelines and use of rolling forecast and Master Planning Scheduling	Lean Assembly Plants
Leading to further planning	Introduction of Project Management paradigm downstream Wind Turbine Manufacturer. Model fully integrated	Wind Farm construction

Table 2.6-1 Phases in Action Research Planning

2.6.1. Supply Chain Configuration

The WB landscape is composed of developers, manufacturers and operators. WTMs generally embrace a range of activities including site development, wind turbine design, manufacturing, wind farm construction, operation, maintenance and technical service. The present study focuses on a WTM.

The wind energy supply chain (Figure 2.6.1-1) is composed of five entities: (1) raw material suppliers; (2) component suppliers; (3) assembly plants – WTM; (4) wind farm construction, including civil works, installation and commissioning, and wind farm technical services; and finally (5) the customer - WPP, who is usually responsible for the operation and maintenance of the wind farm. However, utility companies might also be involved in generating, transmitting and distributing the wind energy.

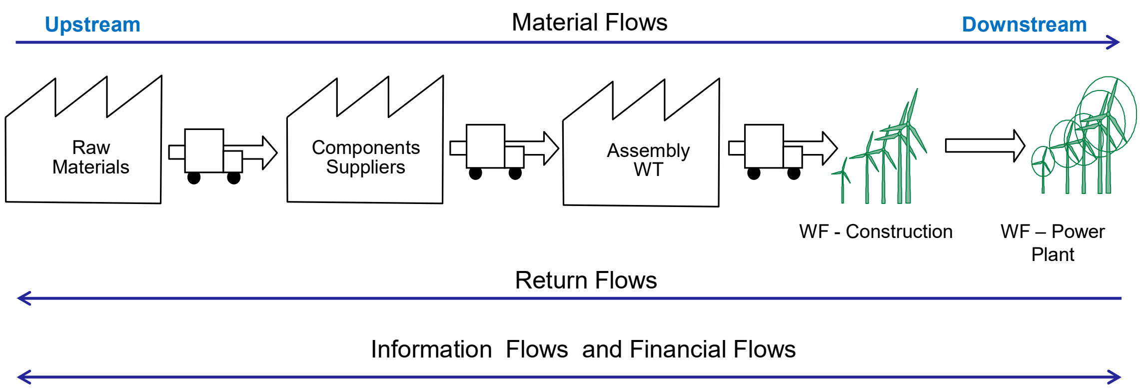

Figure 2.6.1-1 First approach to Wind Business Supply Chain

In the following paragraphs we briefly describe the main activities of the supply chain illustrated in figure 2.6.1-1.

- **Raw material suppliers**: Provide the basic materials such as steel, forged castings, plastics, fibers and copper to manufacture different components and systems for the wind turbines.

- **Component Suppliers**: Are a key strategic point in the supply chain in the WB sector, because many components are developed in collaboration with suppliers (Aubrey, 2007; BTM Consult, 2011; MAKE Consulting, 2013), since the technology of both product and process belongs, in most cases, to the suppliers. Hence, supplier management and development is extremely important.

- **Assembly Plants (Wind Turbine Assembly Plants)**: Are responsible for the assembly of the different components following a master planning schedule (MPS) to produce wind turbines ready for delivery.

- **Wind Farm Construction**: Includes civil work, commissioning and erecting and installing the wind turbines on site according to the customer's contractual requirements. In this phase of the supply chain, the customer closely monitors the installation process as it occurs on the customer's premises and under their supervision.

- **Wind Power Plant**: As the final step in the supply chain is the customer, who is usually a utility company or IPP, and they are responsible for the wind farm operation and maintenance, although this can vary depending on the type of customer and contract.

2.6.2. Component supplier classification based on supply attributes

This section focuses on the supply strategy proposed to a WTM which then leads to four pipeline strategies. As this study focuses on supply strategy, we focus on the sourcing carried out by the WTM. This activity includes the overall management of suppliers, finding new supply sources, selecting and rating suppliers, negotiating and procuring new contracts, monitoring the quality of contract purchases, as well as meeting deadlines, negotiating contracts and technical service assistance guarantees for those components that affect the availability of the wind turbines.

In the partnership between the WTM and its suppliers there are many factors that determine the different strategies adopted. The foundation of the relationship is based on determining the position of the ODP, as this establishes the point where forecasts are replaced by the assignment of a specific wind farm project. As noted above, some authors (Ben Naylor et al.., 1999; Mason-Jones et al, 2000) distinguish between Lean and Agile supply chains, where a Lean supply chain should be applied upstream of the ODP, while an Agile supply chain is more suitable for downstream operations.

According to the characteristics of the components, a different strategy should be followed in each component pipeline, as each has different needs and characteristics. While there are some models for existing supply chain design in the literature review (Christopher et al.., 2006; Fisher, 1997; Kraljic, 1983; Mason-Jones et al.., 2000) and while they are very rich in their content, they are simply not specific enough when the design is required for a particular sector. By designing a sourcing strategy in the WB, we develop a simplified model based on Kraljic (1983) and Christopher et al. (2006) to apply to this case study. The particular attributes have been listed above and highlight the fact that, in this sector the supply of components is fundamental (Aubrey, 2007; BTM Consult, 2011; MAKE Consulting, 2013).

Therefore we classify families of components on two dimensions:

- **Profit Impact**: This is the cost of the component that, in turn, influences the working capital and work in process supported by the WTM. The cost of the ex-work components is around 70% to 76% of the cost of an installed wind turbine and, as a wind turbine has around 8,000 components (Aubrey, 2007), we can reduce costs by classifying and monitoring these components carefully.

- **Supply Risk**: This is the delivery lead time of a component, which determines the time we must wait for a particular component. It is determined by the few key components suppliers, who may have such limited capacity that it could increase uncertainty. In fact, this limits the capacity for key components and causes business uncertainty.

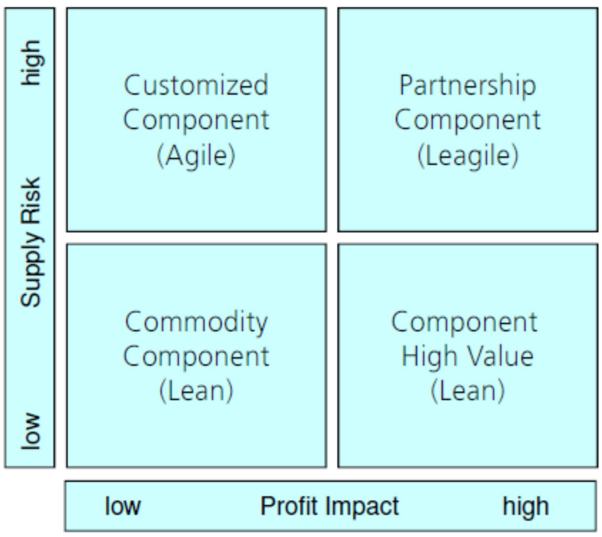

Figure 2.6.2-1 Component Segmentation Matrix for Wind Turbine Manufacturer

These two attributes classified as either "low" or "high" impact, producing the component portfolio (2x2 matrix) depicted in figure 2-6-2-1. This classification allows us to apply different strategies for the supply of each family of components (Lean, Agile, Leagile, etc.) and model the different paradigms, all the while seeking the maximum overall efficiency. The resulting four strategies are described below.

- **Commodities**: These are commercial components that are purchased from a catalogue and have low economic value, compared to the cost of wind turbines, as well as relatively short lead times (weeks or sometimes only days). Usually there is no purchasing strategy for these components and they are purchased at the best price and the best delivery time, and customer-supplier relationships are temporary, project by project "win-lose" deals. The lean supply strategy is continuous replenishment (Christopher et al., 2006), for example under a Kanban system. Component replenishment is the responsibility of the supplier who has to maintain a point of order according to the demand of the assembly plant.

- **Customized**: These are bought according to specific commercial references or technical characteristics as specified in a catalogue or, generally, where the WTM can choose certain attributes to configure them to their particular requirements (e.g. low voltage electric motors, electrical equipment, high voltage cables, hydraulic power, and instrumentation). These components typically have lead times of about 2 months. There is a clear purchasing strategy and the supplier relationships are "win-lose", and alternative suppliers are monitored to help source at better prices and delivery times. In this kind of agile supply, the supplier customizes the components and gives a quick response to customer-driven demand.

- **High Value**: These components are purchased from drawings or according to particular technical specifications because, as they are usually structural components, their fabrication requires meticulous attention and high quality. They are complex in terms of the technology, such as casting, forging, machining, and welding (e.g. hubs, main frames, towers, flanges, covers). Suppliers of these components are involved from the beginning in the design phase, as the methods and processes used have a huge influence on the final quality and attributes of the product. They generally have lead times between 2 and 3 months. There is a clear purchasing strategy for these components and supplier relationships are “win- win” with long-term deals. Such components often cause bottlenecks and some may limit the ability of the whole chain to meet its deadlines. Hence some WTMs have decided to follow a vertical integration strategy (BTM Consult, 2011; MAKE Consulting, 2013). This type of supply is lean and there is an annual agreement with annual forecasts and quarterly adjustments based on demand.

- **Partnership**: To develop this type of components, close cooperation with suppliers is required from the beginning of the design (Kraljic, 1983), since it is actually the supplier who designs the component based on the stated requirements of the WTM, so that it can be integrated with other components. The correct and accurate definition of specifications by the WTM, determines the results of the design (e.g. blades, gearbox, converter, pitch system, generator) and, to a large extent, the reliability of the final components. There is a clear sourcing strategy for these components, based on long-standing and mutual cooperation. The relationship is “win-win” as it is based on long-term co-design and partnership. These components have long lead times of 5 to 7 months, because of the supply of the raw materials and the technological complexity of the processes. The supply strategy should usually be Leagile. As there are framework capacity agreements lasting for several years, and technological developments, the supplier can plan their factories and raw material supplies accordingly. Products are customized based on real demand and quarterly planning. Suppliers may use the same product platform for different customers as a strategy to exploit economies of scale. Some WTMs have also opted for vertical integration (e.g. Gamesa, Vestas, Enercon, GEC), because some components can produce supply chain bottlenecks.

Based on these descriptions it is possible to determine four different pipelines (figure 2.6.2-2) depending on the classification of the components. The place where the **ODP** is located will be fixed by where the pipeline components are situated in the model.

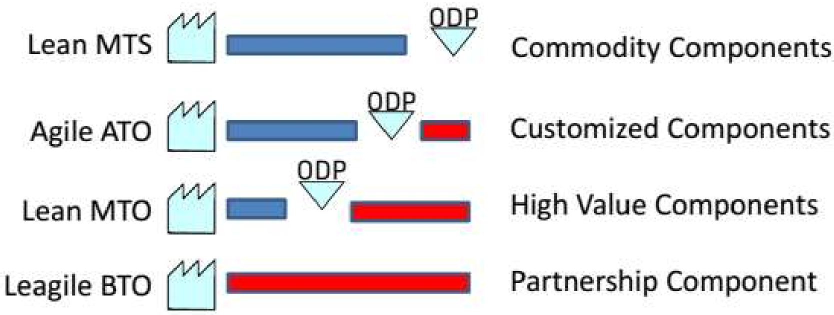

Figure 2.6.2-2 Postponement Strategy for Key Component Suppliers

2.7. Results

Applying the model in the wind energy supply chain, we classify WTM components as in figure 2.7-1. All the WTM components can be classified, determining a clear supply strategy for each. In summary, as shown in figures 2.6.2-2 and 2.7-1, depending on the nature of the components and their attributes, four different pipelines for a WTM have been defined which in turn determine four different ways of managing supplier relationships.

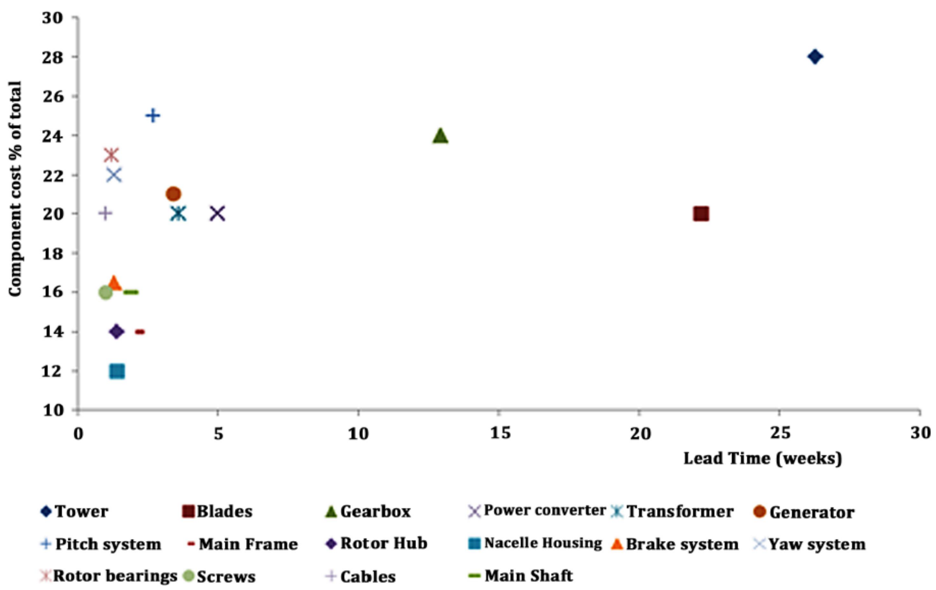

Figure 2.7-1 Matrix results from application model. Segmentation of components

2.7.1. Lean Assembly Plants

The introduction of different supply strategies (i.e. Lean, Agile and Leagile), depending on the nature of components, facilitates the implementation of the Lean paradigm in assembly plants, since it is possible to smooth production assembly requirements. The aim is to have components arrive just in time, according to the supply strategies defined and the required buffer flows, to smooth wind farm demand.

Due to the complexity of the business and demand uncertainty, purchasing orders are based on a mix of confirmed customer orders and forecasting based on historical data, resulting in the rolling forecast represented in figure 2.7.1-1.

This mix of confirmed customer orders and forecasting orders allow us to smooth the schedule of the WTM assembly plan and also manage the assembly capacity according to confirmed wind farm project requirements. At the same time, it facilitates the implementation of lean manufacturing tools and techniques in the assembly plants.

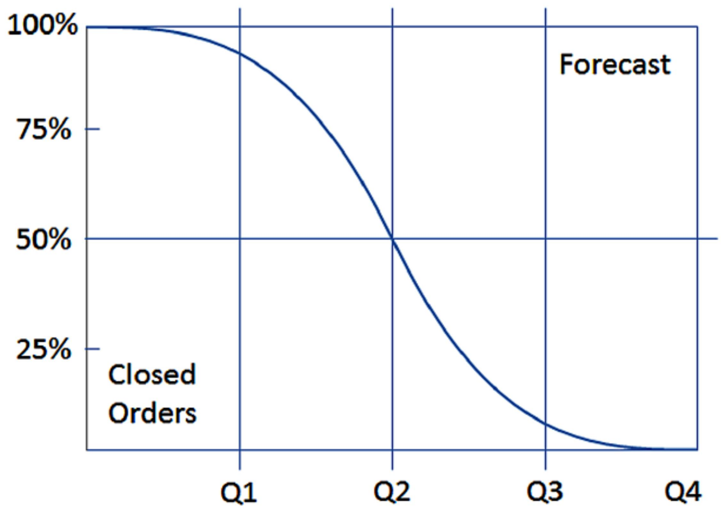

Figure 2.7.1-1 Rolling Master Planning, combining Forecasts and Confirmed Orders

In this supply chain stage, the WTM postponement strategy upstream is a crucial element as it makes it possible to combine confirmed orders with forecast orders until the final customization point of the wind turbine. This provides flexibility as to when an expected order becomes a confirmed, planned order. This key concept of postponement is represented in figure 2.6.2-2 and varies depending on the component supply strategies described above. However, these strategies can be integrated into the entire supply chain (figure 2.7.2-1).

2.7.2. Wind Farm Construction (Project Management)

In this stage of the wind energy supply chain, we introduce the paradigm of Project Management, which, although not a new concept, has not been applied in an SCM context. At this supply chain stage, Project Management handles wind farm construction, installation and commissioning, delivering the wind farm to the final customer. The management at this stage of the supply chain is completely different from the supply stream upstream of the WTM since, as mentioned above, the construction of the wind farm is in a location determined by the customer and on the customer's site. The main parameters are delivery time, cost and quality in compliance with contract specifications and, in this context, interactions/interfaces with the customer are crucial.

Project Management is the last planning tool downstream of the WTM and is used to monitor the first **ODP** close to the customer. There are many specifications to determine in the delivery and installation stages, and they impact the sourcing of components. As appearing in figure 2.7.2-1, we defined **ODP1** and **ODP2**, as two decoupling points firms need to manage the components according to Project management orders. Accordingly, activities defined backward from ODP1 inform the forecast of orders in the rolling plan and forward activities impact on the postponement strategy for key components related to **ODP2**.

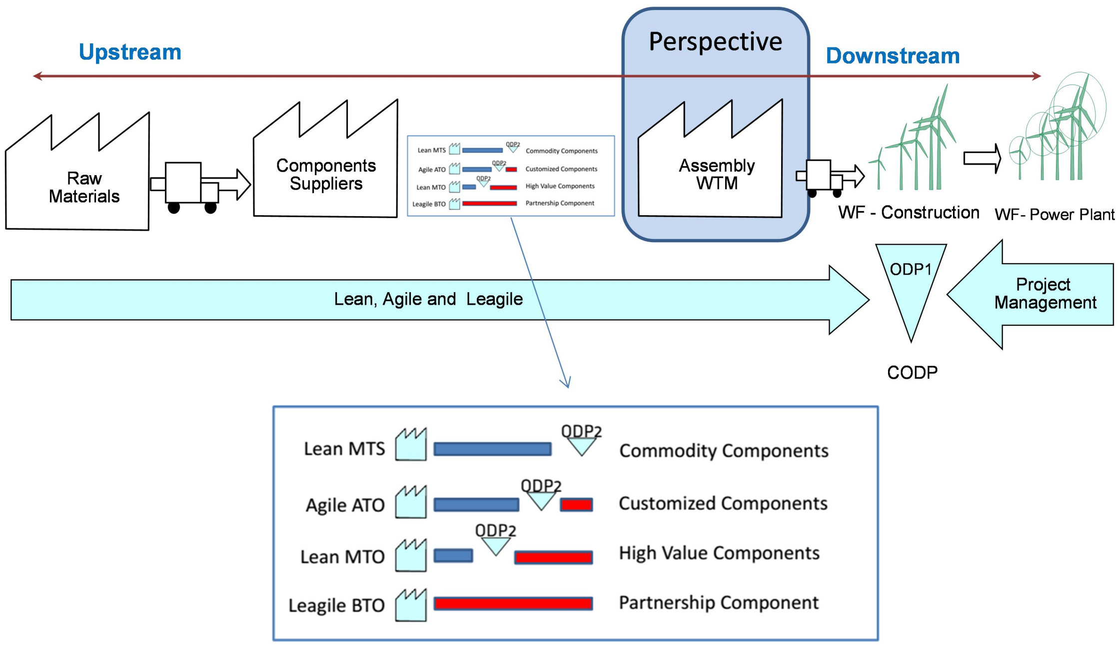

Figure 2.7.2-1 Hybrid Supply Chain

2.8. Conclusions

According to our findings, the wind energy supply chain model consists in a mixed supply chain containing several paradigms in management, and two order decoupling points. The main feature is the separation of decisions related to Project Management downstream from the WTM from component sourcing strategy upstream of the WTM. Up to four manufacturing paradigms can co-exist in a hybrid supply chain (RQ1). The supply chain can have more than one ODP, depending on the complexity of the components (RQ2). There is a need to apply different manufacturing strategies to different supply chain pipelines for components, categorized by supply risk and profit impact (RQ3).

Through this wind energy supply chain case, the effective management of a global supply chain characterized by a high number of components (approximately 8,000) and multiple technologies, different manufacturing paradigms must be combined, to give a quick, agile and competitive response to the customer.

The WTM must be skilled in management and supply chain integration and needs to be able to manage the different Lean, Agile and Leagile paradigms efficiently based on key component attributes. Project Management should be a supply chain integrator so as to gain a competitive advantage over competitors, the cost of the components being 75% of the total cost of an installed wind turbine. In this sector where lead times are long and margins are narrow, SCM is a key success factor.

The needs and requirements, and in particular administrative barriers, involved in planning a wind farm installation, makes component supply a critical element. Component sourcing has to be as fast and efficient as possible following the component classification. Depending on each of the strategies, it is possible to determine a different ODP for each pipeline so that the allocation of a purchased component for a specific wind farm installation project is the most appropriate and efficient way possible to manage the working capital and work in process, for both WTM and suppliers.

2.8.1. Practical implications and future recommendations

This WB case opens up new opportunities for further research, to investigate broad scope of SCM and the variety of management paradigms (depending on the type of product, the complexity of markets and the nature of components) that can be found beyond those required in wind energy. Another line of research would be to test the results with a survey, as So and Sun (2010) did, even though the particular attributes of the sector make it difficult to acquire a big enough sample.

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Chapter Nº3

Lean Manufacturing and their impact in the competitive priorities: Wind Power Supply Chain

3. Lean manufacturing and their impact in the competitive priorities: Wind Power Supply Chain study

Abstract

Purpose - This paper examines to what extent lean manufacturing practices have been adopted by wind power supply chain manufacturers and the impact these practices have on the firms' competitive priorities.

Design/methodology/approach - Using a survey questionnaire, data concerning 22 lean practices were collected from 74 wind power supply chain manufactures.

Findings - Our findings reveal that lean practices are moderately used in the wind power sector and that those most widely employed are cycle time and lead time reduction, problem solving teams, and visual control. The exploratory factor analysis (EFA) grouped these lean practices into four categories: (1) create flow management, (2) remove waste, (3) human and cultural management and (4) way of working. Multiple correlations showed that the competitive priorities (quality, cost, on-time delivery, flexibility, productivity, and customer service) impact the lean dimensions on different levels.

Practical implications - Lean practices and their degree of use vary from sector to sector and company to company and, as such, it is not always possible to apply the same lean practices equally across all sectors. Company culture is also a critical factor to keep in mind when implanting lean practices.

Research limitations/recommendations - The relatively small size of this study means that any generalizations to the population need to be made with caution. However, the study only concentrated on wind power supply chain.

Our study also seeks to encourage other academics and researchers to open up new lines of investigation into the use of LM practices in sectors that experience high levels of variability and uncertainty in demand, low-volume manufacturing and have highly customizable products.

Originality/value - The paper provides insights into the adoption of lean practices in the wind power sector and provides further evidence that lean manufacturing practices are significant in enhancing competitive priorities.

Keywords - Lean manufacturing, competitive priorities, wind power sector, supply chain

Paper type - Research paper

3.1. Introduction

The lean manufacturing (LM) concept has been the “buzzword” in the manufacturing areas for the last decades (Pavnaskar et al, 2003). The origins of lean can be found on the workshops of Japanese manufacturers and, in particular, innovations at Toyota Motor Corporation (Shingo; 1981, 1988, Monden; 1983, Ohno; 1988). These innovations, resulting from a scarcity of resources and intense domestic competition in the Japanese market for automobiles, included the just-in-time (JIT) production system, the Kanban method of pull production, respect for employees, and high levels of employee problem-solving, Jidoka, mistake proofing, and so on.

This LM design approach focused on the waste and excess from the tactical product flows at Toyota “seven wastes” (Shingo, 1981; Ohno, 1993; Womack and Jones,1996; Petersen, 2009) and represented an alternative to mass production; with its large batch sizes, dedicated assets and hidden wastes (Hu et. al; 2015)

The term lean was coin by Krafcik in 1988. Krafcik was the first American engineer to be hired by New United Motor Manufacturing Inc. (NUMMI). Womack and Jones recall offering him to take part in the International Motor Vehicle Program (IMVP) benchmarking study (Holweg, 2007). Later Womack and Jones, used the term lean to contrast Toyota whit the Western «mass production» system in the “The Machine that Change the World” book.

Lean is a philosophy of manufacturing that incorporates a collection of practices and tools into the business processes to optimize time, human resources, assets, and productivity, while improving the quality level of products and services to their customers. Lean philosophy is one of the most important concepts that help enterprises to gain competitive advantage in the world market. LM is a production practice, which regards the use of resources for any work other than the creation of value for the end customer.

According to Womack and Jones (1996), LM is lean because it uses less of everything compared with mass production half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time.

The lean concept can be described at different levels of abstraction in the literature (Womack and Jones, 1996; Spear and Bowen, 1999; Liker, 2004; Hines et. al, 2004). It can be defined as a philosophical perspective (systems), as practical perspective (components) set of practices and tools (Sakakibara et. al, 1993 Ramarapu, 1995; Shah, Ward; 2007).

For instance, Womack and Jones (1996) define lean as a business and manufacturing philosophy that shortens the time between order placement and product delivery by eliminating waste from a product's value-stream.

Shah and Ward (2007) define LM as "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier and customer and internal variability". However, the dominant view in describing and measuring LM rests on a "set of practices and tools" used in eliminating waste (Shah, Ward; 2003). This difference in orientation does not necessarily imply disagreement, but it does undermine conceptual clarity. However, despite significant studies and works on LM, this field has struggled with a lack of clarity about what LM is (Shah and Ward, 2007; Pettersen, 2009)

Many authors have analysed the use of LM practices, and their impacts on different sectors, company sizes, and countries (Sakakibara et al., 1993, Ramarapu 1995, Cua et al 2001, Shah and Ward 2003; Li et al., 2005; Shah and Ward 2007; Ghosh, 2013; Sharma et al., 2015; Jasti and Kadali, 2016). The majority of these studies were focused on the automotive supply chain and on consumer sectors (sectores de gran consumo) where there is (i) a predictable demand, with (ii) high production volumes and (iii) low variability in the mix of product demand. However, after a deep literary review, we exposed the lack of "empirical studies" in this field, with respect to more specific sectors, where (i) demand is unpredictable and uncertain, (ii) manufacturing volumes are low and (iii) where there is high variability in the product mix. An example of these sectors is the wind power (WP) sector. For this reason, our work aims to analyse (i) the intensity of the use of LM practices along the supply chain of this sector, (ii) to find out lean dimensions in this sector and finally (iii) to analyse the impact of these dimensions on competitive priorities.

This paper is structured into the following sections: (1) introduction and research objectives, (2) a literature review overview including the research hypothesis, (3) research methodology, samples and data collection, (4) research results, (5) discussion and findings, and finally (6) conclusions including, practical Implications, research limitations and future research recommendations.

3.2. Literature review and Hypothesis development

Over the last decades, miles of companies around the world have tried to adopt lean practices and lean thinking. Moreover, hundreds of academics and researchers from around the world have tried to capture, study, analyse and develop the lean concept from different points of view. However, after dozens of conceptual, empirical studies, research actions, case studies, validations by mathematical models, etc. we can confirm that there is still no consensus among academics what the term lean means and which traits are associated with it (Shah and Ward, 2007, Pettersen, 2009, Hu et al., 2015).

This divergence of opinion causes confusion at theoretical level and probably at practical level when organizations try to implement the lean concept (Pettersen, 2009). There are many articles relating to different ways to do lean transformation (Black, 2007; Anand and Kodali, 2010, Netland, 2016). However, what we can say with certainty, is that there is a mutual agreement between academics, researchers and practitioners that the use of the lean practices increase the operating profits of companies (Sakakibara et., 1993; Ramarapu, 1994; Womack and Jones, 1996; Shah and Ward, 2003; Li et al., 2005; Shah and Ward, 2007; Ghosh, 2012)

On the other hand, one of the challenges of academics and researchers in their eagerness to capture, analyse and define the lean concept is when they attempt to group practical differences and lean techniques there will be an overlapping with other tools, practices or disciplines as Total Quality Management (TQM), Total Productive Maintenance (TPM), Just in Time (JIT), Human Resource Management (HRM), etc, since many lean practices and techniques share the same common goals with the aforementioned management programs.

3.2.1. Lean practices

Many authors in the academic literature have analysed different lean practices and techniques, to develop measurement scales and dimensions in order to capture and analyse the essence of the lean concept.

For example, Sakakibara et al. (1993) analysed 41 plants in three different types of industry (transport, electronics, and machinery) through an empirical research analysing 16 JIT practices, which were grouped into three dimensions: (1) management people and schedules in a JIT system (2) simplified physical flow (3) supplier management.

Ramarapu et al. (1994), after an extensive literary review of the lean concept and its practices, classified 105 articles into three categories: conceptual (conceptual), empirical and simulation, and / or mathematical models. Collecting 28 different practices and classifying them into five dimensions (1) elimination of waste, (2) production strategy (3) quality control and quality improvement (4) management commitment and employee participation and (5) vendor supplier participation. As a results, "elimination of waste" and "production strategy" are the most critical factors in lean implementation.

Cua et al. (2001) analysed empirically 163 plants from different countries and of different sectors (electronics, machinery, and transportation parts) the relationship between the JIT, TQM, TPM manufacturing programs and their different practices. They demonstrated the importance of the union of these "programs" and their different practices on "operational performance". They also highlighted the "overlapping" that occurs when trying to bring these programs and practices together.

In the same way, Shah and Ward (2003) analysed 1748 American companies in more than 39 different sectors, selecting 22 lean practices and through a factorial analysis. They concluded that they were grouped in four dimensions called: JIT, TPM, TQM and HRM. In the same way as previous authors showed the impact of lean dimensions on "operational performance". Later, Shah and Ward (2007), through an empirical study of 750 companies from different sectors analysed 48 practices and lean tools, which were grouped into 10 dimensions: Supplier feedback, JIT delivery, Supplier development, Customer involvement, Pull, Continuous flow, Setup reduction, Total Preventive Maintenance, Statistical Process Control and Employee involvement. At the end of their analysis they concluded that "LM is conceptually multifaceted, and its definition has philosophical characteristics that are often difficult to measure directly". Further, the practices used to measure LM, even when associated uniquely with a single component, indicate mutual support for multiple components.

The interest in LM practices has not yielded in the last decade by academics and researchers. In this way, Rahman et al. (2010) studied 187 Thai companies from different sectors, according to 13 lean practices. And they saw that these practices were grouped in three dimensions: JIT, Waste minimization, and Flow management. They also showed that these three dimensions are significantly related to operational efficiency.

Ghosh (2012) analysed 7 lean practices, in 79 Indian plants, in different sectors (automotive components, electric goods, machine tools, metal products and others) and different sizes (small, medium and big). He concluded an advanced use of lean practices and their high impact on manufacturing performance.

More recent studies as Sharma et. al (2015) analysed the impact of lean practices in the tool machine industry sector in India, seeing that the use of lean practices has a positive impact on the performance of organizations. Finally, Alaskari et. al (2016) developed a methodology to help small and medium enterprises (SMEs) select the appropriate lean tools, with the objective of obtaining maximum benefit from them.

From the literature review above, it is evident that many researchers have explored “LM practices” and their “competitive priorities” (operational performance) in different countries, sectors, and various sized companies and have found diverse LM practices and their impact in the company’s performance. Thus, we were motivated to explore the LM practices in the wind power (WP) sector.

So, we formulated the following research questions:

- **RQ1**: What is the “intensity of use” of LM in the wind power (WP) sector?

- **RQ2**: What are the different “dimensions” of LM practices are distinguished in the WP sector?

3.2.2. LM and competitive priorities

Manufacturing firms can only outperform competitors, if they can create competitive advantage that they can sustain (Himola et. al, 2015). Competitive advantage cam be created by offering customers superior value, either by providing the same benefits as competitors at a lower cost (cost advantage), or by providing benefits that exceed those of the competing offerings (value advantage) or both (Porter, 1996) .The competitive advantage was formulate in the business strategy and later be transferred to the functional manufacturing strategy (Hayes and Wheelwrigth, 1984). A principal element of manufacturing strategy is a pattern of decisions that firms make, which determine the competitive priorities of manufacturing systems. Typical dimensions of competitive priorities commonly used and included in the initial taxonomy of Miller and Roth (1994) and Frohlich and Dixon (2001) include cost, quality, on time delivery, flexibility, productivity, customer satisfaction. These six dimensions will be the competitive priorities we use to measure the impact of Lean practices.

Moreover according Ward et al. (1998) identified manufacturing competitive priorities, have been considered a key element in manufacturing strategy. Thus, we were motivated to explore the impact of LM practices in the wind power (WP) supply chain and their impact on the competitive priorities.

So, we formulated the following research question:

- **RQ3**: What is the relationship between the LM practices in competitive priorities in the WP sector?

3.3. Research Methodology

3.3.1. Data collection method

To achieve our goals, and based on the research questions above, we carried out our study in WP sector supply chain firms (raw materials suppliers, component suppliers and wind turbine manufacturers). The data collection method used was the survey questionnaire, and the questionnaire design itself was based on the above literature review; a total of 19 practices lean practices were selected for this study.

The questionnaire was initially reviewed by quality managers and academics, and then a pilot test was performed by quality professionals. The final version of the questionnaire had three sections. The first section comprised of questions about the company's profile (company name, respondents and their position in the company, number of employees, main products or services, etc.). The second section collected information about the usage and implantation of 19 lean practices in the WP sector. The answers were ranked on a five-point Likert scale (1 - very low use, 2 - low use, 3 - moderate use, 4 - high use, and 5 – very high use). Finally in the third section, we have analyzed the Lean practices and their impact on competitive priorities. As in section two, the answers were ranked on a five-point Likert scale. (See table 3.3.1-1)

Code	Variable description
Section 1. Companies profile	
P1	Company name
P2	Respondents
P3	Number of employees
P4	Main products or services
Section 2. Lean practices	
VL1	Cycle time and lead time reduction
VL2	Kaizen (continuous improvement)
VL3	Small lots sizes
VL4	Setup time reduction (SMED)
VL5	Kanban (pull system)
VL6	One piece flow production
VL7	Inventory reduction techniques
VL8	Waste / Muda reduction programs
VL9	5 S's
VL10	Total Preventive Maintenance (TPM)
VL11	There are total quality management programs (TQM)
VL12	Problem solving teams
VL13	5 Why's (analysis)

VL14	Multi-Skilled workers
VL15	Employee decision making (empowerment)
VL16	Cross functional teams
VL17	Poka Yoke (tools & devices)
VL18	VSM
VL19	Visual Plants Control (VPC)
Section 3. Lean practices and their impact on competitive priorities	
CP1	Impact on quality improvement
CP2	Impact on cost reduction
CP3	Impact on the improvement of delivery times
CP4	Rapid impact on volume changes and the introduction of new products
CP5	Impact on the productivity
CP6	Customer satisfaction

Table 3.3.1-1 Database variables

3.3.2. Sample characteristics

The survey was launched in May 2016, and 120 questionnaires were collected, from which 74 were retained for our analysis. A substantial number of respondents are global players and have been referred to in the WP sector's specialized journals such as MAKE Consulting (2013) or BTM Consult (2014) (See table 3.3.2-1).

We had access to these companies thanks to the position of one author's role as "Global Quality Director" of a wind turbine company. The companies selected for the survey are located in different regions around the world (Europe, Asia and Latin America) in countries such as Spain, France, Italy, Portugal, Germany, Denmark, China, Japan, Brazil and Mexico. In addition, these companies are key players in the wind power sector producing different components such as towers, blades, hub covers, pitch systems, main frames, main shafts, gearboxes, generators, converters, transformers, and mechanical brakes, hydraulic, lubricating and cooling systems and so on. Moreover, the companies surveyed are specialists in different technologies such as composites, castings, forgings, mechanical and electrical systems and devices, welding and machining etc.

The companies were contacted by phone and then sent the questionnaire via email in order to clarify the scope and objectives of the research. While the response rate was 65%, three questionnaires did have to be discarded because of incomplete answers. The reason for this high ratio of responses was a personalized follow-up of the questionnaires carried out by the authors.

Profile respondents in WP sector Supply Chain	**Number**	**%**
Position/role of the respondents		
Quality manager	10	14%
Quality engineer	7	9%
Process engineer	23	31%
Project manager	5	7%
General manager	6	8%
Plant manager	6	8%
Manufacturing manager	13	18%
Lean manager	4	5%
Total	74	100%
Groups of Components		
Assembly Wind Turbines	5	7%
Welding Components	4	5%
Towers	7	9%
Mechanical systems	16	22%
Bearings	3	4%
Electrical cabinets	4	5%
Electrical systems	9	12%
Blades and composites	4	5%
Castings, forgings and steel plates	5	7%
Machining (large size)	12	16%
Drive train	3	4%
Painting	2	3%
Total	74	100%
Companies size		
Large (>250)	20	27%
Medium (100-250)	21	28%
Small (<100)	33	45%
Total	74	100%

Table 3.3.2-1 Variables description

3.3.3. Analysis methodology

In order to answer our research questions, complementary statistical methodologies have been used.

First of all, and related with the intensity of use of LM in the WP sector (RQ1), we have done a descriptive and inferential statistical analysis of the usage and implementation of the 22 lean practices. The 95% confident intervals (Martin Pliego, 1994) have allowed us to find some significant statistical differences in the implementation and usage between some of the lean practices.

Secondly, linked with the different dimensions of LM practices in the WP sector (RQ2), we have realized a Principal Component Analysis (PCA) with varimax rotation using 19 of the 22 usage and implementation lean practices variables. This three variables have been removed because of the elevated number of missing's in the database, which precludes the PCA analysis (see table 3.3.3-1). As a multivariate technique that analyses a quantitative data table in which observations are several inter-correlated, has allowed us to extract the important information to represent a set of three principal components (Abdi and Williams, 2010; Stewart, 1993). The bundles were empirically validated using a confirmatory factor analysis (CFA) (Kline, 2010) to test whether the data fits a hypothesized measurement model (Preedy and Watson, 2009).

Variable description
Leveled production in the workshop/factory (Heijunka)
Performing JIT deliveries with suppliers
There are "teams" or "specific functions" for supplier development

Table 3.3.3-1 Lean practices variables removed from de PCA analysis

Finally, and related with what is the impact of LM practices in "competitive priorities" in the WP sector (RQ3) we have developed an inferential bivariate analysis. Pearson's correlation coefficient (Cook and Weisberg, 1982) would be useful to show some significant relationships between the bundles and the competitive priorities variables. ANOVA test (Massart et al, 1997) will be used to measure the relationship between the constructs and the company size.

3.4. Results

We have divided this section into three subsections: (i) a descriptive analysis of the use of LM practices and the competitive manufacturing priorities, (ii) an exploratory factor analysis (EFA) of lean practices use in the WP sector and, finally, (iii) a descriptive and inferential bivariate analysis between the competitive priorities and the groups of lean practices dimensions obtained in the CPA.

3.4.1. Descriptive analysis for LM practices

Table 3.4.1-1 depicts LM practices use and degree of use, defined by the mean and standard deviation of the received punctuations using the Liker scale.

Code	Variable	N	Min	Max	Mean	St D	IC 95%	%
VL1	Cycle time and lead time reduction	74	1,0	5,0	3,41	1,13	3,14 - 3,67	68 %
VL2	Kaizen (continuous improvement)	74	1,0	5,0	3,03	1,28	2,73 - 3,32	61 %
VL3	Small lots sizes	74	1,0	5,0	2,85	1,14	2,59 - 3,12	57 %
VL4	Setup time reduction (SMED)	74	1,0	5,0	2,50	1,13	2,24 - 2,76	50 %
VL5	Kanban (pull system)	74	1,0	5,0	2,89	1,40	2,57 - 3,22	58 %
VL6	One piece flow production	74	1,0	5,0	2,96	1,37	2,64 - 3,28	59 %
VL7	Inventory reduction techniques	74	1,0	5,0	2,93	0,95	2,71 - 3,15	58 %
VL8	Waste / Muda reduction programs	74	1,0	5,0	2,69	1,05	2,45 - 2,93	53 %
VL9	5 S's	74	1,0	5,0	3,04	1,40	2,71 - 3,36	61 %
VL10	Total Preventive Maintenance (TPM	74	1,0	7,0	2,89	1,27	2,60 - 3,19	58 %
VL11	Total quality management (TQM)	74	1,0	5,0	2,65	1,07	2,40 - 2,90	53 %
VL12	Problem solving teams	74	1,0	5,0	3,19	1,07	2,94 - 3,44	64 %
VL13	5 Why's (analysis)	74	1,0	5,0	3,04	1,18	2,77 - 3,31	61 %
VL14	Multi-Skilled workers	74	1,0	5,0	2,97	1,01	2,73 - 3,20	59 %
VL15	Employee decision making	74	1,0	5,0	2,89	1,00	2,66 - 3,12	58 %
VL16	Cross functional teams	74	1,0	5,0	2,95	1,03	2,71 - 3,19	59 %
VL17	Poka Yoke (tools & devices)	74	1,0	5,0	2,89	1,22	2,61 - 3,18	58 %
VL18	VSM	74	1,0	5,0	2,27	1,16	2,00 - 2,54	45 %
VL19	Visual Plants Control (VPC)	74	1,0	5,0	3,14	0,98	2,90 - 3,36	63 %

Table 3.4.1-1 Lean practices descriptive statistics

The maximum punctuation corresponds to the Cycle time and lead time reduction (68%) and the minimum refers to the VSM (45%). The average pondered total punctuation is 57%. Regards to this pondered mean we can conclude that the more used tools are related to the Cycle time and lead time reductions, the problem solving teams, the visual plants control, the use of 5 S's, the 5 Why's analysis and the continuous improvement.

On the other hand, we see that waste/muda reduction programs, the total quality management programs, the existence of teams or specific functions for supplier development, the setup time reduction, the leveled production in the workshop and the VSM are tools with less usage than the global average.

Finally, we observe that visual plants control and Inventory reduction techniques are those tools with more homogenous punctuation. And the VSM and Leveled production in the workshop/factory are the more heterogonous ones.

As in figure 3.4.1-1 it's shown, there are some population significant differences in the Lean manufacturing practices punctuations.

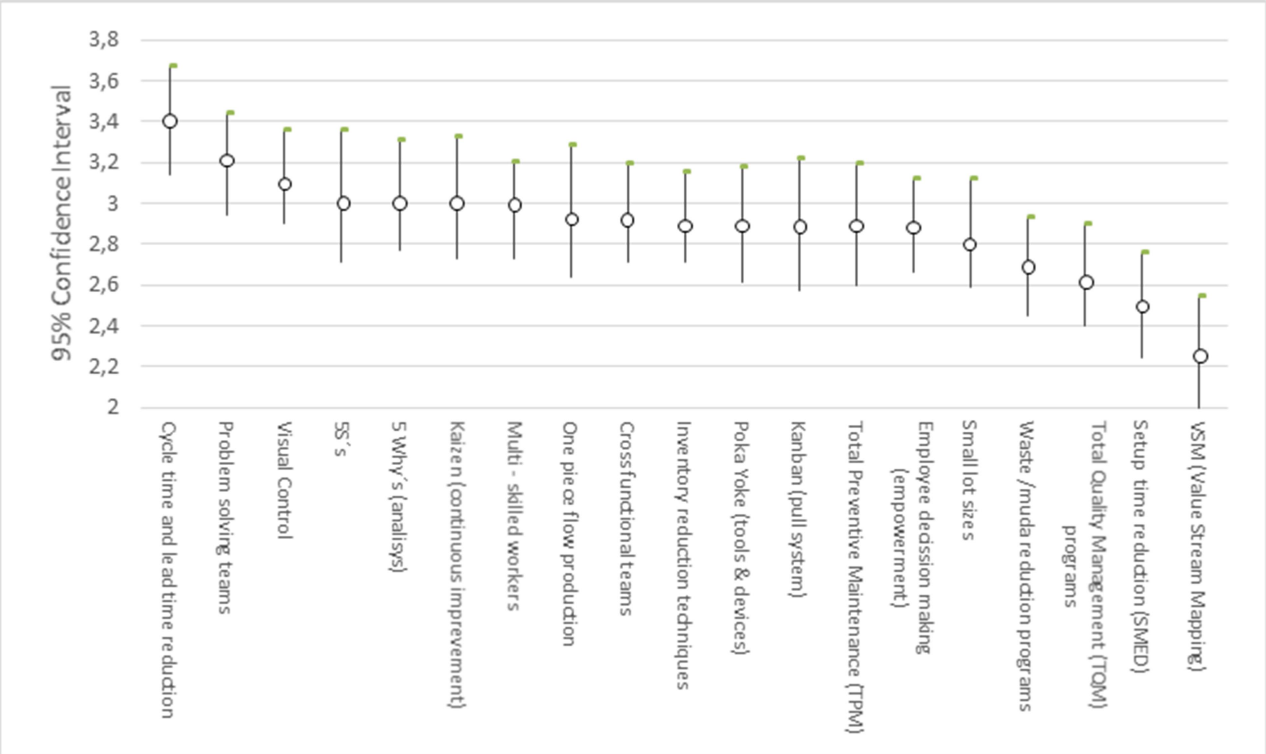

Figure 3.4.1-1 Confidence intervals

3.4.2. Exploratory Factor Analysis (EFA)

In total, 19 lean practices were subjected to the principal component analysis with Varimax rotation to examine their unidimensionality. Related to the goodness of fit, Kaiser-Meyer-Olkin test (>0,6) shows us that all the correlation coefficients between active variables are bigger than 0,3. Also, Bartlett's Test of Sphericity is statistically significant (see table 3.4.2-1) (Morales, 2013).

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0,898
Bartlett's Test of Sphericity	Approx. Chi-Square	836,448
	Df.	171
	Sig	0,000

Table 3.4.2-1 KMO and Bartlett's test

The reliability analysis shows that the Cronbach's alpha value for all of constructs is above the threshold value of 0.6, confirming that these constructs are reliable (Nunnaally, 1967).

	Lean Constructs			
	F1 - Create flow management	F2 - Waste minimization	F3 - Human and cultural management	F4 - Way of working
Total variance explained (%)	51,95	28,70	24,04	19,25
Cronbach´s alpha	0,949	0,862	0,824	0,767

Table 3.4.2-2 Reliability analysis

As it's shown in table 3.4.2-2, the principal component analysis produced four higher level constructs. These are (F1) "Create flow management" (six scales), (F2) "Waste minimization" (six scales), (F3) "Human and cultural management" (three scales), and finally (F4) "Way of working" (four scales). The name of the factors was done according to the statements including in every factor.

Furthermore, all the factor loadings of the scales exceed the 0.5 limit indicating that the scales are valid (Hair et al, 1998) (see table 3.4.2-3).

Lean practices	Lean Constructs			
	F1- Create flow management	F2 - Waste minimization	F3 - Human and cultural management	F4 - Way of working
Cycle time and lead time reduction		0,743		
Kaizen (continuous improvement)		0,611		
Small lots sizes		0,725		
Setup time reduction (SMED)		0,525		
Kanban (pull system)	0,725			
One piece flow production	0,770			
Inventory reduction techniques		0,669		
Waste / Muda reduction programs		0,683		
5 S's	0,814			
Total Preventive Maintenance (TPM)				0,749
Total quality management (TQM)				0,680
Problem solving teams				0,578
5 Why's (analysis)				0,424
Multi-Skilled workers			0,777	
Employee decision making (Empowerment)			0,775	
Cross functional teams			0,464	
Poka Yoke (tools & devices)	0,621			
VSM	0,637			
Visual Plants Control (VPC)	0,612			

Table 3.4.2-3 The four higher levels constructs of LM

3.4.3. Confirmatory Factor Analysis (CFA)

In order to test whether measures of the construct are consistent with previous EFA findings, we have executed a CFA analysis (Thomson, 2004).

Unlike other statistical methods, CFA analysis requires more than one statistical test to determine how well the model fits the data (Suhr, 2006). Following Kline (2010), model fit has been assessed using the chi-squared test and the Turkey and Lewi's Index (TLI), Root Mean Square Error of Approximation (RMSEA) point estimate and 90% CI, Comparative Fit Index (CFI) and Root Mean Residual (RMR) values (see table 3.4.3-1). The factor loadings, uniqueness's, path coefficients, covariance, correlations, standard errors, t values, and SMCs were inspected for appropriate sign and/or magnitude.

f	χ^2	TLI	CFI	RMSEA (90% CI)	RMR
146	196,059	0.92	0.93	0.07 (0.04-0.09)	0.09

Table 3.4.3-1 SEM Analyses testing

Regarding to the chi-squared test, the CFA indicates that four factors model did not represent an entirely acceptable fit ($\chi 2$=196.059, df=146, $p<0.05$). Furthermore, although RMSEA index gives us an acceptable fit, TLI, CFI and RMR index reach values a little bit lower than the ones expected for a suitable fit (Browne, 1993).

An alternative to the goodness-of-fit test, is find misspecifications in the model using the combination of Expected Parameters Change (EPC) and the Modification Index (MI) (Saris, 2009). Regarding to this alternative analysis, we have found small changes in parameters and in the reduction of the test statistic so, according to Saris (1987) it does not make sense to introduce these new parameters, although chi-squared test is significant.

Otherwise, size sample can affect directly to the model goodness-of-fit. According to Wolf (2013), required sample size ranged from 30 cases (for one-factor CFA with four indicators) to 460 (for two-factor CFA with tree indicators). And although the number of indicators per factor may be one way to compensate a small sample size and preserve statistical power, it's possible that our sample size couldn't be enough to achieve a suitable fit in spite of the correct construct.

3.4.4. Relationship between LM practices and competitive priorities

In this section, we analyze, through the four constructs, the relationship between the LM practices and their impact on the "competitive priorities", including customer satisfaction and the size enterprise.

The bivariate correlation is statistically significant between our four constructs and many of the six competitive priorities. As we can see in table 3.4.4-1, all the significant relationships are positive, so we can affirm that as bigger is the score in the lean practices, stronger is the impact on the competitive priorities.

Pearson's correlation	F1 - Create flow management	F2 - Waste minimization	F3 - Human and cultural management	F4 -Way of working
Quality	0,062	0,278*	0,035	0,294*
Cost	0,382**	0,337**	0,269*	0,268*
On time delivery	0,306**	0,363**	0,292*	0,116
Flexibility	-0,017	0,348**	0,281*	0,053
Productivity	0,396**	0,351**	0,300**	0,221
Customer satisfaction	-0,046	0,145	0,180	0,296*
*** Correlation is significant at the 0.01 level (2-tailed)* ** Correlation is significant at the 0.05 level (2-tailed)*				

Table 3.4.4-1 Pearson's correlation coefficient between Factors and Competitive Priorities

Create flow management (F1) has a strong positive significant relationship with the impact on cost reduction, on the improvement of delivery times and on the productivity. Waste minimization (F2) has a positive relationship with all the competitive priorities except on the customer satisfaction. The Human and cultural management (F3) has a positive relationship with the impact on cost reduction, on the improvement of delivery times and on volume changes and the introduction of new products.

Also, this construct has a strong relationship with the impact on the productivity. Finally, the Way of working (F4), has a positive relationship with the impact on quality improvement, on cost reduction and on customer satisfaction.

Size enterprise has only a significant statistical relationship with the first construct (see table 3.4.4-2). So, little enterprises (less than 100 workers) score the lean practices variables included in F1 (Create flow management) worse than big ones (more than 250 workers) or medium ones (from 101 to 250 workers) enterprises, respectively.

Size Enterprise		F1 - Create flow management	F2 - Waste minimization	F3 - Human and cultural management	F4 - Way of working
Less than 100 workers	Mean	-0,449	-0,175	0,076	-0,123
	N	32	32	32	32
	Std. Deviation	1,064	0,820	1,054	0,894
From 101 to 250 workers	Mean	0,439	0,008	-0,158	-0,106
	N	18	18	18	18
	Std. Deviation	0,879	1,066	1,047	1,060
More than 250 workers	Mean	0,269	0,228	0,017	0,244
	N	24	24	24	24
	Std. Deviation	0,755	1,154	0,916	1,084
Eta coefficient		0,399	0,175	0,094	0,170
p-value		0,002	0,333	0,730	0,352

Table 3.4.4-2 ANOVA test between factors and size enterprise

3.5. Discussion and findings

3.5.1. Descriptive analysis

In this section we analyse and discuss the frequency and intensity of the use of LM practices firms along the WP supply chain, through the analysis of descriptive statistics

It is important to emphasize those results and discussions of this study, regarding the use of LM practices, are supported by dozens of visits and interviews to different agents of the SC of the sector. Most of them are referenced in prestigious magazines of the sector such as MAKE or BTM. The information has been validated because, for professional reasons, one of the authors of this article (more than 15 years of experience in the sector) has been developing activities related to the SCM, to SQA (Supplier Quality Assurance) in Quality management systems, to production capacity, to process and product audits in a Wind Turbine Manufacturer. The experience based on personal interviews and monitoring of improvement plans derived from these activities, has given us the opportunity to analyse the implementation, the daily use of these practices, their strengths and weaknesses applied to the sector, as well as their contribution to the profits of companies of most of the LM practices described here in firms. For this reason, we want to emphasize that one of the major contributions of this article is to have been able to contrast the empirical data of our research with the real evidences of the daily practices of the sector, obtained by means of visits and interviews to the different enterprises along the SC of the sector.

Regarding to the intensity and frequency of the use of LM practices, we can say that the most used techniques are the "cycle time and lead time reduction" (68%). From the results obtained in this study and the interviews and visits made to the members of the SC of the sector, we can say that in general the sector is very focused on reducing the times of lead times of materials in the operation stages. Since the variability of the lead times of the components, from 1 week to 7 months (Castelló et al.; 2016) and the different conditions of payment according to each country, requires manufacturers of wind turbines large amounts of "working capital "In the SC.

Secondly, we found "problem solving teams" (64%). Due to the technological complexity of the sector, customers contractual requirements in terms of availability of wind turbines (97.5% minimum), the reduced time to market, as well as the successive integration problems of the components and Systems (such as communication between converters, generators, transformers, multipliers, etc.), makes it necessary to use multidisciplinary equipment for product and process engineering, quality, design, etc. both for wind turbine manufacturers and their suppliers with the objective of giving solution to the frequent problems that appear in the phases of launching of the product, as well as in its stabilization phase.

In the third and fourth ranking we have the “visual control” (63%) and the “5S's Programs” (61%), standard practices typically used in the early stages of the LM implementations with the clear purpose of establishing order and cleaning (everything in its place) in shop floors and give visibility (using graphs and KPIs) to everything that happens there (Liker and Meier, 2006; Lane 2007). These practices are followed by the "5 Why's" (61%) and the Kaizen (61%) practices in habitual LM implementations with the aim of analysing the problems (Liker and Meier, 2006) and initiating continuous improvement processes (Ohno 1993, Imai 1989). These practices are used in order to keep the jobs clean and orderly, have a visual control of what happens in the factory and seek stability in the processes eliminating potential variability causes (Suzaki, 1987, Liker and Meier, 2006, Lane 2007).

According to table 3.4.1-1 and figure 3.4.1-1, it is evident that there is a group of LM practices of minor use, such as "the multi-skilled workers” (59%), "Cross functional teams” (59%), "kanban Pull systems” (58%), “poka-yoke” (58%), "TPM” (58%), etc. Which according to Mondem (1983), Smalley (2004), Liker and Meier (2006) and Lane (2007) are part of the daily practices and activities of LM systems. According to our visits and interviews with the different (stakeholders) which are members of the supply chain of the sector, we can say that this lower intensity in terms of the use of these practices is due to the low manufacturing volumes in this sector compared to other sectors referenced in the literature such as the automotive sector or the commodities sector.

Finally we find the block of practices less used in the sector. Among these practices are the “SMED” (50%), the “levelling of Heijunka" (47%) and “VSM” (45%) which they are production practices very mentioned in the literature (Suzaki, 1987; Tapping et. al, 2002; Liker and Meier, 2006; Lane, 2007), both from the point of view of empirical studies and conceptual theorists. However they have less application in this sector than in general. From the achieved interviews during the visits to the plants and managers of the sector, they affirm that due to the type of demand of the product and the typology of the same, it is normal a low use of the practices SMED as well as the levelling techniques because of production planning is generally based in low volume manufacturing lots, due to the type of product and fluctuating demand on the market. On the contrary, it is surprising to see the low use of typical practices such as VSM, frequently used in the early stages of LM implementation (Rother and Shook, 1998, Tapping et al., 2002) to map value flow, to eliminate waste and create flow by detecting opportunities for improvement (Womack and Jones, 1996).

The moderate percentage in terms of the use of LM practices reveals that the WP sector is in a phase of growth and evolution in terms of the use of LM practices and philosophy. In addition, based on visits to different suppliers, assembly plants and interviews with different managers and technicians of the sector we could state that is not possible to apply the same LM practices in all industrial sectors, or with the same intensity of them. However, the preliminary conclusion is that they must be adapted to the needs of each sector and each market.

On the other hand, it should be noted that some of these practices as the VSM in order to create flow, or SMED to eliminate waste, which are less used, are not intuitive tools such as visual control, or 5why's and thus, it is necessary the support of experts or external consultants for its implementation. This could be one of the reasons of the less use of them.

Therefore with respect to the first question RQ1:

> **RQ1**: What is the "individual level use" of LM tools and techniques in the WP sector?

We can say that the supply chain of the WP sector, there is a moderate use of LM practices with respect to other sectors described in the academic literature.

3.5.2. LM practices by "dimensions"

The exploratory factor analysis (EFA) has grouped the LM practices of the sector into four large dimensions.

The first dimension (F1) corresponds to practices for "create flow management", among which practical practices such as Value Stream Map (VSM), Kanban, one-piece-flow, Poka-Yoke, Visual Control and 5S. It is associated with the philosophical part of lean, where authors such as Womack and Jones (1996) propose the 5 steps of lean thinking for value creation. They are (1) specify value; (2) identify the value stream; (3) flow; (4) pull; and (5) perfection. In the same way Liker (2004) reveals a philosophical part of the lean environment, based on the 4P's (1) philosophy; (2) process; (3) people and partners; and (4) problem solving. We can therefore say that according to the academic literature, the first dimension of our study (F1), which we have called "create flow management", corresponds to a component with a more philosophical approach to LM.

The second dimension (F2) that we called "waste minimization" is more focused on those LM practices that are used in the workshops and that help us eliminate waste (Ohno, 1988; Shingo 1992), reducing the Lead Time of the processes. These include: small lot sizes reduction, cycle time and lead time reduction, inventory reduction techniques, waste reduction programs, setup time reduction (SMED) and Kaizen or continuous improvement. Our findings fit with authors such as Suzaki (1987), Liker and Meier (2006) and Lane (2007) who have focused their studies on analysing techniques for waste disposal.

The third dimension detected in our study (F3), we called "Human and cultural management" among which we find practices such as: the versatility of workers, multifunction teams and decision making by the worker (empowerment). This dimension is consistent with other works in the literature where authors such as Ohno (1988) Spear and Bowen (1999) and Liker (2004) where they demonstrated that lean is not only a package of practices and tools, but also Human and cultural aspects and that they are critical factors for lean implementation. Hence, some companies in the West have failed in their attempts to implement only a tool-box and leave aside the human and cultural factor (Cusumano, 1992; Spear and Bowen, 1999; Watson, 2006).

Finally the fourth dimension found (F4), we called "way of working" groups practices and programs such as TPM, TQM, and problem solving groups and 5 why's. From our point of view, they are organizational and structural programs whose mission is to give a framework to LM implementation. Although authors such as Shah and Ward (2003) have classified TPM and TQM as lean dimensions, other authors like Cua et. Al (2001) has classified them as management programs.

After that, facing our research question,

> **RQ2**: What are the different “dimensions” of LM in the WP sector?

We affirm that in the WP sector supply chain, there are four dimensions of lean. The first dimension (F1) "Create flow management" is closer to the philosophical part of lean thinking with the aim of creating maximum value to the end customer. A second dimension (F2) "waste minimization" is oriented to the use of practices in the shop floor environment with the aim of eliminating all types of waste. The third dimension (F3) "Human and cultural management" is focused on integrating culture and people into lean thinking and finally the fourth dimension (f4) “way of working” integrates different practices and programs to structure and support lean thinking.

In this sense we can validate with the obtained results that LM from the point of view of WP sector, in a firm environment system, whose objective is to create the maximum value to the client, minimizing resources to the maximum, and relying on the knowledge and skills of the people.

3.5.3. LM practices and their impact in the competitive priorities

In this section, we analysed the impact of LM dimensions from the EFA, with respect to the competitive priorities. The results are shown is table 3.4.4-1**.**

With respect to the "Quality", we affirm that there is a significant correlation between the dimensions F2 (waste minimization) and F4 (way of working). But it is surprising that there is no correlation with F3 (human and cultural management). Our findings do not agree with the conceptual and theoretical works of Womack and Jones (1996) and (Liker, 2004) where the human factor, and has impact on the quality priority.

With respect to the "Cost", we see that there is correlation with all dimensions of the LM. The results of our study agree with the majority of authors in the academic literature (Womack and Jones, 1996; Shah and Ward, 2003; Liker, 2004).

With respect to the "On time delivery" we see that there is a strong and significant correlation with (F1) Create flow management, (F2) waste elimination, (F3) Human and cultural management. But there is no correlation with the dimension (F4) Way of working. The variable of “Delivery Date” is key in this sector where many of production orders are based on large projects depending on many correlated actions.

As regards "Flexibility" we see that there is a strong significant correlation with F2 “Waste minimization” and a significant correlation with F3 “Human and cultural management”. In this paper our findings are in agree with Liker (2004) and Spear and Bowen (1999) where the human factor has a main role in the flexibility of organizations.

With respect to "Productivity", we affirm that there is a strong and significant correlation with all the dimensions of the LM, (F1) Create flow management, (F2) waste elimination, (F3) Human and cultural management. But on the contrary it is surprising to see that there is no correlation with the dimension (F4) Way of working. This is the same behaviour that “On time delivery”.

Finally, from table 3.3.4-1 we can see that the competitive priority of "customer satisfaction" is significantly correlated with (F4) Way of working. But surprisingly it is not correlated with the other dimensions. This could be one the highlights of this contribution because the roots of lean implementations (represented by F1, F2, and F3) has not impact on “customer satisfaction”.

Therefore with regard to question RQ3:

> **RQ3**: What is the relationship between the LM practices in “competitive priorities” in the WP sector?

We state that our study shows that the use of LM practices in the supply chain of the WP sector has a high impact on competitive priorities, even though depending on dimensions the impact differs between competitive priorities.

3.6. Conclusions

Several conclusions are drawn from our study. The first conclusion is that there is a moderate use of LM practices in the supply chain of the WP sector. Where "cycle time and lead time reduction", "problem solving groups", and "visual control at the plant" are the most commonly used LM practices. In contrast, VSM and SMED are the least used. This moderate use of LM practices shows us that the supply chain of the WP sector, although they know and use these practices, is still in the process of consolidating them. However, based on descriptive analysis results, we demonstrated this use of lean practices has a high impact on competitive priorities (quality, cost, on time delivery, flexibility, productivity and customer satisfaction).

Secondly, we can affirm from our study that the WP sector clearly shows four dimensions that group the lean concept. A first dimension that is formed by practices related to "create flow management"; A second dimension that is formed by the practices related to the "waste minimisation"; and the last two dimensions related to the culture and the people, that we have called "Human and cultural management" and "way of work" to give support and integration of the whole system LM.

Finally, through a correlational matrix, we have been able to associate "competitive priorities" with the dimensions in our factor analysis (EFA), which has made it clear that "cost", "Delivery time" and "Productivity" are related to "create flow management "," waste minimisation ", and cultural management of human resources" (human and cultural management).

We have also been surprised that the "quality" competitive priority has only been correlated with the "waste minimisation" and "way of work" dimension and finally we have also found that "customer satisfaction" is surprisingly not correlated with "creation of flow" nor with "waste minimization" and it is only correlated with one of the dimensions of "human resources management".

3.6.1. Practical Implications

This study could be considered as a starting point for further studies related to the use of LM practices in the wind power sector and other high technology sectors. Moreover, this research contributes to bridging the gap found in the literature between the use of LM practices and their relationship with the "competitive priorities".

This study also has certain implications for WP sector managers, since it shows that it is still necessary to continue to consolidate the implementation of these practices in the sector. Also this study shows that lean practices vary from company to company and from sector to sector and consequently it is not possible to apply lean practices with the same intensity.

In addition, it has also revealed to us that the cultural human factor is a priority element in the implementation of the LM. And finally this study also revealed to us the overlap existing in the literature between lean practices and "management programs" like TQM, TPM

3.6.2. Research limitations and future research recommendations

This study has certain limitations. Firstly, it is focused on the sector WP, so the conclusions that are derived from it are applicable only to this sector, although you can also be extrapolated to similar high tech sectors. The main characteristics are (1) demand is unpredictable and uncertain; (2) manufacturing volumes are low, and (3) there is a high degree of customization of products.

Moreover, the simple size for this study was not large enough, generalizations from this study to the population need to be made with caution. Moreover the study only concentrated on wind power supply chain.

Finally, we are aware that the CFA analysis does not fit perfectly due to, as above mentioned, insufficient sample size. Even so, the goodness-fit values obtained differ slightly from the ones expected for a suitable fit. This fact, and the coherence in the construct, reaffirms us in the belief that this is a suitable model to aim the objectives set.

In addition, this study also wants to motivate academics and managers to open different lines of research regarding the use of LM practices, in sectors with the three characteristics we have point out in the former paragraph.

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3.8. Attachments

Lean Manufacturing Assessment

Company name:
Nº Employees :
Position of the person answering :

Sector:
Components:

Level of use (intensity) Quality tools and Techniques

Question to answer :

What is the "intensity of use" of the Lean manufacturing tools and techniques in the company?

		Mark with an "X"				
	Lean manufacturing tools and techniques assessment	Very low	Low	Moderate	High	Very high
1	Cycle time and lead time					
2	Continuous improvement programs (Kaizem)					
3	Small lots sizes					
4	Setup time reduction (SMED)					
5	Kanban (pull system)					
6	One piece flow production					
7	Inventory reduction techniques					
8	Jit deliveries with suppliers					
9	Teams to develop suppliers					
10	Waste / Muda reduction programs					
11	5 S´s					
12	Leveled production in the workshop (Heijunka)					
13	Total Preventive Maintenance (TPM)					
14	Total Quality Management programs (TQM)					
15	Problem solving teams					
16	5 Why´s (analysis)					
17	Multi- Skilled workers					
18	Employee decision making (empowerment)					
19	Cross functional teams					
20	Poka Yoke (tools & devices)					
21	Value Stream Map technique's (WSM)					
22	Visual control Plants (VCP)					

Question to answer :

What is the "relationship" between of the Lean manufacturing tools and techniques in their impact in the competitive priorities?

		Mark with an "X"				
	Lean manufacturing tools and techniques - Impact on competitive priorities	Very low	Low	Moderate	High	Very high
1	Quality (improve the quality, reduce scrap, etc.)					
2	Cost (impact on products cost reduction)					
3	Delivery time (improve the delivery time)					
4	Flexibility (in front to the volume changes; quick response to the new products, etc.)					
5	Productivity (increase and improve the productivity)					
6	Improve customer satisfaction					

Part III

Aspects related to **Quality Management**

Chapter Nº4

ISO 9001 Aspects related to performance and their level of implementation

4. ISO 9001 Aspects related to performance and their level of implementation

Abstract

Purpose: In the last three decades, thousands of companies around the world have embraced the ISO 9001 standard in their quest to improve company performance and customer satisfaction. In recent literature, a number of authors have identified different “levels” of ISO 9001 implementation. This study aims to analyse these implementation levels in companies from the point of view of the customer, and provide guidelines for future improvement.

Design/methodology/approach: Research was conducted based on the results of the second-party audits (SPAs) of 90 suppliers, (including component suppliers, assemblers, and wind farm operation and maintenance services), to one of the wind power industry’s largest wind turbine manufacturers. The audits were carried out within the ISO 9001:2008 framework and conducted by one of this study’s authors in his role as the wind turbine company’s Director of Global Quality.

Findings: Auditing suppliers plays a unique role in helping to isolate system weaknesses, identify opportunities and suggest areas for improvement. This study shows that, in terms of management commitment and culture and the good practices of an organization, ISO 9001 certified companies implement differing degrees of the standard. From the results of this research, a "road map" towards improvement can be established; one that allows companies in the sector to go beyond simply being accredited with the standard and instead to take advantage of ISO 9001 certification as a catalyst for change.

Research limitations/implications: This article focuses only on the wind power sector, although its findings could be extrapolated to similar sectors of high technology and high levels of customization.

Originality/value: While quality audits are a customary topic for academics and researchers, few contributions are related to SPAs and their impact on the quality control process of company suppliers. Primary data from the SPAs of suppliers (objective data collected by one of the paper’s authors), was used here and is one of the most valuable aspects of this paper’s contribution.

Keywords: ISO 9001, supplier audit, second/third party audits, implementation level, factor analysis, wind power sector

4.1. Introduction

In the past three decades, thousands of companies around the world have embraced the ISO 9001 standard in their quest to improve company performance and customer satisfaction. However, despite having been internationally recognized and widely accepted since its publication in 1987, the standard has been subject to controversy and criticism concerning the success or failure of its implementation and/or whether its costs outweigh the performance benefits for companies.

The literature is full of research articles describing ISO 9001 certification successes and failures and the resulting impacts on company profits and performance. For instance, Curkovic and Pagell (1999) point out that ISO 9001 is not connected directly to product quality, and Naveh and Marcus (2005) emphasize that a certified company could still have substandard processes and products because certification does not instruct the company on how to design more reliable and efficient products. Romano (2002) reported that ISO 9001 certification is a letter of access (a visiting card) for many companies and Sroufe and Curkovic (2008) state that, “ISO registration alone is not enough to do anything beyond ensure compliance with the registration standard”. Some authors refer to the certification as a “meaningless piece of paper” which is nothing but a cost to a company. Other researchers argue that certification does not ensure an improvement in a firm’s performance (Anderson, Daly & Johnson, 1999; Dimara, Skuras, Tsekouras, & Goutsos, 2004; Morris, 2006; Power & Terziovski, 2007; Tsekouras, Dimara, & Skuras, 2002) and there are many studies that show companies who have adopted ISO 9001 certification as a result of customer pressure (Anderson et al., 1999; Davis, 2004; Martínez-Costa, Martínez-Lorente & Choi, 2008).

Nevertheless, it is not all criticism and controversy. There are studies that highlight how ISO 9001 can help companies improve their performance and efficiency. Some point out that certification improves product and service quality as well as collaboration with suppliers, and reduces customer complaints and internal costs, thus boosting company profitability (Zaramdini, 2007; Casadesús & Karapetrovic, 2005), while others stress that certification strengthens workforce motivation, increases market share and facilitates the international expansion of the company (Brown, van der Wiele & Loughton, 1998; Zaramdini, 2007). Chow-Chua, Goh and Boon Wan (2003) also note that ISO certification improves processes and procedures, enhances a company’s image in the marketplace, as well as assisting its international expansion.

As a result of the controversy aroused by the ISO 9001 standard and its supposed strengths and weaknesses, we were motivated to analyse to what levels it has been implemented in the wind energy sector by means of second-party audits (SPA).

4.2. Literature review and research objectives

4.2.1. Quality Audits

For many years the quality audit has played an important role in an organization's quality management system. Initially used to control financial statements, it has gone on to become a useful management tool in business competitiveness and performance.

ISO 9001 accreditation requires a third-party audit (TPA) certification process to evaluate whether the quality management system complies with the standard's requirements. TPAs are performed by external, independent certification bodies free of any conflict of interest and thus, a key component of a TPA. However, after more than two decades of using TPAs, many quality and manufacturing managers and professionals do not see the value in or the need for them. Some studies reveal significant differences between the perceptions (in terms of profits, performance, standard compliance, improvements, etc.) of auditing that customers have and those that the auditors themselves have (Power & Terziovski, 2007; Castka, Prajogo, Sohal & Yeung, 2015). Consequently, there is no better understanding in how academics and practitioners perceive the TPAs process either (Kluse, 2013).

TPAs and their efficiency is a very commonplace theme for many academics and researchers, but very few a have actually focussed their work on SPAs, i.e. when a company performs an audit of a supplier and the impact they have on the whole quality control process (Ferencikova & Bris, 2013) as well as in the process improvement (Prasad, Kamath, Barkur & Nayak, 2016).

The study carried out by Power and Terziovski (2007), highlights a number of differences in perceptions of auditing that customers and auditors have in terms of compliance versus improvement. Karapetrovic and Willborn (2000) point out that the quality audits typically evaluate whether the QMS activities conform to the documented procedures are effectively implemented and suitable for achieving the quality targets proposed.

In some industrial sectors, for instance the automotive sector, power systems, oil and gas, wind energy, aerospace and the food industry, purchasing managers push for ISO certification (TPAs) of their suppliers bidding for some projects or tenders. Following this, the customer quality team will later perform SPAs of the same suppliers in order to ensure product quality. However, TPAs, from the managers and practitioners' point of view, only consume resources, time, and money and do not add any value to the company.

4.2.2. ISO 9001 implementation levels

In recent literature, several authors have identified different "levels of implementation" of the ISO 9001 standard.

Naveh and Marcus (2004) classified ISO 9001 into two major levels based on practical issues: (i) assimilation, which means establishing rules that allow an organization to effectively adhere to ISO 9001 (quality manual, policies and procedures) and coordinating with external suppliers and customers so that the requirements of the standards fit the needs of the stakeholders, and (ii) go beyond, where the ISO 9001 is used as a springboard for developing additional quality initiatives. In other words, simply being ISO 9001 is not enough, the standard must be used in daily practice and as a catalyst for change (Naveh & Marcus, 2005).

Sroufe and Curkovic (2008), working with the Miles and Snow (1978) framework, classified the different levels of the ISO implementation into (i) defenders, (ii) reactors, (iii) analysers and (vi) prospectors. Defenders look firstly at improving efficiency in existing operations and are focused on cost. Reactors perceive ISO certification as a cost of doing business, and may struggle with finding any real benefits from ISO certification. Analysers include firms that usually operate in two types of product-market, one which is relatively stable and the other which is changeable. While analysers are successfully operating in more than one product domain, they do not have ISO certification for all those domains. Finally, prospectors' firms are continuously searching for new market opportunities and perceive ISO certification as a new opportunity to achieve competitive advantages.

Prajogo, Huo and Han (2012) identified the following three levels of the ISO 9000 implementation, (i) basic (ii) advanced and (iii) supportive.

Basic implementation is when the company strictly follows the ISO 9001 requirements. According to Bradley (1994) and Naveh and Marcus (2005), while these practices are an important first step, they are not enough to yield successful improvements. Advanced implementation is when, rather than considering certification as an end point, the company uses the ISO 9000 as a stimulus for rethinking how it could conduct its business more effectively. Finally, supportive implementation is when top management takes an active (and key) role in a number of crucial resource support areas such as fostering a quality culture, supervising employee behaviour, arranging training programs for employees in order to facilitate skill improvements, and ensuring that a continuous improvement cycle exists within the organization (Sing, 2008; Nair & Prajogo, 2009).

However, the way a supplier belongs to one category or another very much depends on the result of the audit carried out by their customer. In these audits it is possible to qualify the implementation levels of every aspect of ISO 9001 and help the customer to determine if the supplier is more focused on accomplishing quality assurance procedures, than on product or production processes. In other words, to determine if they are good suppliers or if there is room for improvement.

4.2.3. Research Objectives

The aim of this research is to analyse the levels of implementation of the international standard ISO 9001 in the wind power (WP) sector from the point of view of the customer, and provide guidelines for future improvement.

This study also seeks to address the lack of empirical evidence on the relationship between ISO 9001 implementation and SPAs that an extensive literature review revealed.

- Our primary objective is to determine which of the ISO 9001 aspects have an impact on the level of ISO 9001 implementation. The way to achieve this is through a data analysis of the SPAs collected by a manufacturer in the WP sector. Using these audits, the manufacturer classifies its suppliers into three categories, and we assume these correspond to the implementation of ISO standards found in the literature.

- Our secondary objective is to define the constructs, i.e. the ISO aspects which are correlated in the audits a firm makes of its suppliers, and to measure the impact these constructs have on the level of adoption as determined by the customer company.

4.3. Methodology

In order to achieve our objectives, the research was carried out in WP sector supply chain firms (i.e. raw materials, component suppliers, assemblers, and wind farm operation and maintenance services).

An extensive literature review reveals there is little empirical evidence of the relationship between ISO 9001 implementation and supplier activities (Lo & Yeung, 2006; Prajogo et al., 2012). The majority of the contributions referenced in the literature review section are based on surveys (subjective data). In this paper we use primary data (objective data) from the SPAs of suppliers. One of this paper's authors is the Director of Global Quality for the wind turbine manufacturer concerned and has collected and compiled data from the audits of suppliers which, in turn, is one of the most valuable aspects of this paper's contribution.

The data used here are based on the audits of 90 technical suppliers to one of the largest wind turbine manufacturers and ranked in the top 15 largest companies in the sector in terms of installed power (MAKE Consulting, 2013; BTM Consult, 2014). Located in Europe, but with production centers in both North and South America, it employs more than 1.500 workers and has an income of over €400M per annum.

4.3.1. Wind Turbine Manufacturer Supplier Audit

The questionnaire used to assess the suppliers in the audit is based on the ISO 9001:2008 requirements and organized into 21 main "items" spread over the four main processes: (P1) Management system and responsibility, (P2) Resource management, (P3) Product completion, (P4) Measuring, analysis and improvement. These items, classified into the four main ISO processes, are presented in table 4.3.1-1.

Audited Items	
P1	Management System and responsibility
v1	Quality Management System and responsibility (general requirements)
v2	Control of documentation
v3	Control of records
v4	Planning
P2	Resource management
v5	Competence, training and awareness
v6	Infrastructure and work environment
P3	Product realization
v7	Planning of product manufacture
v8	Customer related processes
v9	Design and development
v10	Purchasing process and information
v11	Supplier evaluation
v12	Product and service provision
v13	Product preservation
v14	Identification and traceability
v15	Verification of purchased product
v16	Control of monitoring and measuring equipment
P4	Measuring, analysis and improvement
v17	Monitoring and measurement of processes
v18	Monitoring and measurement of product
v19	Data analysis
v20	Control of nonconforming product
v21	Corrective and preventive action

Table 4.3.1-1 Audited items on supplier site

4.3.2. Sample and audit process

Forty percent of the companies audited are global players and are referred to in the sector's specialized journals such as MAKE Consulting (2013) or BTM Consult (2014). Table 4.3.2-1 shows the scope of the companies audited.

Location/ Employees	Europe	South America	North America	Asia	Total
> 500	8	5	1	8	22
500 - 100	15	3	3	3	24
< 100	37	4	-	3	44
Total	60	12	4	14	90

Table 4.3.2-1 Audit scope

The audits were carried out following the ISO 9001:2008 framework and under the supervision of one of the authors of this paper in his role as the Global Quality Director of the company. The audit teams were trained in accordance with the company's audit procedures. All the suppliers audited work with the ISO 9001:2008 standard thanks to a specific requisite from the set of design requirements (IEC, 2010) that must be met to certify a wind turbine.

In addition, to become an authorized supplier, the audited companies had had to pass a previous assessment and selection process and product qualification, in accordance with the company's standard procedure. This procedure is a three-step process beginning with (i) supplier assessment, followed by (ii) supplier/component qualification and finishing when the (iii) supplier is authorized for future serial production. After approximately a year supplying components to the wind turbine manufacturer, the company's audit team visited the suppliers to carry out audits. These audits have three main objectives: (i) to monitor and verify the proper operation and implementation of the supplier quality management system, (ii) to demonstrate that customer requirements (purchase order, delivery time, technical specifications, drawings, customer quality requirements, and packaging) are effectively implemented and maintained over time, and (iii) to take any appropriate action to eliminate root causes of nonconformities and prevent their recurrence, and to identify any potential improvement areas.

At the end of the appraisal, a closed audit meeting is held with the suppliers. The scope of the meeting is to examine any major and/or minor findings and discuss any future opportunities for improvement. More importantly, the company auditors and the suppliers then develop a plan for improvement together.

The audits were performed in accordance with the procedures and standards of the wind turbine manufacturer and took between three and five days, depending on the size of the company and the complexity of the product being produced.

4.3.3. Measures

The company auditors graded each item on a 4-point scale. The items audited are closely connected to ISO 9001:2008, but as the audit was performed by the customer the answers focused on evaluating the supply performance related to the product. By using a scale where 0 = not implemented item, 1 = partially implemented item with nonconformities, 2 = implemented item with observations and 3 = fully implemented item, each item's level of impact was then then able to be validated according to the value given in the answers, thus making it possible to determine the level of ISO implementation for each and every item asked about. As a result of the audit, the firm receives a Global Audit Score (GAS) when the average of all the audited items has been calculated. Following the criteria assigned to each company, we considered three levels of implementation. If the company scores 85% (GAS>2.55), the supplier has a HIGH level of implementation, if it is 70% (2.55>GAS>2.1) the supplier has a MEDIUM level of implementation, otherwise the supplier is considered as having a LOW level of implementation (GAS<2.1).

4.4. Results

Below, we present the data collected from the supplier classification according to GAS (table 4.4-1). What is made abundantly clear is that more than 40% of suppliers do not and cannot have a positive relationship with the firm because they are classified as LOW. Therefore, we cannot conclude that the ISO 9001 standard ensures a certain level of quality from a supplier i.e. a level which would mean that supplier could be considered an extended capability for the firm.

Grade GAS	Europe	South America	North America	Asia	Total
HIGH	5	2	1	1	9
MEDIUM	31	7	1	4	43
LOW	23	4	2	9	38
Total					90

Table 4.4-1 Supplier classification according to Global Audit Score

The analysis is divided into three. First, we present a descriptive analysis of the 21 items, followed by a factor analysis which allows us to group the 21 items from the audits into latent factors.

In the Descriptive Analysis section, we analyse the implementation of the 21 items individually, while in Discussion and Findings, we argue the strengths and weaknesses of the sector and present potential areas for improvement. Table 4.4-2 shows that “Competence training and awareness” (v5–2.44), “Identification and traceability” (v14–2.4), “Product preservation” (v13–2.31) and “QMS and responsibility” (v1–2.29) are the items that obtained the best assessment in the implementation audits. In contrast, the items “Corrective and preventive actions” (v21–1.81), “Product and service provision” (v12- 1.88), “Data analysis” (v19–1.90) and “Planning of product manufacture” (v7–1.94) were those which obtained the poorest implementation ratings in the audits.

Item	ISO 9001:2008 Item description	Nº	Mean	S. Deviation
v5	Competence, training and awareness	75	2,44	0,54
v14	Identification and traceability	90	2,4	0,64
v13	Product preservation	85	2,31	0,69
v1	Quality Management System and responsibility	87	2,29	0,63
v15	Verification of purchased product	89	2,28	0,65
v17	Monitoring and measurement of processes	87	2,28	0,67
v3	Control of records	85	2,27	0,62
v10	Purchasing process and information	68	2,26	0,65
v16	Control of monitoring and measuring equipment	85	2,24	0,65
v18	Monitoring and measurement of product	87	2,24	0,76
v9	Design and development	11	2,15	0,73
v11	Suppliers evaluation	66	2,13	0,72
v2	Control of documentation	84	2,09	0,69
v8	Customer related processes	84	2,04	0,76
v20	Control of nonconforming product	88	2,02	0,63
v4	Planning	86	2,01	0,68
v6	Infrastructure and work environment	88	1,96	0,69
v7	Planning of product realization	86	1,94	0,71
v19	Data analysis	66	1,9	0,72
v12	Product and service provision	83	1,88	0,69
v21	Corrective and preventive actions	87	1,81	0,69

Table 4.4-2 Descriptive analysis of 21 items

As a second step to our research methodology, we focussed on factor analysis of the data we collected in order to find homogeneous groups of correlated items that would help us verify the existence of latent variables indicating those ISO 9001 items that correlate with the levels of ISO 9001 implementation in the sector. The exploratory factor analysis, shown in table 4.4-3, was performed using the Varimax rotation from the SPSS factor analysis procedure, to identify the latent dimensions (F1, F2, F3) derived from the data and used in the study. The scales were analysed in accordance with the recommendations of Ladhari (2010) who follows the criteria to retain items that (i) load at 0.50 or greater in a factor, (ii) do not load at greater than 0.50 in two factors and (iii) have an item reaching total correlation of more than 0.40.

Items	F1	F2	F3
v16. Control of monitoring and measuring equipment	0.812		
v1. QMS and responsibility (general requirements)	0.730		
v6. Infrastructure and work environment	0.692		
v4. Planning	0.689		
v2. Control of documentation		0.780	
v12. Product and service provision		0.773	
v18. Monitoring and measurement of product		0.744	
v3. Control of Records		0.568	
v15. Verification of purchased product			0.806
v8. Customer related processes			0.683
v17. Monitoring and measurement of processes			0.660
Cronbach's alpha	0.695	0.749	0.600
% of variance explained	21.75	20.78	17.54

Table 4.4-3 Matrix rotated components using the Varimax extraction method

Prior to statistical analysis, several items were removed for two reasons: the inability to assess the requirement as a result of it not being applicable in the company (v9) or not being able to assess the item in the audit because of a lack of time (v5 , v10, v11 and v19) during the visit. Finally, throughout the process of exploratory data analysis, v13, v20, v7, v14 and v21 were eliminated.

The correlation matrix was subjected to two tests: Bartlett's sphericity test [183.941; df 55; pvalue 0.000] and the Kaiser–Meyer–Olkin (KMO) index [0.768]. The Bartlett test's statistical confirmation of the existence of linear dependence between the variables (items) justified, in all cases, continuing the procedure. The KMO also confirmed that factor analysis was likely to generate satisfactory results (Visauta, 1998).

Confirmatory factor analysis (CFA) was applied to the sample data to verify the factor structure that emerged from the EFA. The reliability of the resulting factors was assessed using Cronbach's alpha. All the constructs had an alpha value of greater than 0.6 (Malhotra, 2004).

"**Structural implementation**" is the name we assign to the first factor (F1), as this factor focuses on the basic system requirements of assurance quality management. We called the second factor (F2) "**Internal integration**" and this consists of the requirements which drive the system such as document and record control and the performance of the product and its validation. Finally, the third factor (F3), coined "**External integration and analysis**”, consists of requirements that most affect suppliers and customers, as well as process control.

The final step was to measure the impact of the factors on the level of ISO implementation we considered for each supplier. Table 4.4-4, which compares the average of factors among the three groups (HIGH, MEDIUM, and LOW) determined by the GAS, shows the factors that most affect determining the level of implementation. F1 and F2, are significantly different between HIGH and MEDIUM (pvalue 0.026 and pvalue 0.002) and MEDIUM and LOW (pvalue 0.003, pvalue, 0.030), but in F3 there are no differences between HIGH and MEDIUM (pvalue 0.708), but rather they are between MEDIUM and LOW (pvalue 0.002).

In table 4.4-4, we see that F1 and F2 differ in implementation levels from lowest level (near 0.5) to medium level (near 0) or highest level (near 1) in the same way as GAS differs. However, F3, never achieves a HIGH level (near 1), although it does achieve a medium level according to HIGH or MEDIUM GAS. F1 and F2 have to be considered as achieving a good fit in ISO 9001 implementations in this sector, but F3 does not differentiate between HIGH and MEDIUM instead it only differentiates between LOW and MEDIUM.

	Companies	F1 - Structural implementation	F2 - Internal integration	F3 -External integration and analysis
HIGH	10	0.972	1.025	0.242
MEDIUM	28	0.245	0.082	0.414
LOW	27	-0.614	-0.465	-0.519

Table 4.4-4 Fi average, depending on GAS (Global Audit Score) implementation level

4.5. Discussion and findings

From the SPA data it is possible to confirm that ISO 9001 implementation levels differ, even when all of these suppliers have been ISO 9001 certified by a third party.

In table (4.4-2), we see that the best implemented items are, "Competence training and awareness, "Identification and traceability", "Product preservation" and "QMS and responsibility". In this sense, our findings agree with Naveh and Marcus (2004) and Prajogo et al. (2012), who suggest that employee training and quality management practices, such as quality manual, polices, documentation and instructions, operation identification and traceability form part of the standard assimilation for a company (Naveh & Marcus, 2004), as well as part of its daily routine and thus, are basic and essential requirements of ISO 9000 implementation (Prajogo et al., 2012).

However, in table (4.4-2) the most poorly implemented items are "Corrective and preventive actions", "Product and service provision", "Data analysis" and "Planning of product realization". All of these are related to product execution and continuous improvement. Thus, our findings forge a path (from the customer's point of view) for suppliers, i.e. suppliers must work to improve aspects related to "product and service provision", in the WP sector as these are the areas which have a direct impact on the final product; not to mention company performance. Therefore, and as a way to move beyond the standard alone, areas concerned with "continuous improvement" must be honed and perfected.

In our research, we found that different implementation "levels" can and do provide firms with opportunities for improvement, and we would go as far as to suggest these 'windows of opportunity' are created in accordance with how and to what extent a company has implemented the standard. According to the factor analysis, the sector has three groups of ISO requirements which follow a similar pattern to implementing the standard. Comparing averages of the factors found that the level of implementation depends on all the items studied and are grouped according to certain factors, although it has been shown that F3 (External integration and analysis) seldom, according to GAS, achieves the highest level of implantation in the sector.

Some studies in the literature highlight positive benefits when ISO is implemented, while others demonstrate that there is no discernable impact on a company's performance. From our point of view, as in other studies found in the literature, it is difficult to associate the relationships between ISO 9000 and its effect on business performance. A possible answer is that there are multiple-variables associated with business performance, such as financial factors, market environment, government policies and regulations etc., and therefore, the direct effect on business performance is very difficult to identify, even after carefully controlling samples. For this reason, we consider that a survey questionnaire is not an adequate tool with which to draw any conclusions about the impact ISO 9000 regulations may or may not have on a company's performance.

Instead, what we can conclude is that ISO 9000, depending on the "level" of implementation, does provide opportunities to identify and work on areas for improvement, thus becoming more competitive in the marketplace. Furthermore, certification bodies and the genuine commitment from top management play an important role in ensuring this competitive advantage. In other words, merely being accredited with ISO 9000 certification will not ensure that firms gain a competitive advantage over their rival competitors but, as Naveh and Marcus (2004) also state, if the standard is extremely well implemented internally and carefully coordinated externally with suppliers and customers and becomes part of their daily practices, then it can be used as a springboard for the change which, in turn, would result in the much sought after 'competitive advantage'.

4.6. Conclusions

As a result of this study, several conclusions can be drawn. First, there are some weaknesses in the sector which need to be addressed as they are "Product and service provision", "Data analysis ", and "Corrective and preventive actions", all of which are related to the performance of the product and its processes, as well as its continuous improvement. In other words, analysing these would determine any corrective and/or preventative action to be taken. These findings show that SPAs play a unique and specific role by helping to identify system weaknesses that affect product and processes, by identifying opportunities for change and by suggesting areas for improvement.

Secondly, we can also demonstrate that there are companies in the WP industry, that have been certified ISO 9001:2008 by third parties, who employ varying levels of implementation. This indicates that levels of ISO 9001 implementation and development are related to management commitment and culture and the good practices of the organization in question. In fact, top management plays a crucial role in a company moving beyond the standard.

Finally, from the results of this work, a "road map" towards improvement can be drawn. This road map would enable companies in the sector to go beyond simply applying standard and allow them to fully exploit ISO 9001 certification by using it as a lever for change. In other words, the statistical analysis shows us that companies rated as LOW must improve aspects of F1 (Structural implementation) and F2 (Internal integration) to become MEDIUM and then continue those improvements until they reach the so-called HIGH category. However, in the case of F3 (External integration and analysis) only one step from the LOW to MEDIUM or even HIGH category is required. For the companies in the MEDIUM category, they must consolidate and improve factors F1 and F2, but they do not need to focus on F3 to become HIGH. Firms with the highest implementation levels use ISO 9001 certification as a "lever" to attain business excellence and their daily practices often go beyond the requirements of ISO 9001 certification to follow the criteria we found in the literature.

This article provides some theoretical implications i.e. viewing the standard from the customer‘s perspective which, in turn, leads to an understanding of the standard from the point of view of the customer’s needs. Thus, the usefulness of the audits is clearly demonstrated along with the overall objective of ISO 9001: customer satisfaction.

This article has some limitations as it focuses only on the WP sector, although its findings could be extrapolated to similar sectors of high technology and high customization. It also highlights several implications for managers i.e. certification only implies conformity to the standard and SPAs provide valuable information about supplier quality commitment. Going beyond certification involves the support and commitment of management in a company’s daily practices.

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4.8. Attachments

Supplier Quality Audits

Document No:
Supplier:
Product description, Reference:
Product Qualification Level

Date:
Responsible Function:
Checked by (Co Auditor):
Approved by (Lead Auditor):

Evaluation Criteria

0 - Not Implemented Item
1 - Partially implemented item
2 - Implemented with observations item
3 - Fully implemented Item

Nº	Evaluation issues	Score	Observations
1	Quality management system and responsibility		
2	Control of documentation		
3	Control of records		
4	Planning		
5	Competence, training and awareness		
6	Infrastructure and work environment		
7	Planning of product completion		
8	Customer related processes		
9	Design and development		
10	Purchasing processes and information		
11	Supplier evaluation		
12	Product and service provision		
13	Preservation of product		
14	Identification and traceability		
15	Verification of purchased product		
16	Control of monitoring and measuring equipment		
17	Monitoring and measurement of processes		
18	Product monitoring and measurement		
19	Data analysis		
20	Nonconforming product control		
21	Corrective and preventive actions		

Supplier classification (%):

Percentage %	Classification
0 - 49	Not authorized supplier
50 - 69	Delivery Risk supplier. Long term Improvements
70 -84	Pre-qualified supplier. Short term improvements
85 -100	Pre-qualified supplier.

Chapter Nº5

Evidence for Quality Management System being instrumental in improving supplier performance: The case of the Wind Power sector

5. Evidence for Quality Management Systems being instrumental in improving supplier performance: The case of the wind power sector

Abstract

Purpose - This paper evaluates whether ISO certification enables a supplier to become an extended resource in a specific sector. The suppliers were selected, evaluated and audited as extended resources from a resource based view (RBV) of the firm in question. We test the differences that the qualified suppliers exhibit in main ISO processes and we identify specific areas that will improve supplier relationships.

Design/methodology/approach - The research was conducted based on the results of the second-party audits of 90 suppliers, to one of the wind power industry's largest wind turbine manufacturers. The audits were carried out according to ISO 9001.

Findings - We determine that ISO certification alone is not enough to cement a positive relationship in an upstream Supply Chain environment, despite such relationships being crucial to the success of a business, and support the use of a wider sector-specific certification tool that goes beyond ISO certification. We also demonstrate significant differences exist when the level of technology the supplier uses is taken into account.

Research limitations/recommendations - This article has some limitations as it focuses only on the wind power sector, although its findings could be extrapolated to similar sectors of high technology and high customization.

Practical implications - Second-party audits have a positive impact for both customer and suppliers. They can help suppliers improve their manufacturing processes and, subsequently, the quality of their products. From the theoretical perspective, the ISO 9001 standard should be focused on upstream supply chain activities; because, quality problems usually cross the organization's boundaries and have an impact on the entire supply chain.

Originality/value - Most of the contributions referenced in the literature are based on surveys. In this paper, we used primary data from audits of suppliers who were vetted and chosen using very thorough selection criteria.

Keywords - Supplier evaluation, Supplier relationships, Quality Management, ISO Certification

Paper type - Research paper

5.1. Introduction

Nowadays, quality problems often breach organizations' boundaries (upstream and downstream) and directly impact a whole supply chain. Thus, ensuring quality in upstream supply chains has become a competitive priority for many companies because it is no longer the companies themselves who are competing with each other, but the supply chains that are in competition with each other (Christopher and Towill, 2000). Suppliers are a critical upstream echelon of the supply chain, and their integration has a direct impact on the efficiency and responsiveness of the entire supply chain. Consequently, many manufacturing industries are required to select suitable suppliers who can provide materials and components to the industry at the right time, the right quantity, the right quality and the right place (Maurya et al., 2013).

In sectors with advanced technology and complex products, one of the key areas their attention must be focused on is how to efficiently manage the supply chain. One such industrial sector doing exactly this is the wind power sector.

Wind power is no a longer simple idea, but one that has developed into a major and dependable source of energy. The key to success for the wind power industry is in constructing the supply chain (Prostean et al., 2014).

The wind power supply chain is made up of different echelons: raw materials suppliers, components suppliers, wind turbine manufactures, installation and erection, electrical distribution companies and end customers (Castelló et al, 2016). Wind turbine manufacturers represent one tier in that supply chain and one of their greatest challenges is to achieve maximum availability and reliability of operating wind turbines. Customers (electricity distribution companies) stipulate availability and reliability (usually between 97.5% and 98%) in their contracts, (Wilburn et al., 2011). In other words, maximum, uninterrupted power generation must be achieved.

The technological complexity of wind turbines, with over 8,000 very varied components (Aubrey, 2007), together with the large number of technologies required to produce a turbine (machining, castings, forgings, hydraulics, welding, electricity, electronics, composites), makes quality assurance in the supply chain very complex.

A competitive priority for wind turbine manufacturers, and one of the major challenges they face, is ensuring the quality of the components in the supply chain. Hence, wind turbine developers have focused on identifying suppliers who can provide quality components on time (Prostean et al., 2014).

That said, incorporating quality into the supply chain is not unique to the wind power sector, as quality in the supply chain of a complex product can be a differentiating factor and provide a competitive advantage.

The purpose of this research is to examine the upstream supply chain of the wind energy sector to determine whether the ISO 9001: 2008 quality management system (QMS) model is adequate or whether the sector requires more advanced models to achieve the reliability levels demanded by its customers. We use a resource based view (RBV) as the theoretical paradigm to underpin this study, although we also refer to more developed theories, such as the extended resource-based view which supports the Supply Chain Model (Rungtusanatham et al., 2003).

ISO 9001 accreditation requires a third-party audit which evaluates the QMS the company has in place, against the requirements outlined in the standard. Third-party audits are performed by independent certification bodies free of any conflict of interest in the customer-supplier relationship. Independent auditors are a key component of a third-party audit. However, despite more than two decades of using third-party audits, many quality managers and professionals still do not see the value in or necessity of these third-party audits (Kluse, 2013). Some studies reveal significant differences between the perceptions (in terms of profits, performance, standard compliance, improvements, etc.) of auditing that customers have and those that the auditors themselves have. (Castka et al., 2015; Kluse, 2013; Power and Terziovski, 2007). Neither is there a better understanding of how academics and practitioners perceive the TPAs process either (Kluse, 2013).

In some industrial sectors, for instance aerospace or the automotive sector, power systems, oil and gas, or the food industry, purchasing managers push for ISO certification (third-party audits) of their suppliers bidding for some projects or tenders. Following this, the customer quality team will later perform second-party audits of the same suppliers in order to ensure product quality. Ironically this praxis only consumes resources, time and money and does not add any value to the company.

Second-party audits are an external audit, led by the customer or by a contracted organization on behalf of the customer and performed at and on the supplier’s facilities. In other words, the purchasing order is in place, and the goods or services are being, or will be, delivered. Second-party audits are subject to the rules of contract laws and/or commercial agreements, as they provide contractual direction from the customer to the supplier. Second-party audits tend to be more formal than first-party audits because the outcomes of the audit could well influence the customer’s future purchasing decisions.

This conflict of interest between third-party and second-party audits is the motivation for our research. Furthermore, an extensive literature review reveals there is a lack of empirical evidence regarding the relationship between implementing ISO 9001 and second-party audits and their impact on business performance (Hadzhiev, 2012). For this reason, in our research, we use second-party audits as a 'driving' tool, to analyse if QMS, in accordance with ISO 9001, is an adequate model with which to manage the upstream supply chain in the wind power sector.

The paper is structured as follows: (1) introduction, (2) a literature review relating to supply chain and quality management and including the study's hypothesis, (3) methodology, samples and data collection, (4) results and analysis, (5) discussion, finally, (6) conclusions including research limitations, managerial implications and future research directions.

5.2. Literature review

Traditional wisdom suggests that business network integration is critical for smooth supply chain functioning and higher levels of integration lead to better quality and productivity performance (Hong et al., 2015). Now, organisations are becoming increasingly aware of the importance of a supplier's role in an organization (Soh et al., 2016).

In recent years, interest in emerging synergies and the integration between the paradigms of Supply Chain Management (SCM) and QMS has increased among academics, researchers and practitioners (El Mokadem, 2016; Lin et al., 2013; Prajogo et al., 2012; Sroufe and Cukovic, 2008). In today's highly competitive markets, a company's success or failure largely depends on its SCM. Companies are well aware that as products become more and more complex, diversified and customized, along with a short time to market being demanded, they need to integrate and develop their supply chain to create a competitive advantage. In this context, many resources and capabilities considered to be a competitive advantage are actually shared with suppliers. These capabilities include producing reliable products, fast time to market, low cost, high quality, high flexibility and excellent levels of service. In the face of this, integrating QMS principles and SCM best practices will help companies to achieve a competitive advantage.

5.2.1. Supply chain management

In essence, supply chain management encompasses companies which first transform raw materials into intermediate goods and finally into end products. These same companies then deliver the goods and products to the final customer though a distribution system.

The roots of SCM can be traced to two bodies of knowledge: purchasing and supply activities and (2) transportation and logistics management (Tan et al., 1998).

Christopher and Peck (2004) define the supply chain as: “the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer”.

The SCM paradigm has become a powerful management weapon in recent years, as currently companies do not compete with each other directly, but rather in terms of supply (Fawcett et al., 2006; Christopher and Towill, 2000), because nowadays each and every company depends on their supply chain. This new paradigm implies new ways of managing the supply chain. In a traditional supply chain, suppliers are selected on price alone (Chen and Yang, 2002), but today this way of doing business is no longer an option. In the new and effective supply chain, ‘members must sustain customer driven culture, offering the right product, in the right place, at the right time and the right price’ (Fisher, 1997). In the search for competitive advantages in the supply chain, companies, consultants, practitioners and academics have had to integrate the principles of QMS with the best practices from the process and SCM. Merging these two concepts, SCM and QMS, is a crucial element if companies are to be competitive in the future (Flynn and Flynn, 2005; Prajogo et al., 2012; Robinson and Malhotra, 2005; Truong et al., 2016).

5.2.2. Quality Management System model: the ISO 9000 standards

QMS, in accordance with ISO 9001, may well be the International Organization of Standardization’s (ISO) most popular product. The ISO 9000 series formalized a QMS protocol for evaluating companies’ skills and their ability to design, produce and deliver quality products and services (Curkovic and Pagell, 1999). In the last three decades, thousands of companies around the world have embraced the ISO 9000 standard in their quest to improve company performance and customer satisfaction.

However, despite having been internationally recognized and widely accepted since its publication in 1987, the ISO 9000 standard (even in its latest version ISO 9001:2008) has been subject to controversy and criticism concerning the success and/or failure of its implementation and/or whether its costs outweigh the performance benefits for companies. The literature is full of research articles describing ISO 9000 certification successes and failures and the resulting impacts on company profits and performance.

For instance, Curkovic and Pagell (1999) point out that ISO 9000 is not directly connected to product quality and other researchers argue that certification does not ensure an improvement in a firm's performance (Anderson et al., 1999; Dimara et al., 2004; Morris, 2006; Tsekouras et al., 2002). Moreover, there are many studies that show some companies adopt ISO certification under pressure from their customers (Anderson et al., 1999; Davis, 2004; Martínez-Costa et al., 2008).

According to Romano (2002), while ISO 9000 does define some requirements for the purchasing process, such as evaluating and selecting suppliers, verifying purchased products, and monitoring supplier quality, it does not require suppliers to be certified, unlike other standards such as ISO/TS 16949 which require suppliers to be certified by a third-party certification body equivalent to, at least, ISO 9000:2000 (Davis, 2004; Willem, 2004).

Naveh and Marcus (2005) emphasize that a certified company could still have substandard processes and products because certification does not tell the company how to design more reliable and efficient products; likewise, Sroufe and Curkovic (2008), in a theory building paper, argued that 'ISO registration alone is not enough to do anything beyond ensure compliance with the registration standard.'

Prajogo et al. (2012) suggest that simply being ISO 9000 accredited, does not translate into high performance and firms need to go beyond the basic ISO 9000 requirements. Moreover, Ilkay and Alsan (2012) showed that, in terms of performance, there is no significant difference between firms who are certified and those who are not. More recently, Terziovski and Guerrero (2014) analysed the impact of ISO 9000 on product and process innovation performance, and found that ISO 9000 certification does not have a statistically significant relationship with product innovation performance measures.

Nevertheless, the literature on the ISO 9000 series certification is not all criticism and controversy. Several studies highlight how ISO 9000 can help companies improve their performance and efficiency. Some authors point out that certification improves product and service quality and collaboration with suppliers, and reduces customer complaints and internal costs, thus boosting company profitability (Casadesús and Karapetrovic, 2005). Other authors stress that certification strengthens workforce motivation, increases market share and advances the international expansion of the company (Brown et al, 1998; Zaramdini, 2007). Chow-Chua et al. (2003) also point out that ISO certification improves processes and procedures, enhances a company's image in the marketplace and assists its international expansion.

While the impact ISO 9000 has on performance results remains a source of controversy, all of the studies do agree that a minimum level of improvement in a firm's management can be established and attributed to ISO 9000 (Naveh and Marcus, 2005; Prajogo et al., 2012; Sroufe and Curkovic, 2008).

5.2.3. Integration of QMS and SCM

While the supply chain concept is implicitly referred to in the ISO 9001:2008 standard as «*supplier-organization-customer*», there is still considerable disagreement about integrating ISO 9001 into a company's supply chain management strategy.

Careful reviewing of the ISO 9001:2008 standards shows that it focuses more on the organization than beyond the organization. Although deals superficially with supply chain integration and collaboration, in terms of both upstream to suppliers or downstream to customers, ISO 9001:2008 still remains the most widely accepted and integrated Quality Management System in world-class manufacturing firms.

In some companies ISO 9000 use has become a universal quality management norm and in a review of the literature we found that there are many studies concerning such integration. Some of the starting points of these studies encompass a more strategic view and focus on the links and integration between SCM and TQM (Gunasekaran and McGaughey, 2003; Kanji and Wong, 1999; Talib et al., 2010; Vanichchinchai and Igel, 2009), whereas other contributions start from a more operational approach and are dedicated to examining the supply chain quality management relationship (Flynn and Flynn, 2005; Foster, 2008; Kannan and Tan, 2005; Kaynak and Hartley, 2008; Kuei and Madu, 2001; Lin et al., 2005; Lin et al., 2013; Prajogo et al., 2012; Robinson and Malhotra, 2005; Romano and Vinelli, 2001; Sila et al., 2006; Truong et al., 2016).

Other work in the literature analysed the integrations between ISO 9001 QMS and SC, for instance, Casadesús and de Castro (2005), using empirical methods analysed the impact of ISO 9000 certification on the supply chain and Sroufe and Curkovic (2008) analysed the positive effect of integrating ISO 9000 in the SC. Both studies found that ISO 9000 itself does not provide a competitive advantage, therefore underlining that ISO registration alone is not enough to ensure anything beyond compliance with the registration standard.

Meanwhile, Prajogo et al., (2012) analyzed the effects different aspects of ISO 9000 implementation had on SC management practices and their impact on operational performance and found that advanced implantation of ISO 9000 does have positive effects on SC activities, whereas basic implantation has no direct influence on SC management practices at all. El Mokadem (2015), investigating ISO 9000 implantation and its alignment with SC activities, also found that an advanced level of implemented ISO practices has an impact on customer priorities and supplier selection. And, more recently, Truong et al. (2016) proposed a theory building framework to develop SC quality management practices designed to increase a firm's performance and provided a 'road map' for implementing supply chain quality management practices. They also highlighted the fact that there is very little literature dealing with integrating quality management practices and SC.

5.2.4. Hypothesis development

The literature review leads to some conclusions. A number of authors have pointed out that ISO standards ensure that a QMS exists, but cannot guarantee its functionality in the entire supply chain.

Furthermore, controversy still surrounds ISO 9001 and the standard continues to attract a great deal of criticism, but there is also conflicting evidence concerning the implications of adopting ISO for the supply chain (Sroufe and Curkovic, 2008). However, despite this, the ISO 9001 quality management system is currently one of the most widely accepted and internationally employed standards.

By incorporating the standard, a firm can extend its strategic resources beyond the boundaries of the company itself and with successful supply chain management can use these resources to its competitive advantage. Taking into account the extended resource based view (RBV) of the firm (Mathews, 2003) the ISO system can contribute to gaining a competitive advantage, even though its implementation has different and diverse impacts on a company's performance (Prajogo et al., 2012).

According to the ISO 9000 literature review, some authors go so far as to classify different levels of ISO 9000 implementation, for example, 'daily practices' which refer to basic implementation, the 'catalyst for change' referring to advanced implementation, or 'supportive implementation', when there is a clear top executive commitment to improving firm management (Naveh and Marcus, 2005; Prajogo et al., 2012).

Therefore, within the framework of the literature review above and as the implementation of ISO 9001:2008 in wind turbine (WT) manufacturer suppliers can be considered as an extended resource of the firm, we propose the following research question:

- **RQ1**: When WT suppliers have implemented ISO 9001, can we consider them as an extended resource?

In order to answer this question we propose two hypotheses based on the literature outlined above:

H1a: Wind turbine suppliers implement different levels of ISO9001.

H1b: Implementing ISO9001 assures a positive relationship with the wind power suppliers. As an addendum to this research question, with the level of ISO 9001:2008 implementation in the wind power sector, we wonder whether suppliers completely satisfy the requirements of the standard, or if there are, in fact, potential areas for improvement.

We assumed, based on the literature, that there are differences in the level of internalization of the Quality Management Systems and their real impact. However, we want to examine whether the technological level of a supplier is connected with the positive relationship we are exploring in the supply chain. Therefore, along the very same lines as other authors (Sroufe and Curkovic, 2008) in relation to the supply chain, and given the technical complexity of a wind turbine and the variety of industrial sectors that make up a wind power supply chain, we want to explore the different behaviors associated with the level of implementation, and whether these vary according to the sector the supplier belongs to. Thus, we propose the second research question:

- **RQ2**: Is the technical complexity of a wind turbine and its different technologies responsible for the different levels of ISO9001implementation?

5.3. Methodology

5.3.1. Sample and data collection

The data used in this paper are based on audits of 90 technical suppliers to a major wind turbine manufacturer. This manufacturer is ranked in the top 15 largest companies in the sector in terms of installed power (BTM Consult, 2011). Located in Europe, but with production centers in the United States and South America as well, it employs more than 1,500 workers and has an income of over €400m per annum (EWEA, 2009).

An extensive literature review revealed there is little empirical evidence of the relationship between ISO 9000 implementation and supplier activities (Lo and Yeung, 2006; Prajogo et al., 2012). Most of the contributions referenced in the literature review section are based on surveys. In this paper, we used primary data from audits of suppliers who were vetted and chosen using very thorough selection criteria.

A substantial number of the companies audited (40%) are global players and have been mentioned in the sector’s specialized journals such as MAKE Consulting (2013) or

BTM Consult (2011). Our audits were carried out following the ISO 9001:2008 framework and under the supervision of one of the authors of this paper in his role as the Global Quality Director of the wind turbine company. All the suppliers audited work with the ISO 9001:2008 standard because of a specific requirement from the set of design conditions (IEC 61400-22 (2010)) that must be met in order to certify a wind turbine. Furthermore, all the suppliers had passed a previous assessment and selection process and product qualification in accordance with the company's standard procedure. This procedure is a three-step process beginning with supplier assessment and qualification, followed by supplier/component qualification and finishing when the supplier is authorized for future serial production

One of the key aspects in selecting suppliers is the different technologies they supply to the wind turbine, which is a highly technical and complex product (Aubrey, 2007). With this complexity in mind, we chose the most significant components and technologies that constitute a wind turbine for the scope of this study. Thus, the core components and suppliers involved in manufacturing a wind turbine were chosen and grouped into six categories: (T1) Structural components, (T2) Composites (T3) Machining (T4) Power generation, (T5) General systems, and (T6) Painting. Figure 5.3.1-1 shows a typical wind turbine lay-out with the main components of this study.

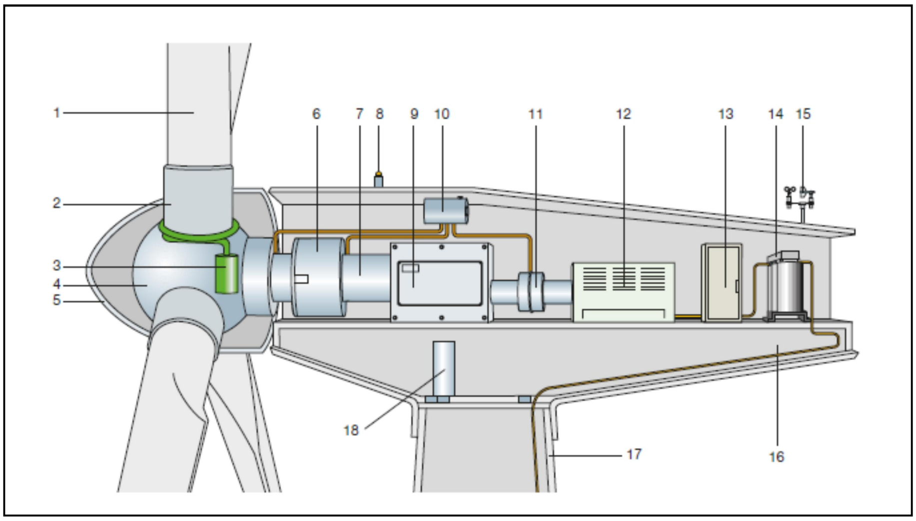


Figure 5.3.1-1 Layout of the components of a wind turbine

Basically, the components and suppliers chosen are those who have a direct impact on the quality, availability, and reliability of a wind turbine, as well and its structural integrity and safety.

The principal components of a wind turbine are: (1) blades, (2) extender, (3) pitch system, (4) hub, (5) cover, (6) main frame, (7) main shaft, (8) lights, (9) gearbox, (10) hydraulic, lubricating and cooling systems, (11) mechanical brake, (12) generator, (13) converter, (14) transformer, (15) anemometer, (16) crane, (17) tower and (18) yaw system.

Table 5.3.1-1 shows the distribution of the sample classified by technologies. The suppliers are classified into six technologies, although for the purpose of this paper the last (painting) has been ignored for two reasons: its level of complexity is low and there is only one supplier.

	Technology	Main Components	Nº of units
T1	Structural Components	Hub, main frames, structural bolts and nuts, flanges, forged rings, towers, extenders, plates and cutting plates, foundations, welding frames	24
T2	Composites	Blades, nacelle cover, deflector	10
T3	Machining	Hub, main frames, support frames, yaw, bearings, yaw crow, main shaft.	25
T4	Power generation	Gearbox, generator, electrical cabinets, transformer, pitch system, converter.	17
T5	General systems	Yaw systems, hydraulic and cooling systems, elevator, internal fits, electrical systems, motor boxes, crane, mechanical brake, lights, wires.	13
T6	Painting	Painting	1
	TOTAL		90

Table 5.3.1-1 Classification of the main components of the wind turbine by technology

Table 5.3.1-2 describes the suppliers by location and size, and table 5.3.1-3 presents the main figures for the audits in terms of number of days required to complete the audits.

Nº of employees	Europe	South America	North America	Asia	TOTAL
> 500	8	5	1	8	22
100 - 500	14	4	3	3	24
< 100	37	4	0	3	44
TOTAL	59	13	4	14	90

Table 5.3.1-2 Sample description by localization and size

	Europe	South America	North America	Asia	TOTAL
Audits	59	13	4	14	90
Audit Days	104	36	7	11	158
Auditors leaders	19	6	-	6	31
Countries	8	1	1	3	13

Table 5.3.1-3 Main figures for the audits

The audits were performed in accordance with the procedures and standards of the company and took between three and five days depending on the size of the supply company being audited and the complexity of the product being produced.

From these tables, the enormous effort involved in collecting the data for this paper can be appreciated. In fact, the rigor of the data collection process is one of the foremost contributions of this paper as, unlike other papers where the data used is based on individual responses to a survey, this paper relies on the data collected during an audit at a supplier's own facilities and workshops and which was then reviewed and accepted by the suppliers in a final closed audit meeting.

To avoid audit "measurement bias", all the auditors were not only trained to the company's standards, but also had a week's training with the company and then during the audits they use the same company guidelines and standards for procedures, instructions, question check list, and criterial scoring.

5.3.2. Measures

The questionnaire used to assess the suppliers during the audit is based on the ISO 9001:2008 requirements and organized into 21 items spread over the four main processes: (P1) Management system and responsibility, (P2) Resource management, (P3) Product completion, (P4) Measuring, analysis and improvement. The company auditor graded these items on a 4-point scale (see table 5.3.2-1).

The items audited are closely connected to ISO 9001:2008, but as the audit was done by the customer (the wind turbine manufacturer) the answers focus on evaluating product related supply performance. Depending on the value of the answers we were able to validate the level of impact each item has.

The Likert scale value was clear: 0 = not implemented item, 1 = partially implemented item with nonconformities, 2 = implemented item with observations and 3 = fully implemented item. With this scoring, it is possible to understand the level of ISO implementation for each and every item we asked about. However, after this audit the supplier classification is based on additional information. The firm that carried out the audits works with four levels which the suppliers are categorized into based on the grades they obtain. Grade A (85% +) is a fully-authorized supplier, grade B (70%-84%) is an authorized supplier requiring some improvements in the long term, grade C (50%-69%) is a conditionally-authorized supplier whose deliveries require monitoring, and grade D (<50%) is a non-authorized supplier. In order to test the hypothesis, we consider that a supplier has a positive relationship if they are graded as A or B.

Questionnaire Description	
P1	Management system and responsibility
v1	Quality management system and responsibility (General requirements)
v2	Control of documentation
v3	Control of records
v4	Planning
P2	Resource management
v5	Competence, training and awareness
v6	Infrastructure and work environment
P3	Product realization
v7	Planning of product completion
v8	Customer related processes
v9	Design and development
v10	Purchasing processes and information
v11	Supplier evaluation
v12	Product and service provision
v13	Preservation of product
v14	Identification and traceability
v15	Verification of purchased product
v16	Control of monitoring and measuring equipment
P4	Measuring, analysis and improvement
v17	Monitoring and measurement of processes
v18	Product monitoring and measurement
v19	Data analysis
v20	Nonconforming product control
v21	Corrective and preventive actions

Table 5.3.2-1 Questionnaire description

5.4. Results

To achieve this study's objectives, the data analysis was performed in two steps:

- an overall descriptive analysis of the data to validate the role of ISO 9001:2008 to assure supplier quality
- a statistical contextual analysis to detect possible differences, by technology, in terms of levels of quality

To carry out the statistical data analysis we conducted three successive analyses based on the data we had collected from the audits. In the first section, we present the results from the descriptive analysis based on the raw data and then, to analyse the level of implementation of QMS, we used a further contextual analysis.

5.4.1. Descriptive analysis

Firstly, we analysed the Global Audit Scores (GAS) we obtained in the 90 audits i.e. the average of the audit results for the 21 items from every supplier. Secondly, we analysed the individual grades of the 21 items transversally.

The GAS, gives the supplier both a letter grade and a numerical score for the level of QMS implementation. The results are the following: the sample average is 2.13 out of 3, with a standard deviation of 0.353 within a range of 1.05 - 2.90. From these results and because of their variation, we can verify (as expected based on the literature review) that there are different levels of implementation. Table 5.4.1-1 presents the classification of the sample by the suppliers' location and the numerical scores they obtained, as well as the letter ranking assigned to them by the auditors. The scores obtained by the suppliers are organized into the four levels described earlier.

With the 90 audits (table 5.4.1-1), we observe that 4 suppliers received a D *(non-authorized supplier)*, 34 suppliers a C *(conditionally-authorized supplier requiring monitoring of deliveries)*, 43 suppliers a B *(authorized supplier requiring long term improvements)* and 9 suppliers an A grade *(fully-authorized supplier)*.

Grade (0-3)	Europe	South America	North America	Asia	TOTAL	%
A (> 2.5)	5	2	1	1	9	10%
B (≥2.1 – ≤2.5)	31	7	1	4	43	47.8%
C (>1.5 – < 2.1)	20	4	2	8	34	37.8%
D (≤ 1.5)	3	-	-	1	4	4.4%
TOTAL					90	100%

Table 5.4.1-1 Supplier classification according to GAS

The assessment is clear: more than 40% of suppliers were unable to have a positive relationship with the firm because they are classified as C or D. Therefore, we cannot conclude that the ISO 9001 standard ensures a supplier's quality level in such a way that they can be considered an extended capability for the firm.

Next, we present the results of the 21 items for the whole sample (table 5.4.1-2).

Process	Item	Nº	Mean (St. Dev.)	**D** 0 – 1.5 (≤ 49%)	**C** 1.5 - 2.1 (50-70%)	**B** 2.1 - 2.5 (71-84%)	**A** 2.5 – 3 (≥85%)
P1	v1	87	2.29 (0.63)			2.292	
	v2	84	2.09 (0.69)		2.092		
	v3	85	2.27 (0.62)			2.267	
	v4	86	2.01 (0.68)		2.007		
P2	v5	75	2.44 (0.54)			2.439	
	v6	88	1.96 (0.69)		1.959		
P3	v7	86	1.94 (0.71)		1.944		
	v8	84	2.04 (0.76)		2.043		
	v9	11	2.15 (0.73)			2.145	
	v10	68	2.26 (0.65)			2.255	
	v11	66	2.13 (0.72)			2.129	
	v12	83	1.88 (0.69)		1.882		
	v13	85	2.31 (0.69)			2.311	
	v14	90	2.40 (0.64)			2.401	
	v15	89	2.28 (0.65)			2.275	
	v16	85	2.24 (0.65)			2.238	
P4	v17	87	2.28 (0.67)			2.284	
	v18	87	2.24 (0.76)			2.245	
	v19	66	1.90 (0.72)		1.898		
	v20	88	2.02 (0.63)		2.021		
	v21	87	1.81 (0.69)		1.811		

Table 5.4.1-2 Descriptive statics of items

Thus, we can observe that all the items have a B or C classification. This result confirms the generally accepted idea that ISO assessment is an average. There are no extremes and all items exhibit 'normal' behavior.

On the other hand, there are items which received an average mark of less than 2.1. These are considered as QMS "weaknesses", meaning that in these areas there is a low implementation level and so these will require greater attention from the suppliers and the wind turbine manufactures. These items were: (v2) control of documentation, (v4) planning, (v6) infrastructure and work environment, (v7) planning of product completion, (v8) customer related product, (v12) product and service provision, (v19) data analysis, (v20) nonconforming product control and (v21) corrective and preventive actions.

During the study, we did not find any items with an average below 1.5 (level D), but we did establish that there are suppliers with C or D classifications (table 5.4.1-1). As a result, we can confirm that ISO 9001:2008 does not guarantee a consistent QMS standard in the wind energy sector and we can identify which areas need to be improved.

5.4.2. Contextual analysis

The contextual analysis section is structured into two parts that follow the analysis process. Firstly, a principal component analysis was performed to build latent constructs for each main process guided by the ISO 9001 standard. Secondly, an analytical approach was applied to determine whether the technology the supplier had at their disposal could affect the results previously obtained.
Because the analysis is strictly based on the ISO 9001 questionnaire, the authors considered using “formative constructs” to assess the original main processes.

Different quality criteria are required to assess the measurement properties of the formative constructs. Loadings are misleading because the estimation does not consider the intraset correlations for each block, thus, aspects such as internal reliability and convergent validity are not applicable to formative constructs (Bollen and Lennox, 1991). Psychometric properties are interpreted using weights and their statistical significance, which provide information on how each indicator contributes to the respective construct.

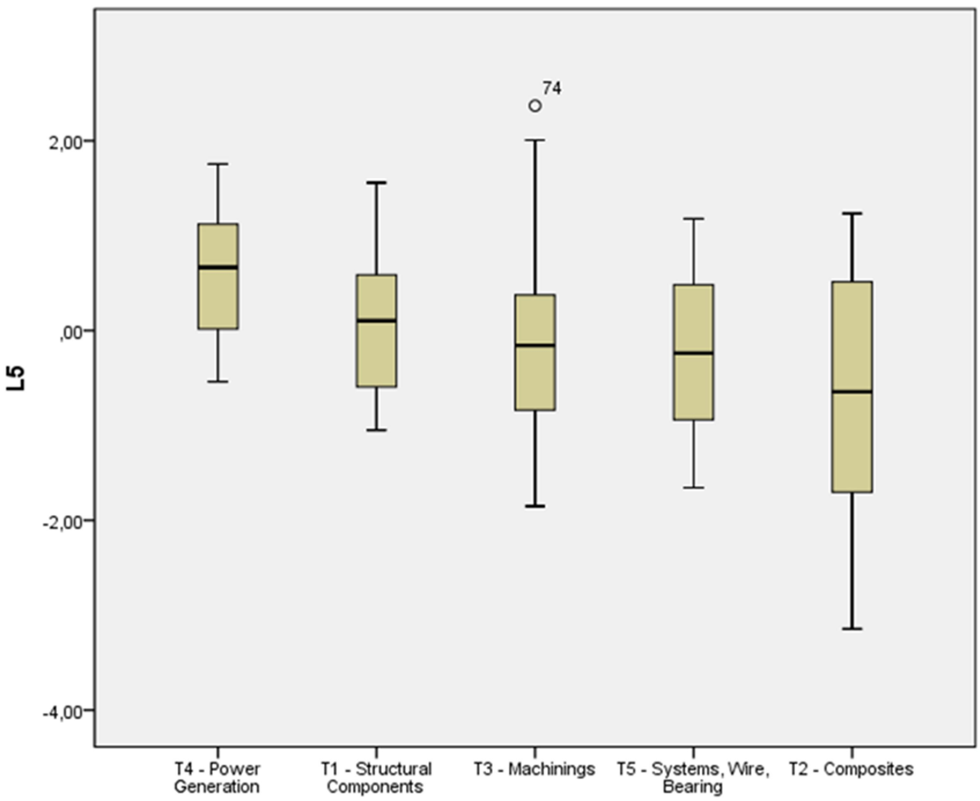
However, we took the precaution to test for multicollinearity. Multicollinearity is an undesirable property in formative models (Diamantopoulos and Winklhofer, 2001) because it may inflate bootstrap standard errors and thus trigger type II errors (Cenfetelli and Bassellier, 2009). An inspection of the variance inflation factor (VIF) using SPSS 20.0 for Windows did not raise any concerns about multicollinearity (table 5.4.2-1) because the VIF values were well below the cut-off value of 5 (Kleinbaum et al., 1988).

Variables		Item Reliability		Significance (bootstrapping)
		VIF	Weights	Significance*
Latent Variable 1 (L1)	v1	1.259	0.347	**
	v2	1.248	0.285	**
	v3	1.26	0.549	**
	v4	1.274	0.245	**
Latent Variable 2 (L2)	v5	1.009	0.516	**
	v6	1.009	0.809	**
Latent Variable 3 (L3)	v7	1.47	0.175	**
	v8	1.358	0.263	**
	v9	1.075	-0.068	
	v10	1.457	0.203	**
	v11	1.358	0.271	**
	v12	1.138	0.246	**
	v13	1.276	0.226	**
	v14	1.266	0.137	
	v15	1.439	0.121	
	v16	1.097	0.235	**
Latent Variable 4 (L4)	v17	1.301	0.276	**
	v18	1.219	0.365	**
	v19	1.149	0.437	**
	v20	1.287	0.223	
	v21	1.279	0.319	**
Latent Variable 5 (L5)	L1	1.939	0.282	**
	L2	1.538	0.128	**
	L3	2.715	0.444	**
	L4	2.314	0.309	**
** significant at p-level < 0.05				

Table 5.4.2-1 Validation of measurement: item reliability and bootstrapping

As for the weight values, the contributions to the formative measure for all dimensions were not significant; as indicated by p-value > 0.05. Nevertheless, they have been included because they belong to the construct from a conceptual point of view. Taken together, these results indicate that the measurement model used in this research is reliable and valid.

Once the latent dimensions were validated, including the second-order latent dimensions composed of the four first-order dimensions, we proceeded to detect statistical differences between suppliers according to their level of technology.



Technology	Mean	St. Dev.	Lower limit	Higher limit
T1 - Structural Components	0.080	0.756	-0.238	0.400
T2 - Composites	-0.726	1.519	-1.813	0.360
T3 - Machining	-0.072	1.060	-0.510	0.365
T4 - Power Generation	0.546	0.720	0.175	0.916
T5 - Systems, Wire, Bearing	-0.231	0.848	-0.744	0.282

Figure 5.4.2-1 Boxplot of the ranking scores by technology

Figure 5.4.2-1 depicts the standardized distribution by technology. Here, we can observe possible differences between T4 (power generation) and the other technologies. There are two reasons for checking these differences. On the one hand, it is the technology with the highest mean value and, on the other hand, its distribution does not include the value 0. This indicates that T4 receives the highest grades of all the technologies, which in all cases includes the value 0.

In order to delve deeper, we also ran a non-parametric test to compare the null hypothesis, that two populations are the same, against an alternative hypothesis, namely differences related to the technology of the supplier. Table 5.4.2-2 presents the results of the Mann-Whitney U test carried out among the technologies.

	N	U Mann-Whitney	W Wilcoxon	Z	Significance (bilateral)
T1 – Structural. Components					
T1 vs T2	24/10	85	140	-1.323	0.186
T1 vs T3	24/25	261	586	-0.78	0.435
T1 vs T4	24/17	134	434	-1.852	0.064 *
T1 vs T5	24/13	128	219	-0.891	0.373
T2 – Composites					
T2 vs T3	10/25	102	157	-0.84	0.401
T2 vs T4	10/17	43	98	-2.109	0.035 **
T2 vs T5	10/13	58	113	-0.434	0.664
T3 – Machining					
T3 vs T4	25/17	127	452	-2.191	0.028 **
T3 vs T5	25/13	156	247	-0.2	0.841
T4 - Power Generation					
T4 vs T5	17/13	56	147	-2.281	0.023 **
* significant at p-value < 0.10; ** significant at p-value < 0.05					

Table 5.4.2-2 Mann–Whitney U test by technologies

5.5. Discussion of results

In this section, we discuss the audit outcomes in order to answer the two research questions proposed in Section 2.

According to the GAS by supplier (table 5.4.1-1) more than 40% of the suppliers are classified as C or D. As we explained in the Measures section, we have considered four levels for supplier classification based on the results for the items in question. We found four suppliers in category D, i.e. four suppliers who do not satisfy the standards and could not be considered authorized suppliers. We then found 34 suppliers in category C (conditionally-authorized supplier whose deliveries require monitoring). In the case of these suppliers, some major noncompliance or deviations according to the standard or contractual specifications were detected during the audits. Forty-three suppliers were ranked as B (authorized supplier requiring some long-term improvements), which means in their case we found some minor nonconformities and notes for improvement. Finally, nine suppliers were placed in category A (fully-authorized supplier) as they did not breach any of the rules, standards or contractual specifications. We understand a positive relationship ranking goes to those suppliers graded A or B, because C or D implies extra monitoring activities which do not allow capabilities to be extended beyond the firm.

However, while a QMS according to ISO 9001 is quite widely implemented in the sector, it is not “well implemented” as there are a large number of suppliers falling into category C.

Therefore, we accept hypothesis **H1a**, because in the wind power sector ISO 9001:2008 is being implemented to varying degrees, and we reject hypothesis **H2a** because some of the suppliers are qualified as C or D.

To sum up, in relation to the first research question **(RQ1)** , we can affirm that generally ISO 9001:2008 is a standard implemented in the sector, but we cannot accept that ISO ensures a positive relationship between suppliers and the wind turbine manufacturer and, in fact, there are areas, as demonstrated by the low scoring, which require improvement.

When the 21 items are reviewed individually (table 5.4.1-2), we can observe points of difference between some of the items. An average below 2.1 points means that during the audit we detected a breach in the standard and so these are areas for improvement. They are v2, v4, v6, v7, v8, v12, v19, v20 and v21. We also present some aspects where there are potential areas for improvement.

To examine the second research question **(RQ2)**, we have to observe results of the contextual analysis.

The model we created was based on a formative principal component analysis based on four main processes guided by ISO 9001. The second order Latent Variable L5 represents to what degree the supplier in question implements ISO 9001, taking into account the four main processes represented by L1-L4 as first order Latent variables. In figure 5.4.2-1, the differences between averages in the T4 (power generation) group of technologies and the averages of the other technologies can be observed. These differences are corroborated and validated by the results in table 5.4.2-2. All significant differences are related to T4 technology, even though there are no differences between the others. Aside from T4 technology, the final order is not significant either, as we cannot be sure of the differences between the degrees of implementation by the suppliers. However, we would like to draw attention to the last position of T2 (composites) technology.

Note that, the components supplied by those suppliers who belong to T4 technology (power generation) are components where the manufacturing processes, with respect to other technologies, have high levels of automation, especially in the case of T2 processes, which contain a great deal of manual content because of the use of moulds and tools. Furthermore, these particular production processes are in of the hands of low-skilled workers.

To sum up, we can say that in the case of the wind power sector, when we are able to assign the degree of QMS implementation using a model and stratify suppliers by manufacturing technologies, and we were able to observe diverse behavior's in their implementation and significant differences, especially in relation to T4, which has a higher degree of implementation than the others.

5.6. Conclusions

In this article, we have provided evidence for integrating the concepts of upstream Supply Chain and QMS to test the use of suppliers as extended resources in very complex product sectors, such as the wind generation sector. However, this behaviour does not extend to all technologies, with some of them showing significant differences in the audit results.

According to the GAS outcomes, we observe that, on average, all the suppliers ensure a minimum quality level as the overall GAS outcome is 2.13 points, i.e. higher than the 2.1 cut-off point. However, due to the deviation of the GAS outcome, we have detected suppliers who fall into categories C and D. In this sense, we must stress that ISO certification alone does not ensure anything beyond a compliance with the standard and that certification only shows that a QMS exists in the organization, but cannot ensure a company's efficiency or its extension of capabilities through its suppliers.

Furthermore, in view of the data obtained from the study of the 21 items and the four main processes (table 5.4.1-2), we can confirm that ISO 9001:2008 is the standard implemented across the wind energy sector and that we did not detect any significant differences between the 21 items. Nevertheless, as we mentioned in the Discussion section, we have identified some areas for improvement: (v2) control of documentation, (v4) planning, (v6) infrastructure and work environment, (v7) planning of product completion, (v8) customer related product, (v12) product and service provision, (v19) data analysis, (v20) nonconforming product control, and (v21) corrective and preventive actions. Moreover, all these items are basically related to P3 (product realization) and P4 (measurement, analysis and improvement). Despite this finding from the descriptive analysis, the results of the contextual analysis highlight and validate the reality of many practitioners' daily experience. There are significant differences in implementation between different 'technological families' that constitute a wind turbine and have the ISO 9001: 2008 standard in operation. Therefore, it is not possible to consider the ISO 9000 series as being the only way to validate a Quality Management System.

After the audits, we organized a number of interviews with some Supplier Quality Assurance Engineer (SQAE) auditors to gather their opinions and explore their feelings about the appraisals. They agree that ISO 9001:2008 is a good tool for aligning company processes towards achieving company integration, but it does not go far enough in some key aspects, such as product realization, data analysis, and corrective and preventive actions.

A lesson learnt from this research is that, although ISO 9001 is implemented in the sector, there are several items or areas which need improving and which are connected directly to the product, namely

- product realization
- measurement analysis and improvement

We can also conclude that the QMS model, according to ISO 9001: 2008, is a general model and is not sufficiently exact to meet the specific product requirements of certain sectors with a high demand of technical complexity.

Hence, some sectors have developed sector-specific QMSs, such as QS 9000 for the automotive industry and AS 9000 for the aerospace industry, TE 9000 for tooling and equipment, TL 9000 for telecommunications, PS 9000 for pharmaceutical packaging materials or GMP for food, drug and pharmaceutical products, GLP for laboratories or FDA for foodstuffs, drugs and cosmetics. These sectors have specific quality management standards to ensure they meet their sector's specific technical requirements.

5.6.1. Practical implications, limitations and research recommendations

In the wind energy sector, we found differing degrees of QMS implementation, depending on the technology being used and/or product complexity, and we tested these differences statistically based on the results from supplier audits. Furthermore, as mentioned in the literature review, the ISO 9001:2008 standard implicitly refers to the supply chain concept as «supplier – organization - customer» but, in fact, focuses specifically on a company's internal organization and does not examine upstream and downstream relationships in depth.

As we mentioned in the introduction, competition between supply chains, rather than competition between individual companies has become more important'. For this reason, (and based on our day-to-day experience and the outcomes of this study), efficiently managing the relationship between company and supplier beyond ISO certification is a key factor in successful performance.

From the authors' the point of view, ISO 9001 must be adopted for concepts and tools (e.g. supplier development, supplier monitoring, Advanced Quality Plans (AQP), Production Part Approval Processes (PPAP) etc.). However, improving the quality of products, the relationship between customer and suppliers, and of course improving a company's efficiency and their supply chain are all issues which need addressing in depth.

One of the limitations of this work is that it has focussed solely on the wind power sector. However, its findings can be extended to other high-tech industrial sectors as well.

Moreover, from the literature review of SCM and QMS (in ISO 9000 model) integration, we have found that the majority of data collection comes from surveys (surveyed feelings and perceptions, whereas in our research we have used primary data collect through customer audits (second-party audits). Furthermore, the extensive literature review demonstrates a lack of empirical evidence regarding the relationship between ISO 9000 implementation and second-party audits. Hence, we encourage researchers to analyse SCM and QMS integration using field data collection methods.

Finally, we would like to highlight the theoretical and managerial implications of this paper as its findings lead to a number of implications for managers and researchers. From a managerial point of view, as mentioned in the introduction, compliance with the ISO 9001 accreditation requires a third-party audit and certification. However, managers should also consider second-party audits as, in our opinion; they have a positive impact for both customer and suppliers. They can help suppliers improve their manufacturing processes and, subsequently, the quality of their product(s). Furthermore, the suppliers can compare themselves to their competitors and identify and eliminate any weak points they may have. Supplies have the opportunity to see their process from the customer's point of view; a point of view which is often more critical and more relevant.

Therefore, from the theoretical perspective, the ISO 9001 standard should be focused on upstream supply chain activities. Suppliers' relationships are a critical echelon in the supply chain because, as we mentioned earlier, quality problems usually cross the organization's boundaries and have an impact on the entire supply chain.

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5.8. Attachments

Supplier Quality Audits

Document No:
Supplier:
Product description, Reference:
Product Qualification Level

Date:
Responsible Function:
Checked by (Co Auditor):
Approved by (Lead Auditor):

Evaluation Criteria

0 - Not Implemented Item
1 - Partially implemented item
2 - Implemented with observations item
3 - Fully implemented Item

Nº	Evaluation issues	Score	Observations
1	Quality management system and responsibility		
2	Control of documentation		
3	Control of records		
4	Planning		
5	Competence, training and awareness		
6	Infrastructure and work environment		
7	Planning of product completion		
8	Customer related processes		
9	Design and development		
10	Purchasing processes and information		
11	Supplier evaluation		
12	Product and service provision		
13	Preservation of product		
14	Identification and traceability		
15	Verification of purchased product		
16	Control of monitoring and measuring equipment		
17	Monitoring and measurement of processes		
18	Product monitoring and measurement		
19	Data analysis		
20	Nonconforming product control		
21	Corrective and preventive actions		

Supplier classification (%):

Percentage %	Classification
0 - 49	Not authorized supplier
50 - 69	Delivery Risk supplier. Long term Improvements
70 -84	Pre-qualified supplier. Short term improvements
85 -100	Pre-qualified supplier.

Chapter №6

Use of quality tools and techniques and their integration into ISO 9001 (A wind power supply chain survey)

6. Use of quality tools and techniques and their integration into ISO 9001 (A wind power supply chain survey)

Abstract:

Purpose - This study focuses on the use of quality management tools and techniques and their integration into the ISO 9001:2008 standard in a wind power sector supply chain.

Design/methodology/approach - The research project was carried out in 119 wind power sector supply chain companies (i.e. component suppliers, wind turbine assemblers, and wind farm operation and maintenance services) using the questionnaire method. The companies selected employ quality management systems which conform to the ISO 9001:2008 standard.

Findings - The survey findings reveal that the degree to which quality tools and techniques are used in the wind power companies can be characterised as “high”. The results show that internal audits, flowchart diagrams and cost of poor quality are the most-commonly applied tools and techniques, although they also indicate some areas for further improvement, for instance, when using advanced and complex quality techniques such as Design of experiments (DOE), Quality Function Deployment (QFD), or Business process management (BPM). In addition to this, the findings reveal that ISO 9001:2008 establishes a favourable environment for the use of quality tools and techniques.

Research limitations/recommendations - The study was based on the perceptions of quality managers, quality engineers, and company mangers (subjective data) and did not examine the reasons for either not implementing and/or the difficulties encountered while implementing quality tools and techniques.

Practical implications - The specific findings indicate that employing quality tools and techniques is useful for mangers, not only when implementing a quality management system, but also when suggesting recommendations for improvement.

Originality/value - This study has provided more detailed knowledge on the use of different quality tools and techniques in the wind power sector, and their relationship in the way ISO 9001:2008 certified companies handle processes.

Keywords - Quality tools and techniques, ISO 9001, process approach, wind power

Paper type - Research paper

6.1. Introduction

The importance of total quality management (TQM), on both a practical and theoretical level, has increased considerably in recent decades. A number of studies have been carried out to develop a set of key practices for TQM implementation, which often vary from company to company or from one author to another. Various studies have been carried out to identify such practices and, according to the literature (Evans and Lindsay, 1999, Tarí and Sabater, 2004, Tari, 2005, Vouzas and Psyhogios, 2007, Fotopoulos and Psomas, 2009, Psomas et al., 2014), TQM elements can be grouped into two dimensions: (i) management or “soft” elements (leadership, strategic quality planning, employee management and involvement, supplier management, customer focus, process management, continuous improvement, information and analysis, knowledge and education), and (ii) technical or “hard” elements (quality tools and techniques).

Successfully developing “soft” TQM elements is a long-term process and so must be emphasized accordingly in any TQM implementation plan. As such, the effective development of a management system’s “soft” elements must be supported by the technical system’s “hard” elements (Zairi and Thiagarajan, 1997, Fotopoulus and Psomas, 2009). The “hard” elements consist of a set of tools and techniques such as histograms, flow charts, relations diagrams, scatter diagrams, control charts, Pareto analysis, quality function deployment (QFD), statistical process control (SPC), design of experiments (DOE) and so on. Nevertheless, past evidence has shown that in some cases TQM has failed because of these success factors not being in place (Curry and Kadasah, 2002). One possible reason for TQM being unsuccessful is the absence of suitable quality management tools and techniques (Zhang, 2000, Tarí and Sabater, 2004, Ahmed and Hassan, 2003). Authors, such as Tari and Sabater (2004), Fotopoulos and Psomas (2009), underline that the failures when applying quality tools and techniques (QT&T) are not because they are ineffective, but rather because of a lack of clear understanding about when, where and how to apply them. Another mistake often made by companies is to take and apply each QT&T as a separate, isolated entity. The relationships between QT&Ts and the sequence they follow are two important aspects that must be taken into consideration for their effective application (Fotopoulos and Psomas, 2009). Other authors, such as Sun et al., (2004), underline that taking steps towards TQM is difficult because of the widespread confusion about TQM components and how they are implemented. This is because TQM used to be a rather abstract philosophy and did not have any clear guidelines or rules on its implementation.

According to the literature review, TQM features “hard” and “soft “elements. In this context, some researchers in the literature have analysed TMQ practices in ISO 9000 certified companies over different time periods, and in different sectors. Researchers, such as Yusof and Aspinwall (2000), Gotzamani and Tsiotras (2001), or Martínez-Lorente and Martinez-Costa (2004), report that the ISO 9001 standard is a good first step on the way to achieving effective TQM. Moreover, in its description ISO 9000 certification includes elements that could be equivalent to some of the TQM principles (Martínez-Lorente and Martinez-Costa, 2004). If nothing else, the literature has served to highlight the debate about the link between TQM and ISO 9000 and whether they are complementary or contradictory to each other. It should be noted that implementing TQM is generally voluntary, whereas certifying for ISO 9000 may be driven by external parties, for example, customers (Prajogo and Brown; 2006).

The clear advantages to using “hard” and “soft” TQM elements, and the absence of an empirical study on such use in the wind power (WP) sector, particularly in the whole supply chain (SC), suggested an empirical study into this should be carried out. Therefore, the purpose of this paper is twofold. First, through an exploratory factor analysis (EFA) and a confirmatory factor analysis (CFA), analyse to what extent quality tools and techniques (hard elements) are used in the wind power sector and validate the QT&T groups (latent factors) to assess their reliability and validity. Second, analyse the relationship these hard QT&T elements have in the ISO 9001:2008 process approach (i.e. the soft elements).

The remainder of the article is structured as follows: Section 2 presents the literature review on the uses of QT&Ts and also on the impact they have on the ISO 9001:2008 process approach. Section 3 describes the research methodology, and Section 4 presents the analysis and the respective results. Section 5 discusses the findings and closes with the conclusions, practical implications, limitations, and future research recommendations.

6.2. Literature review and hypothesis development

This section is divided into two subsections. In the first, we review the literature on QT&T use in different sectors and time periods. In the second, we analyse the relationship between QT&Ts and the ISO 9001 process approach and develop the respective research questions.

6.2.1. Quality tools and techniques

The literature review suggests that there are several differences between QT&Ts. According to McQuater et al., (1995), a single “tool” may be described as a device which has a clear role. It is often narrow in focus and is usually used on its own. Examples of such tools are histograms, Pareto analysis, cause and effect diagrams, control charts, and flowcharts.

A “technique”, on the other hand, has a wider application than a tool. This often results in a need for more thought, skill and training, so that techniques can be used effectively. Techniques can be thought of as a collection of tools. Examples of techniques are statistical process control (SPC) procedures, benchmarking, Quality Function Deployment (QFD), failure mode and effects analysis (FMEA), Design of experiments (DOE), and Six Sigma (DMAIC). For example, SPC uses a variety of tools such as charts, graphs and histograms, as well as other statistical methods, all of which are necessary for the effective use of this technique (Mc Quater et al., 1995).

Several researchers such as Lam (1996), Ahmed and Hassan (2003), Vouzas (2004), Bamford and Greatbanks (2005), Tari (2005), Alsaleh (2007) and Fotopoulos and Psomas (2009), make a distinction between QT&Ts according to their ease for users to understand and implement them. According to Fotopoulos and Psomas (2009), tools such as flowcharts, check sheets, histograms and brainstorming are “simple and basic”, while the more complex techniques such as SPC, DOE, Taguchi methods and QFD are “advanced and sophisticated”.

Along these lines, Ishikawa (1985), Evans and Lindsay (1999), Dale and McQuater (1998), and Dale (1999) introduced a set of seven tools, which were flow charts, Pareto charts, histograms, cause and effect diagrams, brainstorming, run charts and graphs, control charts, and scatter diagrams, and which are widely accepted and used by the organisations.

On the other hand, Deming (1986) emphasised the use of statistical techniques for quality improvement and proposed a PDCA cycle to improve quality in an organisation. Ishikawa (1976, 1985) highlighted the importance of cause and effect diagrams for problem solving, and quality circles to achieve continuous improvement. Imai (1986), Dean and Evans (1994), Goetsch and Davis (1997), and Dale (1999), also proposed a list of tools and techniques for problem solving and quality improvement. Finally, Motorola, through the efforts of reliability engineer Bill Smith, developed the Six Sigma method and provided a clear structure to process improvement thorough a five-stage cycle known as DMAIC, i.e. define-measure-analyse-improve-control (Brady and Allen, 2006).

The literature review shows that there have been numerous studies analysing the critical factors for successful QT&T implementation. On some occasions, tools and techniques do not work exactly how firms tried to apply them. According to Kwok and Tummala (1998), failures when applying QT&Ts are not due to the fact that they are ineffective, but rather due to lack of clear understanding regarding when, where and how to apply them. Another typical mistake made by firms, is to take each QT&T as a separate, isolated tool for application. The relationships and the sequencing of QT&Ts are two important aspects that must be considered for their effective application (Fotopoulos and Psomas, 2009). Thus, McQuater et al., (1995) underline the fact that when using QT&Ts attention needs to be paid to a number of critical success factors such as management support and commitment, effective, timely and planned training, the genuine need to use a tool or technique, defined aims and objectives for use, a co-operative environment, and backup and support from improvement facilitators.

Ahmed and Hassan (2003) investigated the use of QT&Ts in Malaysian SMEs. Their findings show that the SMEs did not make full and efficient use of QT&Ts. Basic quality tools such as flow charts and check sheets were the most frequently used, while the more advanced quality techniques, such as SPC, QFD and DOE, were not popular.

Bayazit (2003) studied large Turkish manufacturing firms who had a relatively mature TQM implementation status and found that the most frequently used QT&Ts were Pareto charts, SPC procedures, process charts and cause and effect diagrams.

Vouzas (2004) analysed the status of the quality improvement efforts in selected Greek industrial organizations. According to his findings, only a few organizations seemed to implement QT&Ts. Simple quality tools such as flowcharts, checklists and the aforementioned set-of-seven quality control tools were predominant.

Lagrosen and Lagrosen (2005) analysed the use of QT&Ts in the Swedish organisations, and they not only found that the only tools used by the majority of the organizations were flowcharts, but they also showed that there was a correlation between the use of QT&Ts and a well-functioning quality management system.

A study performed by Tari (2005), determined that internal audits, graphics, SPC procedures, and flow charts, were highly implemented QT&Ts in ISO 9000 certified Spanish firms.

Alsaleh (2007) conducted a survey in the Saudi food industry sector, and his findings revealed an industry enthusiasm for quality standards as more than two-thirds of the surveyed companies possessed one. Quality tools such as control charts, run charts, and histograms appeared to be utilized throughout the production stages in one-third of the companies surveyed.

In ISO 9001:2000 certified Greek companies, Fotopoulos and Psomos (2009) examined the level of QT&T use, as well as the level of training employees had. They found that most firms used the quality tools that were the easiest to understand and implement and barely used more the complex QT&T techniques.

And finally, Talib et al., (2013), analysed QT&T use in Indian service industries, and found it to be low and with the majority of businesses implementing QT&Ts that were easy and straightforward to use.

While a single firm may not require all the available QT&Ts, there are some tools and techniques which are frequently used in many firms. For example, Pareto charts, cause and effect diagrams, and histograms, are the most popular for problem analysis, while QFD, DOE, and FMEA, are used in design and process development (Thia et al., 2005). Others such as the 8D method, and/or PDCA are used for problem solving, while Six Sigma, BPM, and VSM, for instance, are used for improvements.

In our research, and based on an extensive literature review (Isikawa (1985), Imai (1986), McQuarter et. al., (1995), Bunney and Dale (1997), Dale and McQuarter (1998), Pande et. al., (2000), Harry (2000), Harry and Schroeder (2000), Bamford and Greatbanks, (2005)), as well as sector interviews with quality managers and those with managerial and academic experience, we were able to group 25 quality tools and techniques into three groups according to the following criteria*: (i) tools for consulting and acting proactively, (ii) tools for analysing and control and (iii) tools for problem solving and improvement.*

The main reason we grouped the tools and techniques as such, was to bridge a “gap” that exists in the literature because earlier studies (Ahmed and Hassan (2003), Lagrosen and Lagrosen (2005), Tarí (2005), Alsaleh (2007), Fotopoulos and Psomas (2009), Talib et al., (2013)) analysed all the QT&Ts in the same package. As we mentioned earlier, in some cases there is a lack of clear understanding about what, where, when, why, who, and how to apply them. As the relationships between, and the sequence of, QT&Ts have some important aspects that must be taken in consideration for their effective application. Bramford and Greatbanks (2005) provide guidelines to applying QT&T in everyday situations.

From the literature review above, it is evident that many researchers have explored the level of QT&T use in different countries, sectors, and various sized companies and have found diverse “levels of QT&T use”.

Thus, we were motivated to explore the "level of QT&T use" in companies which have been implementing a quality management system in the wind power (WP) sector consistent with the ISO 9001:2000 standard.

So, we formulated the following research questions:

- **RQ1**: What is the "individual level use" of quality tools and techniques in the WP sector?

- **RQ2**: What are the different levels of "use" of quality tools and techniques groups in the WP sector?

6.2.2. Impact of quality tools and techniques in the ISO 9000 process approach

In recent decades, attention directed towards process management has increased as thousands of organizations adopt process oriented programs such as ISO9001 and TQM (Benner and Veloso, 2008). That said, nowadays defining "process" is no easy task (Psomas et al., 2011). The beginnings of process orientation can be traced back to the evolving quality management movement and its advocated shift away from focussing on "product characteristics" to focussing on "process characteristics" (Shewhart, 1931). This orientation towards processes became a vital element in TQM (Hackman and Wageman, 1995, and Hellström and Eriksson, 2008). However, there is considerable debate as to what process oriented means and how organizations should interpret the process approach message (Psomas et al., 2011). Consequently, different authors in the literature define process in their own words. For instance, Hammer and Champy (1993) define a process as, 'a set of activities which, when taken together, produce a result of value to a customer'. Davenport (1993) calls process, 'a set of structured and measured activities designed to produce a specific output'. According to Palmberg (2009), process can be considered to be, 'a horizontal sequence of activities that transforms an input (need) to an output (result) to meet the needs of customers or stakeholders'. ISO 9000:2005 defines a process as, 'a set of interrelated or interacting activities which transforms inputs into outputs'. Moreover, process orientation has also been embodied in other models of business excellence such as the European Foundation for Quality Management (EFQM), the Malcolm Baldrige National Quality Award (MBNQA) or the Deming Prize.

Organizations receive the ISO 9001 standard upon demonstrating that they have mapped their "process" associated with the quality of their products, such as new product development, manufacturing, customer services, etc., and that they conform to these repeatable and documented processes (Benner and Veloso, 2008). Many academics and practitioners consider "process approach" as a fundamental requirement of ISO 9001:2008. Furthermore, process approach continues to be the central focus in the revised version of ISO 9001, published in 2016.

The ISO 9000 international standards were created in 1987 to standardize Quality Management System (QMS). The main objective of ISO 9001 was to provide a "set of requirements" that, if effectively implemented, would guarantee customers that their supplier can and will provide consistently high quality goods and services. The latest version of ISO 9001 has adopted a "process approach" and a "plan-do-check-act" methodology which is structured into the following core sections: (i) management and responsibility, (ii) resource management, (iii) product realization, (iv) measurement analysis and final target to achieve and (v) customer satisfaction (ISO 9001:2008). *Management and responsibility*, includes a set of requirements for developing and improving QMS per customer needs, as well as developing quality manuals and policies, planning and defining responsibilities, authorities and communication processes to facilitate effective QMS. *Resource management* provides QMS for the requirements of managing both human and infrastructure resources, (including the work environment), to achieve customer satisfaction. *Product realization* involves specific requirements for product completion processes, which include identifying customer needs and requirements, customer communication, designing and developing products, purchasing, production and service forecasting, and controls for monitoring measurement devices. Finally, *measurement analysis and improvement* comprises a set of activities for monitoring information on customer satisfaction, managing and monitoring internal and external audits, measuring and monitoring products and processes, managing non-conformities, analysing data, and taking preventive and/or corrective actions.

Several studies have analysed the use of the 'hard' QT&T elements and their relationship with the 'soft' TQM elements (Fotopoulos and Psomas, 2009, Psomas et al., 2014, Calvo-Mora et al., 2014). However, an extensive literature review revealed a lack of evidence of their relationship with QT&T in the ISO 9001:2008 process approach.

Thus, we were motivated to analyse the relationship between QT&Ts and the impact they may or may not have on the ISO 9001:2008 processes approach.

Thus, we formulated the following research questions:

- **RQ3**: Is there are a relationship between the use of quality tools and techniques and ISO 9001 processes-approach?
- **RQ4**: Does the ISO 9001 standard provide a favourable environment for the use of quality tools and techniques?

To answer RQ3, we propose the "five sets" of hypotheses based on the literature above.

6.2.2.1. Management and Responsibility

The organization shall establish, document, implement and maintain a quality management system and continually improve its effectiveness in accordance with the requirements of this International Standard (ISO 9001:2008). Thus, the company must determine and improve QMS processes and their application throughout the company. Furthermore, the top management team must review QMS at planned intervals to ensure its continuing suitability, adequacy and effectiveness. This review must include opportunities for improvement and align quality polices with quality objectives (ISO 9001:2008).
In this context, QT&Ts are used in the organization to improve processes and management review reports and to promote communication and feedback within the whole organization. For instance, management reviews must include audit results, customer feedback, product conformity, process performance, preventive and corrective action status, recommendations for improvement, etc.

Thus, we propose our first set of hypotheses:

H1a: ISO 9001 "Management and responsibility" processes are positively related to tools for "acting proactively and monitoring"

H1b: ISO 9001 "Management and responsibility processes" are positively related to tools for "analysing and controlling"

H1c: ISO 9001 "Management and responsibility" processes are positively related to tools for "providing improvement and solving problems"

6.2.2.2. Resource Management

According to ISO 9001:2008, the organization shall define and provide the resources needed to implement and maintain the quality management system and continually improve its effectiveness to enhance customer satisfaction. In this way, the organization must define the competences required and provide training for personnel performing tasks that affect product requirements.
QT&Ts contribute to companies by enhancing organizational managers' and employees' knowledge, improving communication and promoting team work.

Therefore, we propose our second set of hypotheses:

H2a: ISO 9001 “Resource Management” processes are positively related to tools for “acting proactively and monitoring”.

H2b: ISO 9001 “Resource Management” processes are positively related to tools for” analysing and control”.

H2c: ISO 9001 “Resource Management” processes are positively related to tools for “providing improvement and solving problems”

6.2.2.3. Product Realization

The organization shall plan and develop the processes for product completion. These activities include planning product completion, customer related processes, design and development, purchasing, production and service forecasting, and controls to monitor measurement equipment. In addition, the organization shall establish processes and documents required for verification, monitoring measuring, inspection and testing, records to provide evidence of process realization and product outputs that meet with the requirements (ISO 9001:2008).

During the accreditation process, it is usual for manufacturing companies, through defect cost of poor quality (COPQ), to discover defects and non-conformities that have a direct impact on the final product and process performance. QT&Ts can assist with these activities and provide methods to solve non-conformities, as well as provide tools for analysis to reduce COPQ.

Therefore, we propose another set of hypotheses:

H3a: ISO 9001 “Product Realization” processes are positively related to tools for “acting proactively and monitoring”.

H3b: ISO 9001 “Product Realization” processes are positively related to tools for “analysing and control”.

H3c: ISO 9001 “Product Realization” processes are positively related to tools for “improvement and solving problems”

6.2.2.4. Measurement, analysis and improvement

The organization shall plan and implement the monitoring, measurement, analysis and improvement processes needed to demonstrate conformity of the products and to customer requirements, as well as ensure QMS conformity and continually improve its effectiveness. The organization must also determine applicable methods, including statistical techniques, to include and the extent of their use (ISO 9001:2008).

Thus, QT&Ts play an important role in companies as they can help the organisation not only measure, analyse and monitor processes, and implement continuous improvement, but also provide them with problem-solving methods to find the root cause of any problems.

Therefore, we propose our fourth set of hypotheses:

> H4a: ISO 9001 “Measurement, analysis and improvement” processes are positively related to tools for “acting proactively and monitoring”

> H4b: ISO 9001 “Measurement, analysis and improvement” processes are positively related to tools for “analysing and control”

> H4c: ISO 9001 “Measurement, analysis and improvement” processes are positively related to tools for “improvement and solving problems”

6.2.2.5. Customer (and another's parts) satisfaction

ISO 9001:2008 focusses on customer satisfaction as, “Customers require products with characteristics that satisfy their needs and expectations. These needs and expectations are expressed in product specifications and collectively referred to as customer requirements. Customer requirements may be specified contractually by the customer or may be determined by the organization itself. In either case, the customer ultimately determines the acceptability of the product” (ISO 9000:2005).

Therefore, we propose our final set of hypotheses:

> H5a: ISO 9001 “Customer satisfaction” processes are positively related to tools for “acting proactively and monitoring”

> H5b: ISO 9001 “Customer satisfaction” processes are positively related to tools for “analysing and control”

H5c: ISO 9001 “Customer satisfaction” processes are positively related to tools for “improvement and solving problems”

6.3. Research Methodology

6.3.1. Questionnaire

To achieve our objective, and based on the research questions above, we carried out our study in WP sector supply chain firms (raw materials, component suppliers, assemblers, and wind farm operation and maintenance services). The data collection method used was the survey questionnaire, and the questionnaire design itself was based on the literature review of the work of Isikawa (1985), Imai (1986), Stephens (1997), Bunney and Dale (1997), Dale and Mc Quarter (1998), Pande et. al., (2000), Harry (2000), Harry and Schroeder (2000), Bamford and Greatbanks (2005), and Hagemeger et al., (2006). As a result, a total of 25 tools and techniques were identified.

The questionnaire was initially reviewed by quality managers and academics, and then a pilot test was performed by quality professionals. The final version of the questionnaire had three sections. The first comprised of questions about the company’s profile (company name, respondents and their position in the company, number of employees, main products or services, etc.). The second section collected information about the usage and implantation of 25 quality tools and techniques in the WP sector. The answers were ranked on a five-point Likert scale (1 – very low, 2 - low use, 3 - moderate use, 4 - high use, and 5 – very high). Table 6.3.2-1 shows company size and the profile of respondents. The third section in the questionnaire was based in QT&T use and the subsequent impact on the main processes in ISO 9001:2008. The answers were given on a five-point Likert scale (1 - very low, 2 - low, 3 - moderate, 4 - high and 5 - very high).

6.3.2. Sample and method

The survey was launched in January 2015, and 125 questionnaires were collected, from which 119 were retained for our analysis. A substantial number of respondents are global players and have been referred to in the WP sector’s specialized journals such as MAKE Consulting (2013) or BTM Consult (2014). The criterion for selecting the companies that would participate in this study was ISO 9001:2008 certification.

First, a descriptive analysis of the sample shed light on the nature of the sample. Then, the next step was to analyse the three QT&T constructs composed as per the literature review.

Next, a factor analysis of these tools was carried out (i.e. first an exploratory analysis where the internal consistency and reliability of the factors were probed), and then a confirmatory factor analysis using structural equation modelling was performed.
Finally, a correlations matrix between these groups of tools and the five groups of impacts on the ISO 9000 were performed to determine which of them have an impact on each group of tools using the ISO 9000 process approach.

Profile respondents in WP sector	Number	%
Position/ role of the respondents		
Quality manager	51	43%
Quality engineer	22	18%
Quality technician	18	15%
General manager	9	8%
Plant manager	13	11%
Manufacturing manager	2	2%
Customer & project quality	4	3%
Total	119	100%
Regions		
Europe Suppliers	58	49%
Europe wind farms	14	12%
Asia suppliers	15	13%
Latin America suppliers	20	17%
Global quality engineers	12	10%
Total	119	100%
Companies Size		
Large (>250)	37	31%
Medium (100-250)	33	28%
Small (<100)	49	41%
Total	119	100%

Table 6.3.2-1 Descriptive variables relative to company size and respondents' profile

6.4. Results

We have divided this section into four subsections: (i) a descriptive analysis of the use of quality tools and techniques, (ii) an exploratory factor analysis (EFA) and a confirmatory factor analysis (CFA) of quality tools and techniques use in the WP sector (iii) a descriptive analysis of the impact QT&Ts have on the main processes in ISO 9001 and, finally, (v) a correlation matrix between the main processes in ISO 9001:2008 and the QT&T "groups" detected in the factor analysis.

6.4.1. Descriptive analysis quality tools and techniques

6.4.1.1. Individual analysis

Table 6.4.1-1 depicts QT&T use and degree of use, as defined by the responding WP sector. The percentage is understood as the mean of answers using the Liker scale (from 1 to 5) out of 5. From table 6.4.1-1 we can observe that internal audits (83%), flowchart diagrams (78%), cost of poor quality (78%), sheets and control charts (76%), and team work (76%) are very popular because they are easy to implement and simple to use.

On the other hand, QT&T procedures such as DOE (36%), QFD (42%), Value stream mapping (VSM) (44%), Six Sigma (48%) and Business Process Management (BPM) (46%), are used less frequently because they are rather more complex QT&Ts. The results show that QT&Ts needing greater knowledge and skills are used less frequently than QT&Ts requiring a lower knowledge and skill level. These results are also in line with the findings of Fotopoulos and Psomas (2009) and Heras et al. (2011).

Quality tools and techniques	Groups	Nº	Average	Std. Deviation	%
Internal audits	L1	119	4,17	0,87	83%
Flowchart diagrams	L2	119	3,92	1,03	78%
Cost of poor quality	L2	118	3,92	1,19	78%
Team work	L1	118	3,84	1,09	77%
Sheets and Control Charts	L2	119	3,82	1,17	76%
Customer satisfaction surveys	L1	119	3,61	1,30	72%
PCDA (Deming Cycle)	L3	119	3,56	1,20	71%
Pareto Chart	L2	117	3,52	1,17	70%
Brainstorming	L2	119	3,50	1,14	70%
8 D Method	L3	119	3,46	1,17	69%
5-S (Method)	L3	119	3,45	1,15	69%
5 Whys and 2 How's	L2	119	3,40	1,24	68%
Cause - Effect diagrams	L2	119	3,35	1,12	67%

Histograms	L2	118	3,26	1,32	65%
Suggestion system (mailbox suggestions)	L1	118	3,20	1,27	64%
Poka Yoke tools	L2	118	3,06	1,39	61%
FMEA (Failure Mode Effect Analysis)	L2	119	3,04	1,15	61%
Employee satisfaction surveys	L1	119	2,91	1,10	58%
SPC (Statistical process control)	L2	119	2,84	1,21	57%
Benchmarking	L2	118	2,67	1,29	53%
Six sigma (DMAIC)	L3	119	2,41	1,00	48%
Business Process Management (BPM - BPR)	L3	118	2,31	1,27	46%
VSM (Values Stream Mapping)	L3	119	2,19	1,08	44%
QFD (Quality Function Deployment)	L2	118	2,10	1,12	42%
DOE (Design of experiments)	L3	118	1,84	0,86	37%

Groups of Quality Tools and Techniques	Groups	Average	%
Tools for acting proactively and consulting	L1	3,55	71%
Tools for analysing and control	L2	3,26	65%
Tools for problem solving and improvement	L3	2,75	55%

Table 6.4.1-1 Intensity of use quality tools and techniques (individual and groups)

6.4.1.2. Descriptive analysis quality tools and techniques by proposed groups

The descriptive analysis of QT&Ts considering the proposed three groups, show that the most-used (with 71%) group of tools is **(L1) tools for acting proactively and consulting**. One of the main reasons for the "high" use and good knowledge of these types of QT&Ts is that some of them are mandatory in the ISO 9001: 2008 standard. Some are implicit, for example, “internal audits” (83%), while others are explicit, for instance, “customer satisfaction surveys” (72%). On the other hand, other QT&Ts in this group such as "employee satisfaction surveys" (58%) or "suggestion system" (64%) are used internally to analyze organizational structures, management styles, communication and/or the work environment. These QT&Ts are different from other groups because they require little investment and little employee training. Usually these tools are qualitative and do not require any specific statistical knowledge. They are easy to apply and are used by management for making long-term decisions from a qualitative point of view. These tools are usually used for long-term action plans, typically within the company strategic plan framework, or quality management system revisions.

Second, we have the **(L2) tools for analyzing and control** group, used by 65% of the sector. These types of QT&Ts, for instance "Flowchart diagrams" (78%), "Brainstorming" (70%), "the Pareto chart" (69%), "Cause-Effect diagrams" (67%), and "5 Whys and 2 How’s" (68%), are used for analyzing and diagnosing problems faced in daily practice and in production process controls. They are designed primarily for analyzing and resolving problems that usually appear in daily production work. In this same group, we found some tools such as "FMEA" (61%), "QFD" (42%) or "Benchmarking" (53%) are also commonly used in product development phases or in advanced quality planning. The results of the study show that they are known by and used "regularly" in the sector. Therefore, we can say that the industry has applied knowledge and problem analysis tools "regularly" but there is still a lot of room for improvement. With respect to monitoring tools such as "SPC" (57%), "Poka Yoke" (61%), "Sheets and Control Charts" (76%), we see that they are also well known and used "regularly" by the sector. These tools are regularly used in monitoring and control of production processes. However, we were surprised by the high use of SPC in the WP sector, since one of its characteristics is low volume and high variability, and SPC is more commonly used in high-volume, low-variability scenarios where processes tend to be more stable.
As with group (L1), some of the tools and techniques used in group (L2) are mandatory or are implicit in ISO 9001:2008 (i.e. mandatory procedures such as "quality records procedure" or specific sections of the standard such as "Analysis of data"). One of the reasons for the "regular" use and good knowledge of these tools is the sense of the sector belonging to a supply chain. These quality tools are known of and introduced into companies by process engineers and manufacturing, as well as managers and quality engineers. However, while some of these concepts, such as "SPC" or "FMEA", require initial training from external consultants and internal facilitators, the rest form a well-established part of daily practices in the sector.

Finally, we have QT&Ts which are less frequently used (55%) and belong to the **(L3) tools for problem solving and improvement** group. These techniques, with respect to the other groups, are much more complex to use and they are generally techniques, such as "Six Sigma" (48%) or "DOE" (36%) that require an excellent knowledge of statistics or some knowledge of processes and manufacturing methodologies in the case of "VSM" (44%). All of them tend only to be used with the help of external consultants and internal facilitators, who provide support through a solid knowledge of statistics and develop specific methodologies. The use of these techniques is restricted and generally responds to top management initiatives launching procedures such as "Six Sigma" or "Lean manufacturing" programs. On the other hand, the group (L3) also has 5s (69%), 8D's (69%) and PDCA (71%), which are techniques used for continuous improvement and solving complex problems. Although less complex statistically, these techniques also require the help of external consultants or internal facilitators to meet objectives and, as such, tend to respond to top management programs.

6.4.2. Exploratory Factor Analysis

To validate the grouping of the 25 tools and techniques used, and learn about their structure, an exploratory factor analysis (EFA) was performed to verify that the families raised were homogeneous. In this exploratory analysis, the 25 tools were initially distributed according to five factors (table 6.4.2-1). Since the goal here was to obtain three groupings of tools, data was iterated until its simplification. After three iterations looking for loadings higher than 0.5 and that each factor had 3 or more variables involved, the results were validated and passed on to the next confirmatory analysis.

Quality Tools	F1	F2	F3	F4	F5
Suggestion system (mailbox suggestions)		0.741			
Customer satisfaction survey		0.839			
Internal audits		0.736			
Brainstorming	0.713				
Flowchart diagram	0.666				
Histogram	0.654				
Cause - Effect diagram	0.755				
Pareto chart	0.793				
Sheets and control charts		0.606			
5 Why´s and 2 How's	0.602				
5S Methodology				0.706	
FMEA (Failure Mode and Effects Analysis)			0.683		
QFD (Quality Function Deployment)					0.689
PCDA (Deming circle)					0.639
8D Method			0.801		
DOE (Design of experiments)			0.567		
VSM (Value Stream Mapping)				0,605	

Table 6.4.2-1 Quality tools and techniques Exploratory Factor Analysis (EFA).

6.4.3. Confirmatory Factor Analysis

Table 6.4.3-1 summarizes the reliability analysis of the three dimensions of these three factors. The internal reliability of these factors was then assessed and confirmed as the indicators retained exhibited loadings of 0.5 or higher. The internal consistency of the constructs reaffirmed our approach, obtaining values that exceeded the recommended threshold value of 0.7 for both Cronbach's alpha coefficient and composite reliability (CR). The Average Variance Extracted (AVE) also surpassed the cut-off point of 0,5 (Nunnally and Bernstein 1994) for all factors. Results revealed that Cronbach's alpha value did not improve when an item was removed; therefore, we decided not to exclude any items.

These results confirmed a linear dependence between the variables and supported our view that the results were sound. Only three factors emerged with eigenvalues greater than one (Kaiser criterion). Looking more closely at the tools included in each factor, the following labels were provided: (L1) Tools for acting proactively and consulting, (L2) Tools for analyzing and monitoring and (L3) Tools for improvement and solving problems. A confirmatory factor analysis (CFA) was performed. Table 6.4.3-1 shows only those items with significant loads, i.e. the items proposed for the three constructs. The model was estimated using the robust maximum likelihood method from the asymptotic variance–covariance matrix. The fit indices obtained in the measurement model estimation showed that the variables converged toward the factors established in the CFA. $\chi 2$ Satorra-Bentler was 59.00, with 41 degrees of freedom and a p-value of 0.034. RMSEA was 0.062 and the CFI was 0.955.

Taking the significance of the robust $\chi 2$ statistic with caution and noting the global indicators, the global fit was acceptable (Hair et al., 2010). The composite reliability and the AVE of the constructs are above the threshold recommended, showing good psychometric values which in turn vouch for internal consistency and reliability.

Tools for acting proactively (L1) (CR = 0.841 & AVE = 0.799)	Standardized load	t-value	r^2
Suggestion system (mailbox suggestions)	0.654	-	0.427
Customer satisfaction survey	0.687	6.675	0.752
Internal audits	0.643	5.211	.0413
Tools for analysing and control (L2) (CR = 0.856 & AVE = 0.773)	Standardized load	t-value	r^2
Brainstorming	0.754	-	0.569
Flowchart diagrams	0.694	8.731	0.482
Cause - Effect diagrams	0.860	9.033	0.739
Pareto Charts	0.757	9.064	0.573

Tools to improve and for solving problems (L3) (CR = 0.767 & AVE = 0.775)	Standardized load	t-value	r^2
5S Methodology	0.756	-	0.586
8D Method	0.563	5.248	0.288
DOE (Design of experiments)	0.523	4.997	0.274
VSM (Value Stream Mapping)	0.533	5.604	0.285

Table 6.4.3-1 Confirmatory Factor Analysis of the use of quality tools.

From the results, we found that the group of families is consistent with the data and is structured in three constructs**. Factor 1 (L1) tools for acting proactively and consulting, Factor 2 (L2) tools for analyzing and control and Factor 3 (L3) tools for improvement and solving problems**.

6.4.4. Descriptive analysis of quality tools and techniques, and their impact on ISO 9001

Table 6.4.4-1 shows the list of Impacts on Results as a result of QT&T application. Each item was assigned to an ISO main process (P1 to P5) and then, with a Confirmatory Factor Analysis, performed the constructs of each main process.

As can be seen from specific results, QT&Ts promote continuous improvement (88%), help companies to improve the quality of their products (87%), promote problem-solving methods (87%), help the companies to reduce non-conformities (87%) and also are used to improve the customer's image of the company (86%).

At the bottom of the list, there are the low impacts on the expected results and this reveals that QT&Ts are used by company operators (58%), in company strategic planning (67%) and in collaboration with the supplier(s) (70%), which are the lowest values among the expected results.

Moreover, after the factor analysis to reduce dimensions and increase the understanding of these results, table 6.4.4-1 also shows the impact of QT&T use with respect to the ISO 9001 process approach as per the impact categories established in the previous section. "(P4) measurements analysis and improvement" scored (86%), while "(P3) product realization" scored (85%) and "(P5) customer satisfaction" (80%).

We detected that the use of QT&Ts in "(P2) resource management" had less impact (74%) and in "(P1) management and responsibility" it scored (75%). However, we consider there are no significant differences between this and the ISO 9001 process.

ISO Impacts	Nº	ISO Main Process	Average	Std. deviation	%
Promote continuous improvement	119	P4	4,38	0,86	88%
Can help improves product quality	118	P3	4,37	0,76	87%
Promote problem solving methods	119	P4	4,36	0,82	87%
Can help reduce the "Non Conformities"	119	P3	4,35	0,82	87%
Improve the company "image" in front to customers	118	P5	4,31	0,91	86%
Can help reduce ‘’cost of poor quality’’	119	P3	4,31	0,83	86%
Increase the customer satisfaction (external)	118	P5	4,16	1,03	83%
Improve the company profit	116	P4	4,10	0,85	82%
Can help improve internal processes	118	P1	4,03	0,89	81%
Can help improve the productivity	118	P3	4,03	0,98	81%
Increase the customer satisfaction (internal)	118	P5	3,93	1,06	79%
Improve employee knowledge	119	P2	3,90	0,94	78%
Promote teamwork	118	P2	3,90	0,98	78%
Are used by engineers and managers	119	P2	3,89	0,95	78%
Can help enhance knowledge within the company	119	P2	3,83	0,93	77%
Are used in top management reports	117	P1	3,82	1,02	76%
Improve the internal communication	118	P1	3,80	0,93	76%
Are used with suppliers	119	P5	3,51	0,98	70%
Are used for strategic planning	118	P1	3,34	1,13	67%
Are used by (blues collar) operators	119	P2	2,90	1,04	58%

ISO 9001 Main Processes	ISO Main Process	Average	%	Cronbach's alpha
Management and responsibility	P1	3,75	75 %	0,785
Resource management	P2	3,70	74 %	0,812
Product realization	P3	4,26	85 %	0,869
Measurement analysis and improvement	P4	4,28	86 %	0,833
Customer satisfaction	P5	3,98	80 %	0,841

Table 6.4.4-1 Intensity of impact due to QT&T classified by ISO 9001 Main Processes.

6.4.5. Impact and relationship between quality tools and techniques and ISO 9001

In this section, we analyse the relationship between the QT&Ts and the impact they have on the main processes, including customer satisfaction, in ISO 9001. On the one hand, we have the three constructs formed by the QT&Ts and, on the other hand, the results classified into the main ISO 9001 processes. We then performed a correlation to validate the implication each group of tools (L1, L2 and L3) has on each of the main process (P1, P2, P3, P4 and P5).

According to the authors; this is the main contribution of this article because, in establishing the relationship between the QT&Ts classified in the three constructs we proposed and validating these against the expected results related to each of the main ISO 9001 processes, we are able to demonstrate the correlation that exists between the QT&Ts and each of the core ISO 9001 practises.

Table 6.4.5-1 shows the correlations between the QT&T groups and the ISO 9001:2008 process approaches, i.e. (P1) management and responsibility, (P2) resource management, (P3) product realization, (P4) measurement analysis and improvement, and the final output (P5) customer satisfaction. These correlation results validate the hypotheses we proposed as follows:

Bilateral correlation		P1	P2	P3	P4	P5
L1	Pearson's correlation	**,299****	**,407*****	**,354*****	**,340*****	**,370*****
	Significance	,002	,000	,000	,000	,000
	Nº	110	114	113	112	113
L2	Pearson's correlation	**,337*****	**,410*****	**,322****	**,299****	**,402*****
	Significance	,000	,000	,001	,001	,000
	Nº	110	114	113	112	113
L3	Pearson's correlation	,169	**,193***	**,281****	**,191***	**,197***
	Significance	,078	,040	,003	,043	,036
	Nº	110	114	113	112	113

*** Correlation is strongly significant at the 0,001 level (bilateral). Very Strong
** Correlation is strongly significant at the 0,01 level (bilateral). Strong
* Correlation is strongly significant at the 0,05 level (bilateral). Exists

Table 6.4.5-1 Based on results, bilateral correlations between the constructs created

6.4.5.1. Hypothesis H1

Table 6.4.5-1 indicated that (P1) "management and responsibility" is positively and significantly ($p < 0, 01$) related to QT&T for (L1) "consulting and acting proactive" and significantly very strong ($p < 0,001$) with tools for (L2) "analysing and control". Hence, H1a and H1b are supported.

Nevertheless, the coefficient between (P1) "management and responsibility" and QT&Ts for (L3) "problem solving and improvement" is not significant at ($p > 0, 05$) and, consequently, H1c was not supported.

6.4.5.2. Hypothesis H2

The interaction terms between (P2) “resource management” and QT&Ts for (L1) “consulting and acting proactive”, and QT&Ts and (L2) “analysing and control” is positive and significantly very strong ($p < 0{,}001$), thus, H2a and H2b are supported. Likewise, (P2) “resource management” had a significant and positive moderate effect (p-value $< 0{,}05$) on the relationship to (L3) “problem solving and improvement”, hence, H2c is supported.

6.4.5.3. Hypothesis H3

The relationship between (P3) “product realization” and QT&Ts for (L1) “consulting and acting proactive”, are positively significant and very strongly related ($p < 0{,}001$). Also, tools for (L2) “analysing and monitoring”, and tools for (L3) “problem solving and improvement” are positively significant ($p < 0{,}01$) related to (P3) “product realization”. Thus, hypotheses H3a, H3b, and H3c, are fully supported.

6.4.5.4. Hypothesis H4

The interaction between (P4) “measurement analysis and improvement”, and tools for (L1) “consulting and acting proactively” are positively significant and very strongly related ($p < 0{,}001$). Likewise, the relationships between tools for (L2) “analysing and monitoring” is positively significant and strongly related ($p < 0{,}001$). Lastly, (P4) “Measurement and analysis and improvement” is positively significant related ($p < 0{,} 05$) to tools for (L3) “problem solving and improvement”, thus H4a, H4b, and H4c are fully supported.

6.4.5.5. Hypothesis H5

The relationship between (P5) “customer satisfaction”, and tools for (L1) “consulting and acting proactively”, and (L2) tools for “analysing and monitoring” are positively significant and very strongly related ($p < 0{,}001$). Likewise, tools for (L3) “problem solving and improvement” are positively significant related to ($p < 0{,}05$) to (P5) “customer satisfaction”. Thus, we can say H5a, H5b, and H5c, are supported.

6.5. Discussion and findings

6.5.1. Quality tools and techniques descriptive analysis

In view of the results, we can say that the WP is a sector that has a high level of QT&T use. One of the main features of the sector is the high technological complexity of the product, the short production runs (low volume) and high variability (constant technological developments and customizations) and, consequently, all these considerations involve a constant practice of analysis and problem solving.

Our study shows that, on the individual level, QT&T use is "higher" in the WP sector when compared to the other sectors referenced in the literature (Ahmed and Hassan (2003), Lagrosen and Lagrosen (2005), Alsaleh (2007), Fotopoulus and Psomos (2009), Heras et al., (2009) and Talib et. al., (2013)).

We can show that the most widely-used tools in the WP sector are internal audits (83%), flowchart diagrams (78%), cost of poor quality (78%), sheets and control charts (76%) and team work (76%). Some of the techniques and tools mentioned, such as “internal audits”and “flowchart diagrams”, agree with previous studies referenced in the literature, (e.g. Tarí and Sabater (2004), Heras et al., (2011) and Talib et al., (2013). However, we cannot state the same in terms of ‘degree of use’, since the evidence from the WP sector shows a much higher use than that of other sectors.
One of the aspects that makes our findings different, with respect to other referenced literature (Ahmed and Hassan (2003), Logrosen and Logrosen (2005), and Fotopoulos and Psomas (2009)), is that these studies did not focus on a specific sector as ours did.

Furthermore, we note that the QT&Ts "least used" in our study are DOE (36%), QFD (41%), VSM (44%), Six Sigma (48%) and BPM (46%). Here, we are more in line with other referenced literature, despite our use of these tools and techniques being somewhat more extended, but we also agree with the work of Heras et. al., (2011) and Talib et. al., (2013), where less frequent use of quality techniques, such as DOE, Six Sigma and BPM, is evident.

Concerning the first research question RQ1:

> RQ1: What is the “individual level use” of quality tools and techniques in the WP sector?

We can confirm that we have a “high” level of QT&T use in the WP sector.

6.5.2. Quality tools and techniques by “groups”

In our view, a highly complex technology sector like the WP sector facilitates the use and development of QT&Ts because of its highly technological environment. However, when we divide the QT&Ts into categories in terms of the specific uses we proposed, some variations are observed. The QT&Ts in the group (F1) "tools for consulting and acting proactively”, show that among the population surveyed there is a "high" use (71%). One of the reasons for this “high” result, is because the tools associated with this group form part of the ISO 9001: 2008 environment, which implies the use of some tools and techniques derives from some of the standards procedures or mandatory processes (i.e., internal audits, customer satisfaction, etc.). With the second group (F2) “tools for analyzing and control”, we, like other sectors referenced in the literature, also found a “frequent” level of use (65%). The third group (F3) "tools to improve and solving problems" scored a 55% use. In this sense, the result is “regular” since, as McQuarter et al., (1995) noticed, between sectors there are significant differences in the use of tools and techniques. Greene (1993) and Tarí and Sabater (2004) also pointed out that the specific situations each company experiences in the daily practices requires certain tools. Employing techniques for improving and solving problems (e.g. 8Ds, DOE, VSM, QFD, BPM), requires company commitment and management support, along with explicit planning, investment in training programs and specific guidance (in some cases from external consultants as well as from internal facilitators) to train staff, implement the tools and develop and support their use.

From the results of the EFA and the CFA, we found the group of families is consistent with the data and is structured into three constructs. Factor 1 (F1), tools for consulting and acting proactively, factor 2 (F2), tools for analysing and control, and finally, factor 3 (F3), tools for improvement and solving problems.

With the second research question, RQ2:

> RQ2: What are the different levels of “use” of quality tools and techniques groups in the WP sector?

We can confirm that we have ascertained a "regular" level QT&T use among groups in the WP sector.

6.5.3. Impact of quality tools and techniques in the ISO 9001 processes approach

From the results of our research (table 6.4.5-1), we can state that the QT&Ts from groups (F1) *"tools for consulting and acting proactive",* (F2) *"tools for analyzing and control"* and (F3) *"tools for problem solving and improvement"* have a positive relationship with the main processes in the ISO 9001 standard, i.e. (P1) *management and responsibility*, (P2) *resource management*, (P3) *product realization*, (P4) *measurement, analysis and improvement*, and (P5) *customer satisfaction*.

Therefore, concerning the research questions raised above, we can report that for RQ3:

> RQ3: There are relationships between the use of quality tools and techniques and ISO 9001 processes approach?

We can confirm, there is a positive and significant relationship between QT&Ts and the main processes in the ISO 9001 standard.

With the final research question posed RQ4,

> RQ4: The ISO 9001 standard provides a favourable environment for the use of quality tools and techniques?

According to the results of the above hypothesis, we can confirm that ISO 9001 provides a favourable environment for QT&T use.

To conclude this section, although the impact of training in terms of the use of QT&T in this study has not been empirically analysed, authors such as McQuarter et al., (1995), and Bunney and Dale (1997), note that key factors in the successful implantation of QT&Ts are both a total commitment from management, and full support and correct training being given to the right people at the right time.

6.6. Conclusions

Quality tools and techniques help organizations and companies to analyse and solve problems by providing the methodology required to detect a problem, determine its root causes, plan and develop any corrective and preventive action, validate the efficiency of the solutions, and finally, monitor the proposed solutions. Thus, the use of QT&Ts improves communication between managers, engineers and operators, and also helps them to understand the processes and distinguish possible causes of process variation.

From the results of our study, we can confirm that, with respect to other referenced works in the literature, there is a "high" use of QT&Ts in the WP sector. However, and as noted in the earlier literature review, there is no clear agreement regarding the use of QT&Ts. So, we can say that QT&T use can vary from organization to organization, from sector to sector and from region to region. Moreover, while the present study has also shown that the ISO 9001: 2008 environment provides a clear framework for the use of QT&Ts, it should be noted that an appropriate environment for their development is required and it is the responsibility of top management to provide the right environment and sufficient resources and to lead the program. To conclude, a point to consider when analysing the results of this study is that the WP sector is considered a high-tech sector due to its product requirements (i.e. 97.5% availability, 24 hours a day is required for wind turbines). It shows that, in day to day practice, the industry’s technicians and engineers are used to analysing and solving problems caused by these turbines.

In conclusion, we can say there is a ‘high’ use of quality tools and techniques in the WP sector, albeit with some opportunities to improve, as in "continuous improvement" and "problem solving". However, using QT&T alone cannot provide results and companies must use them in an integrated way, in other words, connected with main ISO 9001 processes and factors to ensure success.

6.6.1. Practical Implications

For managers, this article has some practical implications as the results provide WP sector firms, managers and practitioners with a practical understanding of the tools and techniques required for quality improvement. Therefore, WP sector managers should focus on the less-used quality tools and techniques, and understand what DOE, QFD, VSM, Six Sigma (DMAIC) and BPM really mean and implement these procedures accordingly to improve not only their overall business performance, but also to enhance quality performance. If firms wish to go beyond ISO 9001, they must improve these aspects to become more competitive.

Firms and their managers should understand that the quality of a product does not only depend on the quality of the process, but also on the quality of management systems that adopt key QT&T practices. Furthermore, it is vital that top management teams provide an adequate atmosphere and the resources and training required for continuous improvement programs promoting the advantages applying QT&Ts. Well-designed training and development programmes should be provided to all the members of the company to help them understand the importance of both basic and advanced tools and techniques and how to apply them.

6.6.2. Research limitations and future research recommendations

While this study focused on the WP sector, the findings could be extended to other "high-tech" sectors. Furthermore, it should be acknowledged that the use of QT&Ts may vary between companies or sectors and so every company or sector will need to implement specific QT&T procedures according to their particular situation. Therefore, for future research we would encourage academics and ISO 9001 researchers to focus on developing a framework or road map that integrates the main QT&T procedures into the main ISO 9001 processes.

6.7. References

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6.8. Attachments

Quality Tools and Techniques Survey

Company name :
Nº Employees :
Position of the person answering :

Sector/Components:
Year ISO /EFQM certification:
Year company was founded:

Level of use (intensity) Quality tools and Techniques

Question to answer :

What is the "individual level use (intensity)" of quality tools and techniques in the company?

		Mark whit a "X"				
Nº	Quality tools	very low	low	moderate	high	very high
1	Team work					
2	Suggestion system (mailbox suggestions)					
3	Customer satisfaction survey					
4	Employee satisfaction survey					
5	Internal audits					
6	Brainstorming					
7	Flowchart diagram					
8	Histogram					
9	Cause - Effect diagram					
10	Pareto Chart					
11	Sheets and Control Charts					
12	5 Whys and 2 How's					
13	5-S (method)					
14	SPC (Statistical process control)					
15	FMEA (Failure Mode and Effects Analysis)					
16	QFD (Quality Function Deployment)					
17	Business process Management (BPM - BPR)					
18	Benchmarking					
19	Poka Yoke tools					
20	Cost of poor quality					
21	PCDA (Cycle de Deming)					
22	8 D Method					
23	Six sigma (DMAIC)					
24	DOE (Design of experiments)					
25	VSM (Values Stream Mapping)					

Quality Tools and Techniques Survey

Relationships between Quality Tools and Techniques and ISO 9001 main process

		Mark whit a "X"				
ISO Process	ISO Impacts	very low	low	moderate	high	very high
P1	Are used in the top management reports ?					
	Are used for strategic planning ?					
	Improve internal communication ?					
	Can help improve internal processes ?					
P2	Improve employee knowledge ?					
	Promotes teamwork ?					
	Are used by engineers and managers ?					
	Can help enhance knowledge within the company ?					
	Are used by (blues collar) operators ?					
P3	Can help improves product quality ?					
	Can help reduce the "Non Conformities" ?					
	Can help reduce "cost of poor quality" ?					
	Can help improve the productivity ?					
P4	Promote continuous improvement ?					
	Promote problem solving methods ?					
	Improve the company profits ?					
P5	Are used with suppliers ?					
	Improve the company "image" in front to customers ?					
	Increase the customer satisfaction (external) ?					
	Increase the customer satisfaction (internal) ?					

Chapter Nº7

Discussion, Conclusions, Implications and Future Research

7. Discussions, Conclusions, Implications and Future Research

7.1. Discussions and Conclusions

In recent years, the renewable energy sector has awakened economic and social interest in various fields (industrial groups, builders, manufacturers of capital goods and services, investors, environmental groups, politicians, education, etc.). The advantages of renewable energy and, in particular, the WP sector are already a proven reality. Not only from the economic perspective, where the large utilities Iberdrola, Endesa, EDF, EOM, EDP, etc. have seen the profitability of this sort of energy, but also as an alternative energy to those produced from fossil fuels.

At the same time, there is an industrial scope as many manufacturers of components, capital goods of different sectors, installers, and constructors, have seen as a business opportunity in developing different types of applications for the sector and, notwithstanding, from an academic point of view, where more and more "Master's degrees" and university specializations, with the aim of training the new generations of professionals in this sector have appeared.

For this reason, after 17 years of experience as a professional in the sector, this thesis has given me the opportunity to deepen in some aspects related to the sector and its supply chain. It has been incredibly enriching to be able to explore this area and deepen the knowledge of it with the academic rigor that different aspects related to the management of the SC of the sector deserves. With my professional experience accumulated during these years, I have looked at this through the "eyes" of the practitioner, but at the same time through the "lenses" of the "researcher" and with the support of the research team that participated in the different articles that form this thesis.

Through the research questions and the hypotheses posed in the different papers, we have had the opportunity to discern many of the issues that we have been debating for years in the professional field, albeit without the scientific and academic rigor that the subject deserves.

In this section, and as a summary, we try to recap the discussion and main conclusions of the research we carried out. These conclusions are the result of the practical and empirical evidence and the fruit of the contributions, ideas and thoughts expressed throughout the research project. Logically, these conclusions are put into context with the opinions and reflections of the author and the research team to which he belongs. In addition, the foremost practical implications, limitations and main lines of research that remain open in relation to the doctoral thesis are also established.

The discussions, conclusions, and reflections of the research are framed in each of the "five papers" that make up this doctoral thesis.

In the **paper** "**Hybrid supply chain - Strategies in wind power**" (Chapter Nº 2) we have characterized the supply chain of the sector under the following attributes*: (1) Low-volume, (2) High-variability, (3) Highly-customized, (4) High-technology, (5) High-quality and (6) Short life cycle*.

According to the research findings, the wind power supply chain model consists of a "hybrid" supply chain containing several paradigms in management, and two order decoupling points (ODP). The main feature is the separation of decisions related to project management downstream of the WTM from component sourcing strategy upstream of the WTM. Up to four manufacturing paradigms can co-exist in a hybrid supply chain. The supply chain can, depending on the complexity of the components, have more than one ODP. Different manufacturing strategies need to be applied to different supply chain pipelines for components categorized as "supply risk" and/or "profit impact". Furthermore, the WTM must be skilled in management and supply chain integration and needs to be able to manage the different lean, agile and leagile paradigms efficiently based on key component attributes. Finally, project management should be a supply chain integrator so as to gain a competitive advantage over competitors.

The **paper** "**Lean manufacturing and its impact on competitive priorities: A wind power supply chain study"** (Chapter Nº 3) refers to the use of "lean" practices in the sector. Although according to our literature review, the SC of this sector does not behave in the characteristic way of a typical lean supply chain i.e. characterized by *(i) a predictable demand, (ii) high manufacturing volumes,* and *(iii) little variability in the product mix*. On the contrary, the WP sector is characterized by: *(i) an uncertain and unpredictable demand, (ii) low production volumes* and *(iii) high variability in the product mix* due to the high customization of the sector.

Given this premise, we have shown a "moderate" use of lean practices. We can say that the sector is in a phase of implementation regarding the use of such practices. Our research has also shown that there are four lean dimensions in the sector, which we have called: create flow, waste minimization, human and cultural management and way of work.

We have also found that the four dimensions of lean found have a direct impact on competitive priorities (quality, cost, on-time delivery, flexibility, productivity and customer satisfaction), with differing levels of significance.

The **paper** "**ISO 9001 aspects related to performance and their level of implementation**" (Chapter Nº 4) resulting from our research has shown that in the sector there are three different levels of implementation of ISO 9001 practices.

A first elementary level that we have called structural implementation is used by companies that only want to meet the minimums of the standard and do not decide to go beyond it. These types of companies are limited to meeting the minimum requirements of the standard and they often use the ISO standard as a cover letter for customers or to bid for certain tenders.

On the other hand, we have another group of companies that we have called internal integration. They are organizations that take advantage of the opportunities o ISO 9001 certification provides to optimize and integrate their internal operations and processes. These types of companies use ISO certification as the leverage to introduce change within the organization.

Finally, we find other types of companies who are more "visionary" and whose goal is to go beyond the standard. We have called these companies external integration. They are the ones who use the ISO 9001 standard to try to integrate all the elements of the upstream and downstream supply chain, including stakeholders.

Our research has also shown that second-party audits are essential both for improving the quality of the product, the processes, as well as for the entire quality management system (QMS), since they are performed by experts in the subject being audited as well as experts in the sector. Hence, in some sectors such as the automotive industry, the oil & gas industry or in food manufacturing, etc., customers use this type of audit to ensure that the supplier is able to meet quality, capacity, and the term stipulated in the contract.

In addition, our research has revealed that according to the second-party audit carried out, some suppliers in the sector have not satisfied the minimums required by the ISO standard. Therefore, our research has shown that in many cases the ISO 9001 standard does not meet the needs and requirements of customers in sectors of high technological complexity of products.

In the **paper** **"Evidence for quality management systems being instrumental in improving supplier performance: the case of the wind power sector"** (Chapter Nº 5) we have provided evidence for integrating the concepts of upstream Supply Chain and QMS to test the use of suppliers as extended resources in very complex product sectors, such as the wind power sector. However, this behavior does not extend to all technologies, with some showing significant differences in the audit results.

Also, the audits of the different suppliers of the SC sector have revealed that there are suppliers that do not meet the minimum requirements of the ISO 9001 standard. At the same time, we have detected some ISO 9001 areas for improvement such as product execution and measurement analysis and improvement.

Moreover, there are significant differences in implementation between different "technological families" that constitute a wind turbine and have the ISO 9001 standard in operation. Therefore, it is not possible to consider the ISO 9000 series as being the only way to validate a QMS. According our findings, we can point out that the QMS model, according to ISO 9001, is a general model and is not sufficiently exact to meet the specific product requirements of certain sectors with a high demand of technical complexity.

Hence, some sectors have developed sector-specific QMS, such as VDA, ISO/TS, IATF, for the automotive industry, AS 9000 for the aerospace industry, TE 9000 for tooling and equipment, TL 9000 for telecommunications, PS 9000 for pharmaceutical packaging materials or GMP for food, drug and pharmaceutical products, GLP for laboratories or FDA for foodstuffs, drugs and cosmetics. These sectors have specific quality management standards to ensure they meet their sector's specific technical requirements.

We can also conclude that the QMS model, according to ISO 9001: 2008, is a general model and is not sufficiently exact to meet the specific product requirements of certain sectors with a high demand of technical complexity.

Finally, in the **paper** **"The use of quality tools and techniques and their integration into ISO 9001"** (Chapter Nº 6), our research has revealed a "high degree" of use of quality tools and techniques (QT&T) in the wind power sector, compared to other sectors referenced in the academic literature.

In the same way, our research has grouped the quality tools and techniques into three dimensions with respect to their use. The first dimension refers to tools for acting proactively and consulting. They are the classic mandatory tools that are derived from the application of the ISO 9001 standard in all quality management systems (QMS). A second dimension, tools for analyzing and control, are those tools used to solve daily problems and control processes. Finally, in the third dimension, tools for problem solving and improvement, tools of greater complexity and used for the resolution of complex problems and continuous improvement are framed.

Lastly, we correlated the groups of quality tools and techniques found with the main ISO 9001 processes (*management and responsibility, resource management, product realization, measurement analysis and improvement,* and *customer satisfaction)*. As a result of this correlation, we have shown that the ISO 9001 standard provides a suitable environment for the use of quality tools and techniques.

7.1.1. Conclusions summary

In summary and to conclude this section, we can say that the SC of the wind power sector is a complex chain in which different management paradigms are combined. This complexity means the supply chain coexists with different order decoupling points (ODP) depending on the complexity of each component.

The high working in process due to the cost of the components in the pipeline, the high variability in the lead times of the components (from 1 day to 7 months) and the large number of references that constitute a wind turbine (more than 8,000) makes the management of its supply chain complex. In this way, companies in the sector must model their supply chain upstream depending on the type of component or system to be supplied and downstream according to the needs and "customizations" of the customers.

Thus, this complexity creates the need for the sector's supply chain to become a hybrid, combining different management paradigms, lean, agile, leagile and project management, where different management skills are needed for the managers of the same.

In addition, our research led us to show the moderate use of lean practices in the sector. It has also been shown that their use has a positive impact on competitive priorities.

On the other hand, our research on issues related to Quality Management in the sector has discerned that the ISO 9001 standard only ensures that a documented Quality Management System (QMS) exists, and it has not been possible to demonstrate the correct implementation of it in all its scope.

As we have been able to demonstrate through second-party audits, there are ISO 9001 certified suppliers who do not meet the minimum required by the standard. Also with respect to the points of the standard analyzed, we have seen that there are many deficiencies in its implementation with respect to activities related to key processes such as product execution and measurement analysis and improvement, points that directly impact the quality of the product. In this way, we can say that the ISO 9001 standard does not guarantee the quality of the final product.

For this reason, some specific sectors opt for second-party audits together with their own quality standards (example VDA, IATF, Formel Q, etc.) to ensure the quality of the final product. Our research has also shown the usefulness of third-party audits regarding second-party audits and how the different stakeholders perceive the use and the need of them.

In the opinion of the author of this thesis, and according the findings, ISO certification is only a preliminary step to constructing a quality management system (QMS). Since certification alone does not ensure the quality of the final product or the stability of the processes.

Finally, the technological complexity of the sector has revealed a high use of quality tools and techniques. It has also demonstrated that the ISO 9001 standard provides a favorable environment for the use of the same. But all this depends to a large extent on the commitment made by top management.

7.2. Practical implications

This study could be considered as a starting point for further studies related to the use of Manufacturing and Quality Management practices in the wind power sector. Moreover, we believe that the implications of our findings go beyond the wind power supply chain and could be valid in other settings with similar characteristics, such as complex projects/products with multiple and varied suppliers.

This study also shows that lean practices vary from company to company and from sector to sector. Therefore, the intensity of the use of lean practices varies according to the sector in which we are in. In addition, the lack of consensus regarding the definition of lean creates conflict and confusion among organizations and consultants when trying to implement it.

With regard to the role of Quality Management, managers and organizations must understand that ISO 9001 certification is not synonymous of product conformity and that it is only a guarantee that the quality management system meets the standard.

From the authors' the point of view, ISO 9001 must be adopted for concepts and tools (e.g., supplier development, supplier monitoring, advanced quality plans (AQP), production part approval processes (PPAP) etc.). However, improving the quality of products, the relationship between customer and suppliers, and of course improving a company's efficiency and their supply chain are all issues which need addressing in depth.

Likewise, the role of top management is a key element for the implementation of the Quality Management System (QMS). Since, depending on the commitment made by the top management to the standard, different levels of implementation of the standard are obtained.

Managers should also consider second-party audits as, in our opinion; they have a positive impact for both customer and suppliers. They can help suppliers improve their manufacturing processes and, subsequently, the quality of their product(s). Furthermore, the suppliers can compare themselves to their competitors and identify and eliminate any weak points they may have. Supplies have the opportunity to see their process from the customer's point of view; a point of view which is often more critical and more relevant.

Furthermore, as mentioned in the literature review, the ISO 9001:2008 standard implicitly refers to the supply chain concept as "supplier-organization-customer" but, in fact, focuses specifically on a company's internal organization and does not examine upstream and downstream relationships in depth. From the theoretical perspective, the ISO 9001 standard should be focused on upstream supply chain activities. Suppliers' relationships are a critical echelon in the supply chain because, as we mentioned earlier, quality problems usually cross the organization's boundaries and have an impact on the entire supply chain.

7.3. Research limitations and future recommendations

This thesis has certain limitations, the first limitation of which is that all the articles are based on the wind power sector. Therefore, the conclusions drawn from them can only be applicable to this sector, although they can also be extrapolated to similar sectors. The second limitation is that it is necessary to note the size of the samples (between 90 and 120). Although in other more general studies perhaps it would be considered insufficient for the making of some decisions, in our case, and given that a specific sector has been analyzed, we consider the size of the sample is sufficiently significant to validate the results and the conclusions.

On the other hand, the results of this thesis open new opportunities for future lines of research regarding the supply chain management environment, applicable to the wind power sector and similar sectors.

The first opportunity that this thesis offers us is to continue to move forward on complex supply chain management (SCM) models, incorporating the concept project management within the classic management paradigms such as lean, agile and leagile.

In addition, it also opens the opportunity for further investigation into the use and behavior of lean practices in supply chains where there is an unpredictable demand, manufacturing volumes are low and there are high levels of customization with respect to product mix.

With regard to issues related to Quality Management, the content of this thesis gives us the opportunity to continue exploring the need for other quality management models more advanced than ISO 9001 since, as has become evident in our findings, the ISO standard in some industrial sectors is only a ‘business card’ or a ‘cover letter’ to have the opportunity to bid for tenders or participate in contests. As we have demonstrated in our study, the ISO 9001 standard does not strictly meet the needs of some sectors from the point of view of their customers.

Finally, this thesis has also demonstrated the need to analyze the role and utility of third-party audits with respect to second-party audits, and how companies perceive the need and usefulness of them.

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Abstract

The present chapter aims to increase the understanding of possible supply chain models and their fit and most effective configuration in a typically engineer-to-order sector, namely the wind business. Our findings argue the pertinence of a Hybrid Supply Chain model combining elements of the Lean, Agile and Leagile paradigms upstream and the Project Management paradigm downstream in the case of a Wind Turbine Manufacturer. We also find that, depending on the complexity of the market and supply diversity, multiple decoupling points emerge. Through the present Wind Energy Supply Chain case, we find that for effective management of a global supply chain characterized by a high number of references and multiple technologies, it is necessary to mix different manufacturing paradigms in order to provide a quick, agile and competitive response to the customer.

Supply Chain Strategies and the Engineer-to- Order Approach

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Chapter 10
Hybrid Supply Chain Strategies in Wind Business

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ABSTRACT

The present chapter aims to increase the understanding of possible supply chain models and their fit and most effective configuration in a typically engineer-to-order sector, namely the wind business. Our findings argue the pertinence of a Hybrid Supply Chain model combining elements of the Lean, Agile and Leagile paradigms upstream and the Project Management paradigm downstream in the case of a Wind Turbine Manufacturer. We also find that, depending on the complexity of the market and supply diversity, multiple decoupling points emerge. Through the present Wind Energy Supply Chain case, we find that for effective management of a global supply chain characterized by a high number of references and multiple technologies, it is necessary to mix different manufacturing paradigms in order to provide a quick, agile and competitive response to the customer.

INTRODUCTION

Key enabling technologies generating smart industries and alternative sources of energy contributing to sustainable societies have become an economic priority.

The wind business (WB) is a relatively new industry and in Western Europe its origins date back to the 1970s. Despite its relative infancy, the global wind energy market has experienced a steady 25% annual growth rate over the past 10 years. Nowadays, wind energy represents a major trend as countries try to establish renewable energy technologies and diversify their energy mix. Wind energy is the world's fastest growing energy source and will power industry, businesses and homes with clean, renewable electricity for many years to come.

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ISO 9001 Aspects Related to Performance and Their Level of Implementation

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Abstract:

Purpose: In the last three decades, thousands of companies around the world have embraced the ISO 9001 standard in their quest to improve company performance and customer satisfaction. In recent literature, a number of authors have identified different "levels" of ISO 9001 implementation. This study aims to analyse these implementation levels in companies from the point of view of the customer, and provide guidelines for future improvement.

Design/methodology/approach: Research was conducted based on the results of the second-party audits (SPAs) of 90 suppliers, (including component suppliers, assemblers, and wind farm operation and maintenance services), to one of the wind power industry's largest wind turbine manufacturers. The audits were carried out within the ISO 9001:2008 framework and conducted by one of this study's authors in his role as the wind turbine company's Director of Global Quality.

Findings: Auditing suppliers plays a unique role in helping to isolate system weaknesses, identify opportunities and suggest areas for improvement. This study shows that, in terms of management commitment and culture and the good practices of an organization, ISO 9001 certified companies implement differing degrees of the standard. From the results of this research, a "road map" towards improvement can be established; one that allows companies the sector to go beyond simply being accredited with the standard and instead to take advantage of ISO 9001 certification as a catalyst for change.

Research limitations/implications: This article focuses only on the wind power sector, although its findings could be extrapolated to similar sectors of high technology and high levels of customization.

Originality/value: While quality audits are a customary topic for academics and researchers, few contributions are related to SPAs and their impact on the quality control process of company suppliers. Primary data from the SPAs of suppliers (objective data collected by one of the paper's authors), was used here and is one of the most valuable aspects of this paper's contribution.

Keywords: ISO 9001, supplier audit, second/third party audits, implementation level, factor analysis, wind power sector

1. Introduction

In the past three decades, thousands of companies around the world have embraced the ISO 9001 standard in their quest to improve company performance and customer satisfaction. However, despite having been internationally recognized and widely accepted since its publication in 1987, the standard has been subject to controversy and criticism concerning the success or failure of its implementation and/or whether its costs outweigh the performance benefits for companies.

The literature is full of research articles describing ISO 9001 certification successes and failures and the resulting impacts on company profits and performance. For instance, Curkovic and Pagell (1999) point out that ISO 9001 is not connected directly to product quality, and Naveh and Marcus (2005) emphasize that a certified company could still have substandard processes and products because certification does not instruct the company on how to design more reliable and efficient products. Romano (2002) reported that ISO 9001 certification is a letter of access (a visiting card) for many companies and Sroufe and Curkovic (2008) state that, "ISO registration alone is not enough to do anything beyond ensure compliance with the registration standard". Some authors refer to the certification as a "meaningless piece of paper" which is nothing but a cost to a company. Other researchers argue that certification does not ensure an improvement in a firm's performance (Anderson, Daly & Johnson, 1999; Dimara, Skuras, Tsekouras, & Goutsos, 2004; Morris, 2006; Power & Terziovski, 2007; Tsekouras, Dimara, & Skuras, 2002) and there are many studies that show companies who have adopted ISO 9001 certification as a result of customer pressure (Anderson et al., 1999; Davis, 2004; Martínez Costa, Martínez-Lorente & Choi, 2008).

Nevertheless, it is not all criticism and controversy. There are studies that highlight how ISO 9001 can help companies improve their performance and efficiency. Some point out that certification improves product and service quality as well as collaboration with suppliers, and reduces customer complaints and internal costs, thus boosting company profitability (Zaramdini, 2007; Casadesús & Karapetrovic, 2005), while others stress that certification strengthens workforce motivation, increases market share and facilitates the international expansion of the company (Brown, Wiele & Loughton, 1998; Zaramdini, 2007). Chow-Chua, Goh and Boon-Wan (2003) also note that ISO certification improves processes and procedures, enhances a company's image in the marketplace, as well as assisting its international expansion.

As a result of the controversy aroused by the ISO 9001 standard and its supposed strengths and weaknesses, we were motivated to analyse to what levels it has been implemented in the wind energy sector by means of second-party audits (SPA).

1.1. Quality Audits

For many years the quality audit has played an important role in an organisation's quality management system. Initially used to control financial statements, it has gone on to become a useful management tool in business competitiveness and performance.

ISO 9001 accreditation requires a third-party audit (TPA) certification process to evaluate whether the quality management system complies with the standard's requirements. TPAs are performed by external, independent certification bodies free of any conflict of interest and thus, a key component of a TPA. However, after more than two decades of using TPAs, many quality and manufacturing managers and professionals do not see the value in or the need for them. Some studies reveal significant differences between the perceptions (in terms of profits, performance, standard compliance, improvements, etc.) of auditing that customers have and those that the auditors themselves have (Power & Terziovski, 2007; Castka, Prajogo, Sohal & Yeung, 2015). Consequently, there is no better understanding in how academics and practitioners perceive the TPAs process either (Kluse, 2013).

TPAs and their efficiency is a very commonplace theme for many academics and researchers, but very few a have actually focussed their work on SPAs, i.e. when a company performs an audit of a supplier and the impact they have on the whole quality control process (Ferenčíková & Briš, 2013) as well as in the process improvement (Prasad, Kamath, Barkur & Nayak, 2016).

The study carried out by Power and Terziovski (2007), highlights a number of differences in perceptions of auditing that customers and auditors have in terms of compliance versus improvement. Karapetrovic and Willborn (2000) point out that the quality audits typically evaluate whether the QMS activities conform to the documented procedures are effectively implemented and suitable for achieving the quality targets proposed.

In some industrial sectors, for instance the automotive sector, power systems, oil and gas, wind energy, aerospace and the food industry, purchasing managers push for ISO certification (TPAs) of their suppliers bidding for some projects or tenders. Following this, the customer quality team will later perform SPAs of the same suppliers in order to ensure product quality. However, TPAs, from the managers and practitioners' point of view, only consume resources, time, and money and do not add any value to the company.

1.2. ISO 9001 Implementation Levels

In recent literature, several authors have identified different "levels of implementation" of the ISO 9001 standard.

Naveh and Marcus (2004) classified ISO 9001 into two major levels based on practical issues: (i) assimilation, which means establishing rules that allow an organization to effectively adhere to ISO 9001 (quality manual, policies and procedures) and coordinating with external suppliers and customers so that the requirements of the standards fit the needs of the stakeholders, and (ii) go beyond, where the ISO 9001 is used as a springboard for developing additional quality initiatives. In other words, simply being ISO 9001 is not enough, the standard must be used in daily practice and as a catalyst for change (Naveh & Marcus, 2005).

Sroufe and Curkovic (2008), working with the Miles and Snow (1978) framework, classified the different levels of the ISO implementation into (i) defenders, (ii) reactors, (iii) analysers and (vi) prospectors. Defenders look firstly at improving efficiency in existing operations and are focused on cost. Reactors perceive ISO certification as a cost of doing business, and may struggle with finding any real benefits from ISO certification. Analysers include firms that usually operate in two types of product-market, one which is relatively stable and the other which is changeable. While analysers are successfully operating in more than one product domain, they do not have ISO certification for all those domains. Finally, prospectors' firms are continuously searching for new market opportunities and perceive ISO certification as a new opportunity to achieve competitive advantages.

Prajogo, Huo and Han (2012) identified the following three levels of the ISO 9000 implementation, (i) basic (ii) advanced and (iii) supportive.

Basic implementation is when the company strictly follows the ISO 9001 requirements. According to Bradley (1994) and Naveh and Marcus (2005), while these practices are an important first step, they are not enough to yield successful improvements. Advanced implementation is when, rather than considering certification as an end point, the company uses the ISO 9000 as a stimulus for rethinking how it could conduct its business more effectively. Finally, supportive implementation is when top management takes an active (and key) role in a number of crucial resource support areas such as fostering a quality culture, supervising employee behavior, arranging training programs for employees in order to facilitate skill improvements, and ensuring that a continuous improvement cycle exists within the organization (Sing, 2008; Nair & Prajogo, 2009).

However, the way a supplier belongs to one category or another very much depends on the result of the audit carried out by their customer. In these audits it is possible to qualify the implementation levels of every aspect of ISO 9001 and help the customer to determine if the supplier is more focused on accomplishing quality assurance procedures, than on product or production processes. In other words, to determine if they are good suppliers or if there is room for improvement.

2. Objectives

The aim of this research is to analyse the levels of implementation of the international standard ISO 9001 in the wind power (WP) sector from the point of view of the customer, and provide guidelines for future improvement.

This study also seeks to address the lack of empirical evidence on the relationship between ISO 9001 implementation and SPAs that an extensive literature review revealed.

Our primary objective is to determine which of the ISO 9001 aspects have an impact on the level of ISO 9001 implementation. The way to achieve this is through a data analysis of the SPAs collected by a manufacturer in the WP sector. Using these audits, the manufacturer classifies its suppliers into three categories, and we assume these correspond to the implementation of ISO standards found in the literature.

Our secondary objective is to define the constructs, i.e. the ISO aspects which are correlated in the audits a firm makes of its suppliers, and to measure the impact these constructs have on the level of adoption as determined by the customer company.

3. Methodology

In order to achieve our objectives, the research was carried out in WP sector supply chain firms (i.e. component suppliers, assemblers, and wind farm operation and maintenance services).

An extensive literature review reveals there is little empirical evidence of the relationship between ISO 9001 implementation and supplier activities (Lo & Yeung, 2006; Prajogo et al., 2012). The majority of the contributions referenced in the literature review section are based on surveys (subjective data). In this paper we use primary data (objective data) from the SPAs of suppliers. One of this paper's authors is the Director of Global Quality for the wind turbine manufacturer concerned and has collected and compiled data from the audits of suppliers which, in turn, is one of the most valuable aspects of this paper's contribution.

The data used here are based on the audits of 90 technical suppliers to one of the largest wind turbine manufacturers and ranked in the top 15 largest companies in the sector in terms of installed power (MAKE Consulting, 2013; BTM Consult, 2014). Located in Europe, but with production centers in both North and South America, it employs more than 1,500 workers and has an income of over €400m per annum.

3.1. Wind Turbine Manufacturer Supplier Audit

The questionnaire used to assess the suppliers in the audit is based on the ISO 9001:2008 requirements and organized into 21 main "items" spread over the four main processes: (P1) Management system and responsibility, (P2) Resource management, (P3) Product completion, (P4) Measuring, analysis and improvement. These items, classified into the four main ISO processes, are presented in Table 1.

P1	Management System and responsibility
v1	Quality Management System and responsibility (general requirements)
v2	Control of documentation
v3	Control of records
v4	Planning
P2	**Resource management**
v5	Competence, training and awareness
v6	Infrastructure and work environment
P3	**Product completion**
v7	Planning of product manufacture
v8	Customer related processes
v9	Design and development
v10	Purchasing process and information
v11	Supplier evaluation
v12	Product and service provision
v13	Product preservation
v14	Identification and traceability
v15	Verification of purchased product
v16	Control of monitoring and measuring equipment
P4	**Measuring, analysis and improvement**
v17	Monitoring and measurement of processes
v18	Monitoring and measurement of product
v19	Data analysis
v20	Control of nonconforming product
v21	Corrective and preventive actions

Table 1. Audited items on supplier site

3.2. Sample and Audit Process

Forty percent of the companies audited are global players and are referred to in the sector's specialized journals such as MAKE Consulting (2013) or BTM Consult (2014). Table 2 shows the scope of the companies audited.

Location/ Employees	Europe	South America	North America	Asia	Total
>500	8	5	1	8	22
500-100	15	3	3	3	24
<100	37	4	-	3	44
Total	60	12	4	14	90

Table 2. Audit scope

The audits were carried out following the ISO 9001:2008 framework and under the supervision of one of the authors of this paper in his role as the Global Quality Director of the company. The audit teams were trained in accordance with the company's audit procedures. All the suppliers audited work with the ISO 9001:2008 standard thanks to a specific requisite from the set of design requirements (IEC, 2010) that must be met to certify a wind turbine.

In addition, to become an authorized supplier, the audited companies had had to pass a previous assessment and selection process and product qualification, in accordance with the company's standard procedure. This procedure is a three-step process beginning with (i) supplier assessment, followed by (ii) supplier/component qualification and finishing when the (iii) supplier is authorized for future serial production. After approximately a year supplying components to the wind turbine manufacturer, the company's audit team visited the suppliers to carry out audits. These audits have three main objectives:

(i) to monitor and verify the proper operation and implementation of the supplier quality management system, (ii) to demonstrate that customer requirements (purchase order, delivery time, technical specifications, drawings, customer quality requirements, and packaging) are effectively implemented and maintained over time, and (iii) to take any appropriate action to eliminate root causes of nonconformities and prevent their recurrence, and to identify any potential improvement areas.

At the end of the appraisal, a closed audit meeting is held with the suppliers. The scope of the meeting is to examine any major and/or minor findings and discuss any future opportunities for improvement. More importantly, the company auditors and the suppliers then develop a plan for improvement together.

The audits were performed in accordance with the procedures and standards of the wind turbine manufacturer and took between three and five days, depending on the size of the company and the complexity of the product being produced.

3.2. Measures

The company auditors graded each item on a 4-point scale. The items audited are closely connected to ISO 9001:2008, but as the audit was performed by the customer the answers focused on evaluating the supply performance related to the product. By using a scale where 0 = not implemented item, 1 = partially implemented item with nonconformities, 2 = implemented item with observations and 3 = fully implemented item, each item's level of impact was then then able to be validated according to the value given in the answers, thus making it possible to determine the level of ISO implementation for each and every item asked about. As a result of the audit, the firm receives a Global Audit Score (GAS) when the average of all the audited items has been calculated. Following the criteria assigned to each company, we considered three levels of implementation. If the company scores 85% (GAS>2.55), the supplier has a HIGH level of implementation, if it is 70% (2.55>GAS>2.1) the supplier has a MEDIUM level of implementation, otherwise the supplier is considered as having a LOW level of implementation (GAS<2.1).

4 Results

Below, we present the data collected from the supplier classification according to GAS (Table 3). What is made abundantly clear is that more than 40% of suppliers do not and cannot have a positive relationship with the firm because they are classified as LOW. Therefore, we cannot conclude that the ISO 9001 standard ensures a certain level of quality from a supplier i.e. a level which would mean that supplier could be considered an extended capability for the firm.

Grade GAS	Europe	South America	North America	Asia	Total
High	5	2	1	1	9
Medium	31	7	1	4	43
Low	23	4	2	9	38
Total					90

Table 3. Supplier classification according to Global Audit Score

The analysis is divided into three. First, we present a descriptive analysis of the 21 items, followed by a factor analysis which allows us to group the 21 items from the audits into latent factors. Finally, the U Mann-Whitney test is applied, enabling us to compare latent factors of the categorized suppliers by GAS.

In the Descriptive Analysis section, we analyse the implementation of the 21 items individually, while in Discussion and Findings, we argue the strengths and weaknesses of the sector and present potential areas for improvement. Table 4 shows that “Competence training and awareness” (v5–2.44), “Identification and traceability” (v14–2.4), “Product preservation” (v13–2.31) and “QMS and responsibility” (v1–2.29) are the items that obtained the best assessment in the implementation audits. In contrast, the items “Corrective and preventive actions” (v21–1.81), “Product and service provision” (v12- 1.88), “Data analysis” (v19–1.90) and “Planning of product manufacture” (v7–1.94) were those which obtained the poorest implementation ratings in the audits.

Item	ISO 9001:2008 Item description	N	Mean	Standard Desviation
v5	Competence, training and awareness	75	2.44	0.54
v14	Identification and traceability	90	2.4	0.64
v13	Product preservation	85	2.31	0.69
v1	Quality Management System and responsibility (General requirements)	87	2.29	0.63
v15	Verification of purchased product	89	2.28	0.65
v17	Monitoring and measurement of processes	87	2.28	0.67
v3	Control of records	85	2.27	0.62
v10	Purchasing process and information	68	2.26	0.65
v16	Control of monitoring and measuring equipment	85	2.24	0.65
v18	Monitoring and measurement of product	87	2.24	0.76
v9	Design and development	11	2.15	0.73
v11	Suppliers evaluation	66	2.13	0.72
v2	Control of documentation	84	2.09	0.69
v8	Customer related processes	84	2.04	0.76
v20	Control of nonconforming product	88	2.02	0.63
v4	Planning	86	2.01	0.68
v6	Infrastructure and work environment	88	1.96	0.69
v7	Planning of product realization	86	1.94	0.71
v19	Data analysis	66	1.9	0.72
v12	Product and service provision	83	1.88	0.69
v21	Corrective and preventive actions	87	1.81	0.69

Table 4. Descriptive analysis of 21 items

As a second step to our research methodology, we focused on factor analysis of the data we collected in order to find homogeneous groups of correlated items that would help us verify the existence of latent variables indicating those ISO 9001 items that correlate with the levels of ISO 9001 implementation in the sector. The exploratory factor analysis, shown in Table 5, was performed using the Varimax rotation from the SPSS factor analysis procedure, to identify the latent dimensions (F1, F2, F3) derived from the data and used in the study. The scales were analysed in accordance with the recommendations of Ladhari (2010) who follows the criteria to retain items that (i) load at 0.50 or greater in a factor, (ii) do not load at greater than 0.50 in two factors and (iii) have an item reaching total correlation of more than 0.40.

Items	F1	F2	F3
v16. Control of monitoring and measuring equipment	0.812		
v1. QMS and responsibility (general requirements)	0.730		
v6. Infrastructure and work environment	0.692		
v4. Planning	0.689		
v2. Control of documentation		0.780	
v12. Product and service provision		0.773	
v18. Monitoring and measurement of product		0.744	
v3. Control of Records		0.568	
v15. Verification of purchased product			0.806
v8. Customer related processes			0.683
v17. Monitoring and measurement of processes			0.660
Cronbach's alpha	0.695	0.749	0.600
% of variance explained	21.75	20.78	17.54

Table 5. Matrix rotated components using the Varimax extraction method

Prior to statistical analysis, several items were removed for two reasons: the inability to assess the requirement as a result of it not being applicable in the company (v9) or not being able to assess the item in the audit because of a lack of time (v5, v10, v11 and v19) during the visit. Finally, throughout the process of exploratory data analysis, v13, v20, v7, v14 and v21 were eliminated.

The correlation matrix was subjected to two tests: Bartlett's sphericity test [183.941; df 55; p value 0.000] and the Kaiser–Meyer–Olkin (KMO) index [0.768]. The Bartlett test's statistical confirmation of the existence of linear dependence between the variables (items) justified, in all cases, continuing the procedure. The KMO also confirmed that factor analysis was likely to generate satisfactory results (Visauta, 1998).

Confirmatory factor analysis (CFA) was applied to the sample data to verify the factor structure that emerged from the EFA. The reliability of the resulting factors was assessed using Cronbach's alpha. All the constructs had an alpha value of greater than 0.6 (Malhotra, 2004).

"Structural implementation" is the name we assign to the first factor (F1), as this factor focuses on the basic system requirements of assurance quality management. We called the second factor (F2) "Internal integration" and this consists of the requirements which drive the system such as document and record control and the performance of the product and its validation. Finally, the third factor (F3), coined "External integration and analysis", consists of requirements that most affect suppliers and customers, as well as process control.

The final step was to measure the impact of the factors on the level of ISO implementation we considered for each supplier. Table 6, which compares the average of factors among the three groups (HIGH, MEDIUM, and LOW) determined by the GAS, shows the factors that most affect determining the level of implementation. F1 and F2, are significantly different between HIGH and MEDIUM (p value 0.026 and p value 0.002) and MEDIUM and LOW (p value 0.003, p value, 0.030), but in F3 there are no differences between HIGH and MEDIUM (p value 0.708), but rather they are between MEDIUM and LOW (p value 0.002).

In Table 6, we see that F1 and F2 differ in implementation levels from lowest level (near 0.5) to medium level (near 0) or highest level (near 1) in the same way as GAS differs. However, F3, never achieves a HIGH level (near 1), although it does achieve a medium level according to HIGH or MEDIUM GAS. F1 and F2 have to be considered as achieving a good fit in ISO 9001 implementations in this sector, but F3 does not differentiate between HIGH and MEDIUM instead it only differentiates between LOW and MEDIUM.

	Companies	F1. Structural implementation	F2. Internal integration	F3. External integration and analysis
HIGH	10	0.972	1.025	0.242
MEDIUM	28	0.245	0.082	0.414
LOW	27	-0.614	-0.465	-0.519

Table 6. Fi average, depending on GAS (Global Audit Score) implementation level

5 Discussion and Findings

From the SPA data it is possible to confirm that ISO 9001 implementation levels differ, even when all of these suppliers have been ISO 9001 certified by a third party.

In Table 4, we see that the best implemented items are, “Competence training and awareness, “Identification and traceability”, “Product preservation” and “QMS and responsibility”. In this sense, our findings agree with Naveh and Marcus (2004) and Prajogo et al. (2012), who suggest that employee training and quality management practices, such as quality manual, polices, documentation and instructions, operation identification and traceability form part of the standard assimilation for a company (Naveh & Marcus, 2004), as well as part of its daily routine and thus, are basic and essential requirements of ISO 9000 implementation (Prajogo et al., 2012).

However, in Table 4 the most poorly implemented items are “Corrective and preventive actions”, “Product and service provision”, “Data analysis” and “Planning of product realization”. All of these are related to product execution and continuous improvement. Thus, our findings forge a path (from the customer’s point of view) for suppliers, i.e. suppliers must work to improve aspects related to “product and service provision”, in the WP sector as these are the areas which have a direct impact on the final product; not to mention company performance. Therefore, and as a way to move beyond the standard alone, areas concerned with “continuous improvement” must be honed and perfected.

In our research, we found that different implementation “levels” can and do provide firms with opportunities for improvement, and we would go as far as to suggest these ‘windows of opportunity’ are created in accordance with how and to what extent a company has implemented the standard. According to the factor analysis, the sector has three groups of ISO requirements which follow a similar pattern to implementing the standard. Comparing averages of the factors found that the level of implementation depends on all the items studied and are grouped according to certain factors, although it has been shown that F3 (External integration and analysis) seldom, according to GAS, achieves the highest level of implantation in the sector.

Some studies in the literature highlight positive benefits when ISO is implemented, while others demonstrate that there is no discernable impact on a company’s performance. From our point of view, as in other studies found in the literature, it is difficult to associate the relationships between ISO 9000 and its effect on business performance. A possible answer is that there are multiple-variables associated with business performance, such as financial factors, market environment, government policies and regulations etc., and therefore, the direct effect on business performance is very difficult to identify, even after carefully controlling samples. For this reason, we consider that a survey questionnaire is not an adequate tool with which to draw any conclusions about the impact ISO 9000 regulations may or may not have on a company’s performance.

Instead, what we can conclude is that ISO 9000, depending on the “level” of implementation, does provide opportunities to identify and work on areas for improvement, thus becoming more competitive in the marketplace. Furthermore, certification bodies and the genuine commitment from top management play an important role in ensuring this competitive advantage. In other words, merely being accredited with ISO 9000 certification will not ensure that firms gain a competitive advantage over their rival competitors but, as Naveh and Marcus (2004) also state, if the standard is extremely well implemented internally and carefully coordinated externally with suppliers and customers and becomes part of their daily practices, then it can be used as a springboard for the change which, in turn, would result in the much sought after ‘competitive advantage'.

6 Conclusion

As a result of this study, several conclusions can be drawn. First, there are some weaknesses in the sector which need to be addressed as they are "Product and service provision", "Data analysis", and "Corrective and preventive actions", all of which are related to the performance of the product and its processes, as well as its continuous improvement. In other words, analysing these would determine any corrective and/or preventative action to be taken. These findings show that SPAs play a unique and specific role by helping to identify system weaknesses that affect product and processes, by identifying opportunities for change and by suggesting areas for improvement.

Secondly, we can also demonstrate that there are companies in the WP industry, that have been certified ISO 9001:2008 by third parties, who employ varying levels of implementation. This indicates that levels of ISO 9001 implementation and development are related to management commitment and culture and the good practices of the organization in question. In fact, top management plays a crucial role in a company moving beyond the standard.

Finally, from the results of this work, a "road map" towards improvement can be drawn. This road map would enable companies in the sector to go beyond simply applying standard and allow them to fully exploit ISO 9001 certification by using it as a lever for change. In other words, the statistical analysis shows us that companies rated as LOW must improve aspects of F1 (Structural implementation) and F2 (Internal integration) to become MEDIUM and then continue those improvements until they reach the so-called HIGH category. However, in the case of F3 (External integration and analysis) only one step from the LOW to MEDIUM or even HIGH category is required. For the companies in the MEDIUM category, they must consolidate and improve factors F1 and F2, but they do not need to focus on F3 to become HIGH. Firms with the highest implementation levels use ISO 9001 certification as a "lever" to attain business excellence and their daily practices often go beyond the requirements of ISO 9001 certification to follow the criteria we found in the literature. This article provides some theoretical implications i.e. viewing the standard from the customer's perspective which, in turn, leads to an understanding of the standard from the point of view of the customer's needs. Thus, the usefulness of the audits is clearly demonstrated along with the overall objective of ISO 9001: customer satisfaction.

This article has some limitations as it focuses only on the WP sector, although its findings could be extrapolated to similar sectors of high technology and high customization. It also highlights several implications for managers i.e. certification only implies conformity to the standard and SPAs provide valuable information about supplier quality commitment. Going beyond certification involves the support and commitment of management in a company's daily practices.

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Attached III

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Abstract

This paper evaluates whether ISO certification enables a supplier to become an extended resource in a specific sector. The evaluation consisted of a statistical analysis of data from 90 suppliers to a wind turbine manufacturer. The suppliers were selected, evaluated and audited as extended resources from a resource-based view (RBV). We test the differences that the qualified suppliers exhibit in main ISO processes and we identify specific areas that will improve supplier relationships. We also demonstrate significant differences exist when the level of technology the supplier uses is taken into account. Our results may well be applicable in a wider manufacturing processes context. We determine that ISO certification alone is not enough to cement a positive relationship in an upstream supply chain environment, despite such relationships being crucial to the success of a business, and support the use of a wider sector-specific certification tool that goes beyond ISO certification.

Keywords

supplier evaluation; supplier relationships; quality management; ISO certification.

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Evidence for quality management systems being instrumental in improving supplier performance: the case of the wind power sector

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Abstract: This paper evaluates whether ISO certification enables a supplier to become an extended resource in a specific sector. The evaluation consisted of a statistical analysis of data from 90 suppliers to a wind turbine manufacturer. The suppliers were selected, evaluated and audited as extended resources from a resource-based view (RBV). We test the differences that the qualified suppliers exhibit in main ISO processes and we identify specific areas that will improve supplier relationships. We also demonstrate significant differences exist when the level of technology the supplier uses is taken into account. Our results may well be applicable in a wider manufacturing processes context. We determine that ISO certification alone is not enough to cement a positive relationship in an upstream supply chain environment, despite such relationships being crucial to the success of a business, and support the use of a wider sector-specific certification tool that goes beyond ISO certification.

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