CRANFIELD UNIVERSITY

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BENCHMARKING BEST PRACTICES IN AEROSPACE SECTOR FOR THE QUALIFICATION AND VALIDATION OF MEDICAL DEVICES

SCHOOL OF APPLIED SCIENCES

MSc by Research Thesis

Academic Year: 2011 – 2012

Supervisors:

Prof Ashutosh Tiwari

Dr Yuchun Xu

SEPTEMBER 2012

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MSc THESIS

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ABSTRACT

The validation stage in the development of a medical device plays a critical role as it demonstrates that the new product meets all the functional, reliability and quality requirements of both customer and regulatory authorities. Operating under a highly constrained process, where multiple requirements must be satisfied, the identification and implementation of innovative and improved methods can result in great cost and time savings.

This project aims to develop a highly reliable and efficient procedure for the validation of medical devices. In order to achieve this, a qualitative approach has been adopted and a benchmarking study has been performed within the aerospace sector with the purpose of identifying and adapting the best practices into medical device validation procedures. The organisation current practices have been reviewed in order to identify improvement opportunities. Through several methods, including interviews, extensive literature and publications review, leading practices have been identified and proposed to the organisation. Finally, the implementation guidelines for the new procedures are provided in this research project.

The outcomes of the study showed that the development of some critical procedures within the organisation, combined with an adequate resources allocation result in performance improvements and time-and-cost savings for the validation process. These results provide a starting-point for future studies basing on a quantitative approach and the particularisation of the benchmarking study scope.

Keywords:

Medical, devices, aerospace, defence, validation, best practices, benchmarking, manufacturing, process validation.

ACKNOWLEDGEMENTS

I would like to take this opportunity to express my gratitude to the individuals who have contributed in the success of this project.

First of all, I would like to thank my academic and industrial supervisors, Prof Ashutosh Tiwari and Dr Yuchun Xu, from the School of Applied Sciences – Cranfield University, Mr Donald Redpath from the sponsoring company and Mrs Carole Randall from the Low Carbon KEEP/ERDF programme. Their advice, guidance and support have been constant and a key element in the success of this project.

I would also like to express my sincerest appreciation to all the employees of the company, who have contributed and assisted in the development of this project, and the academic and administrative staff from Cranfield University, who have helped me in dealing with the different academic issues and consultations.

In addition to this, I would also like to acknowledge all the colleagues, personnel and companies who took part in the benchmarking campaign, for their time and information provided.

Finally, I would like to express my gratitude to my family and friends, who have never stopped supporting me during this project and never gave up on me. Thank you all.

Hao Chen Chen, Suffolk

September 2012

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ACRONYMS

CAD	Computer Assisted Design
CM	Configuration Management
CP	Control Plan
CRM	Customer Relationship Management
ERP	Enterprise Resource Planning
FDA	United States Food & Drugs Administration
IQ	Installation Qualification
ISO	International Organisation for Standardization
JEB	JEB Engineering Design Ltd.
OQ	Operational Qualification
pFMEA	Process Failure Mode Effect Analysis
PLM	Project Life-cycle Management
PQ	Performance Qualification
QMS	Quality Management System
V&V	Validation & Verification
WI	Work Instruction

1. INTRODUCTION

In the development process of a new medical device, the validation stage plays a critical role. At this phase, the commercial production and put-into-market of the final product depends on the success of this cost and time consuming critical phase.

This project is part of the company initiative to develop new methods and improve the current procedures involved in the validation and qualification process of the medical devices it is manufacturing.

For achieving this objective, a cross-industry benchmarking study within the aerospace sector has been selected in order to identify the best practices for this stage of the product development.

Despite being at first glance two different sectors, they both share some points in common; both are highly regulated industries, working under exceptionally high standards of quality and safety and where the final performances of the product are critical for complying with customer and end-user requirements.

Taking into account all the similarities and focusing on the elements that could be developed, it has been concluded that a cross-sector benchmarking study will be an enrichment process that will assist a medical device manufacturing company to achieve a more efficient, time and cost effective validation process, while ensuring all the regulatory compliance and meeting customer quality expectations.

1.1. BACKGROUND AND MOTIVATION OF THE PROJECT

In the development process of a new product by a medical device manufacturing company, the validation and qualification stage plays a critical role; at this point the commercial production and time-to-market of the final assembly depends on the success of this cost and time consuming phase. It represents the last metres of a long-run race, where all the resources and efforts need to be pushed into in order to cross the finish line and commercialise a device which fulfils the regulations and satisfies safely and successfully all the customer requirements.

Moving within a highly constrained process, where multiple and nature different requirements from the involved parts (production, facilities, customer, industry & government regulations, etc.) must be satisfied; the improvement or development of innovative and more efficient methods can result in great cost and time savings for the whole production process.

Under this particular working conditions and project environment, performing a benchmark research for the best practices is always an exciting and unique opportunity of learning new things, find new and innovative paths to face the existing problems and lead the changes to higher level performances and time and cost optimised solutions.

In addition to this, although performing a benchmarking study of the internal industry and competitors would have been a useful solution, the decision of carrying out a cross-sector study supposes an even greater challenge to this project and increases vastly the learning opportunities. The sum of all this elements results in a complex and multidisciplinary activity which requires strong commitment and high motivation.

The source of the motivation starts in the interest of undertaking a challenging project and take part in a unique opportunity for innovation by proposing new approaches and translating the best techniques and practices from one sector into another.

1.2. SPONSORING COMPANY

JEB Engineering Design Ltd (JEB), based at Mildenhall, Suffolk, is a leading company within medical device sector, focused on precision press tool design and manufacturing coupled with component manufacture.

With 40 years of experience, JEB offers efficient solutions to multi-part complex assemblies manufacturing, providing their accumulated expertise in different manufacturing technologies, including laser resistance welding and plastics moulding. The organisation supplies to a diverse range of high-technology industries such as:

- Computer hardware, electronics and Information Technology.
- Medical devices
- Automotive
- Domestic electrical / white goods
- Ammunition

The *Low Carbon KEEP* (Knowledge-East of England-Partners) programme, in collaboration with the *European Regional Development Fund* (ERDF) scheme, provides support to East of England business focused on innovation and knowledge transfer, by improving the organisations' internal capabilities and increasing their competitiveness by undertaking the following projects:

- Development of new products, processes or procedures and efficient business solutions focused on reducing costs
- Delivering programmes to improve resource efficiency, reduce consumption and operating costs
- Reducing the environmental impact, attaining regulatory compliance and implementing sustainable development strategies.

1.3. SCOPE

From the different elements and players involved in the previous lines, where the aim and objectives of this project were defined, a great variety of definitions, meanings and conclusions could be extracted. In order to avoid any ambiguities

and establish a clear and well-defined path for this research project, the definition of the scope of the study is required.

The elements that are included in the scope are listed below:

- Medical devices manufactured by JEB
- Validation and qualification process related procedures
- Aerospace industry verification and validation processes.

As the elements described on the lines above might result quite general, some clarifications are made below.

JEB is a precision tooling and component manufacturing company involved in different business areas (electrical components, ammunition, conversions), so many of the improvement requirements and findings could be applied on these productions lines. However, this research project will be mainly focused on the manufacturing of medical devices.

Following the same actuation line, many of the improvement areas and findings could be applied to different stages pre and post validation; but these will be considered as secondary objectives of the project. In addition to this, despite sharing the same principles and philosophy of the validation structure, software validation is not included within the scope.

Finally, this study and the field-work experience were done for 2 particular medical product projects of the company. The results are fully applicable to further medical device validation projects.

1.4. AIM AND OBJECTIVES

The aim of this project is to perform a benchmarking study of the best practices in the aerospace sector for developing an efficient process for the validation of medical devices.

Four specific objectives were identified; which could be considered as the main stops of a roadmap and the *genesis* of the research methodology.

- Evaluate the current procedures and the several normative, industry standards and regulations framework for medical device manufacturing; looking for gaps and improvement areas.

- Perform a cross-industry benchmark study of validation and qualification practices within the aerospace industry in order to identify best practices.

- Carry out validation, embedding assessment and implementation feasibility analysis of the identified methods.

- Develop a set of guidelines with proposals for the implementation of the new practices.

1.5. SUMMARY

This first chapter of the thesis has presented an introduction to the research project. The background of the research area of learning aerospace best practices for improving medical device process validation is described, highlighting the motivation for the project. The sponsoring company, JEB Engineering Design Ltd is introduced and the scope, aims and objectives of the project are stated.

2. LITERATURE REVIEW

The objective of this chapter is to provide a general view of the available literature sources that cover the different concepts and basis of the elements involved in this project and any previous research that has been done.

2.1. BENCHMARKING THEORY AND PRACTICE

2.1.1. Definition

The main motivation behind different companies around the world decided to start a analysis and comparison campaign may be found in Codling's (1998) definition, where benchmarking is introduced as a "powerful tool for gaining and maintaining competitive advantage", resulting in an tool which drives to the "best practice continuous improvement through an organisation".

A similar definition is given by Andersen and Pettersen (1996), who defined Benchmarking as a "tool for improvement". It can be concluded from these statements that benchmarking is a tool of the company. It should be considered as a technique for achieving a specific objective (improvement) and not as a goal itself or the solution to all the problems of the organisation.

The next figure (Dolan, 2003) demonstrates this fact and shows that benchmarking is the main process improvement tool used within organisations.

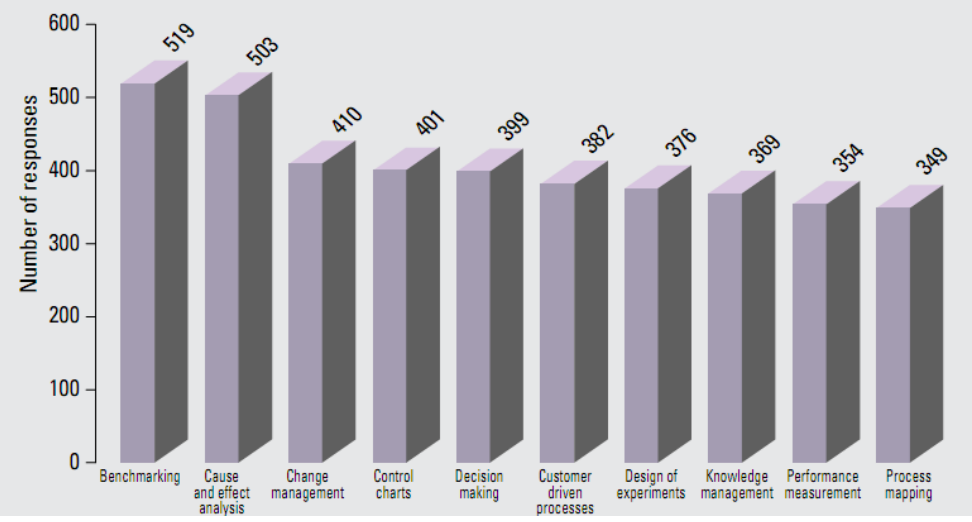

Figure 2.1. Top 10 Process Improvement Tools in use (Dolan, 2003)

Finally, this introduction paragraph can be closed with the final definition of the benchmarking concept, which is considered as a standard among a large number of companies and cited by Watson (1993):

“Benchmarking is a systematic and continuous measurement process; a process of continuously measuring and comparing an organisation’s business process against business process leaders anywhere in the world to gain information which will help the organisation take action to improve its performance”.

2.1.2. Types

According to Andersen and Pettersen (1996), depending on what is compared and whom it is compared, several types and combinations of benchmarking practices can be identified.

Through the vast literature about this classification, it can be pointed out that there are mainly four types of benchmarking which are predominant within the different sources and authors. (Camp, 1995; Andersen and Pettersen, 1996):

- *Internal Benchmarking*
- *Competitive Benchmarking*
- *Functional or Industrial Benchmarking*
- *Generic Benchmarking*

Camp (1995) considers *Internal Benchmarking* as the starting point of the research study and a pre-requisite to a further external benchmarking, assisting in identifying the main operations and critical points and will expose the organisation practices for future developments (Crom, 1996). The basis of the internal benchmarking relies on the idea of understanding the own process and measuring the performances prior to undertaking any comparison with others. However, as it could be considered the easiest and fastest, according to the matrix on Figure 2.3 it provides the lowest level of expected benefits.

Competitive and Functional Benchmarking both look on the same industry sector for comparisons, improvement opportunities and advantages (Elmuti et al., 1997). For the competitive case, the benchmarking partner will be easy to

find, but the availability of the information will depend on the willingness to cooperate and requires careful consideration (Camp, 1995). On the other hand, the *Functional Benchmarking* seeks for comparisons focusing on similar functions within the same sector, where the partners may share common technological or market characteristics (Elmuti et al, 1997). An accurate definition is given by Camp (1995), as "a comparison of practices at companies with similar processes in the same function but outside the industry*".* The most common example of Functional Benchmarking success would be the Xerox case, who improved its practices by learning from outdoor specialist resulting in a significant reduction of costs, time and an increase of the quality (Camp, 1995; Cross et al., 1996).

The *Generic Benchmarking* compares processes across companies and organisations from different industries or sectors. An excellent example of this practice may be the Dupont's case (Camp, 1995); where an ammunition manufacturing company, in order to improve the surface finish of their product, selected lipstick producing companies as comparison partners. "Finding companies in totally unrelated industries that perform similar processes as oneself might sometimes a solid portion of creativity"(Andersen and Pettersen, 1996) This study requires a careful and insightful understanding of the procedures (Elmuti et al, 1997), implies a broad and extensive conceptualisation and innovative "out-of-the-box thinking attitude" (Codling, 1992).

The next figure, as part of McDonnell Douglas Aerospace Benchmarking procedures (BMP, 1995), compares the different benchmarking types with the time required to conduct the study, cost and the capability.

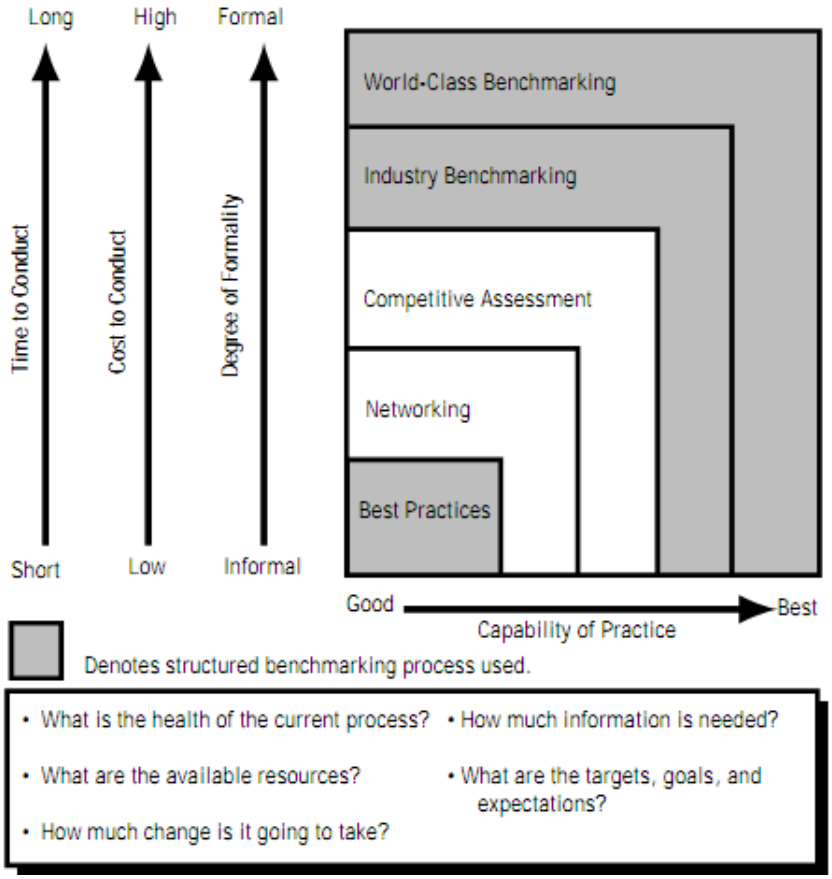

Figure 2.2. McDonnell Douglas Benchmarking Hierarchy Model (BMP, 1995)

Finally, the following figure (Andersen and Pettersen, 1996) shows in a matrix-display the possible combination of benchmarking processes depending on what we are comparing (the organisation's performance, a particular process or the strategy of the company) and whom we are comparing. In addition to this, it also reveals what combination of the different techniques is supposed to proportionate the best and most valuable results for the research.

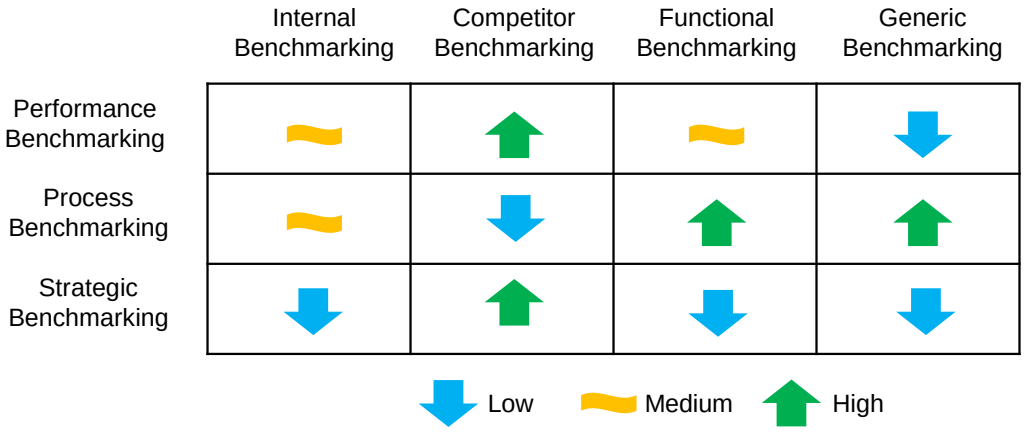

Figure 2.3. Benchmarking Matrix: Expected benefits (Andersen and Pettersen, 1996)

Basing on this figure and the considerations of the authors, it can be shown that *Functional and Generic Benchmarking* produce the highest value when they are used for evaluating and comparing an organisation's process. From this conclusion, it can be stated that the object of this thesis, the comparison of medical device manufacturing and aerospace industries, has been the most appropriate selection and has the potential to provide useful result for the improvement of the current validation process.

Finally, the selection of the benchmarking type may also depend on other factors, such as the organisation requirements, the nature of the process, available resources and internal support or the transferability of the information (Codling, 1992). In a general case, companies will start practising benchmarking with internal partners, progress to "external" practice partners and gradually over a period of time build up to benchmarking against the "best".

2.1.3. Process

In a similar way to the types of benchmarking, depending on the consulted publication and author several stages and configurations for a benchmarking process could be identified.

As an example, the figures below show the 5-step (*Plan – Search – Observe – Analyse – Adapt*) process proposed by Andersen and Pettersen (1996) or the more specific and detailed 12-stages wheel published by Codling (1992)

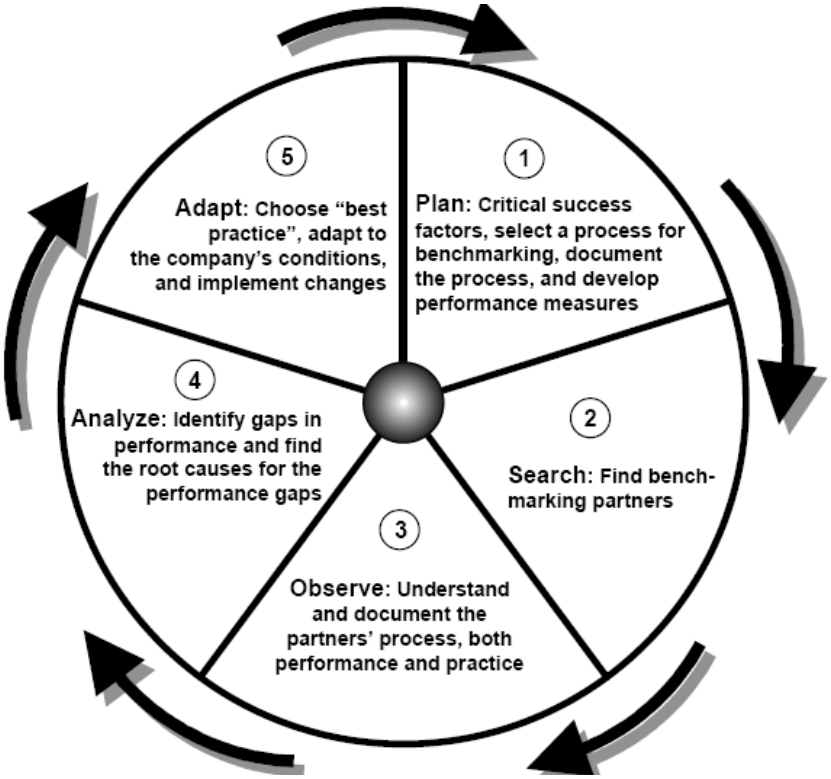

Figure 2.4. Benchmarking Process Steps (Andersen and Pettersen, 1996)

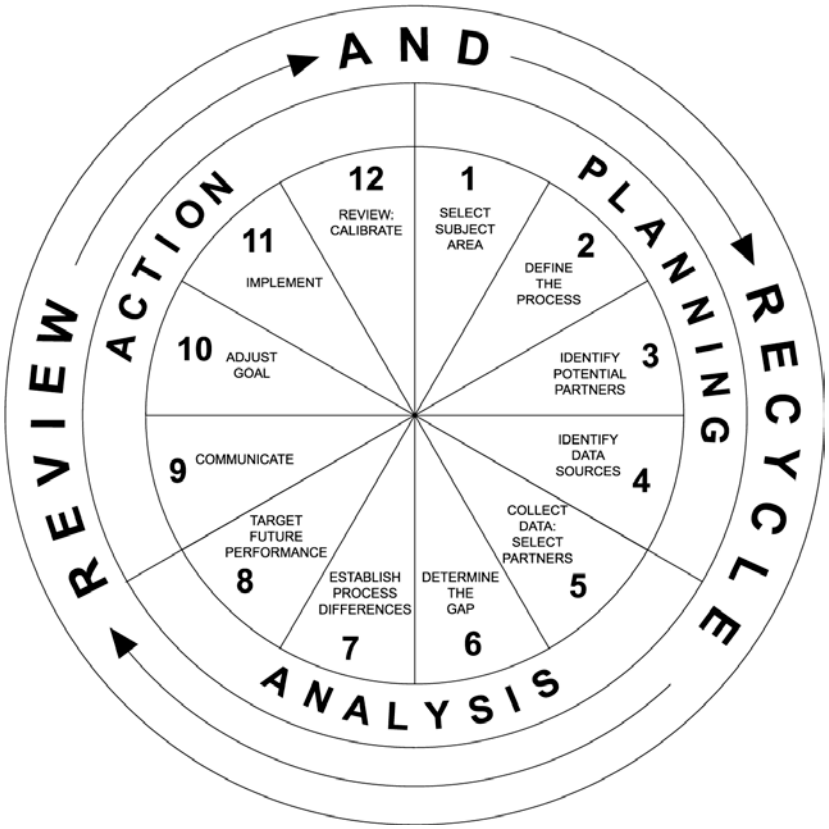

Figure 2.5. Benchmarking Process Wheel (Codling, 1992)

If a synthesis exercise is carried out and the several process models proposed by the literature are evaluated, a common *way-to-proceed* can be identified and classified into the following key components.

- *Plan*

This is a common stage identified by all the reviewed authors in this literature research. The experience through several benchmarking projects has shown that this is the most important phase, which defines the foundations of the study for an effective process guaranteeing good results (Andersen and Pettersen, 1996). The key activities at this stage may include the selection of what to benchmark, the subject selection and deciding which would be the best data collection method (Codling, 1992).

- *Partners and Information sources*

At this stage, the definition of the criteria for benchmarking partners, the identification and the selection of the final partners is performed. Codling (1992) stresses that the word *"partner"* used throughout benchmarking reflects its cooperative emphasis, in contrast with the competitive analysis, which can be conducted without an existing agreement.

Zairi (1996) advises that several major categories and classifications should be used when determining the benchmarking partners, including those with demonstrated performance, robust procedures and same objectives. Another important fact is that the identified partner should be able and have the will to share information and discuss the different practices.

Finally, (Bendell, 1993) suggests that when performing a best practice benchmarking, the partners are selected regardless of business, industry sector or culture. However, Andersen and Pettersen (1996) advises that the "Halo-effect" is something that should be taken into account; defining this as a psychological term which involves attributing too positive or negative traits to someone based on only one highly visible characteristic.

- *Data Collection and Analysis*

This phase covers the data collection, comparison and evaluation activities. According to Codling (1992), both qualitative and quantitative nature information should be gathered; and the collection methods can vary from publications research, questionnaires, surveys or company visits (Bendell, 1993). The following table lists some of these sources of information.

	INTERNAL	EXTERNAL
Data sources	Company Archives	External libraries
	Corporate publications	Special reports and surveys
	Databases	External Databases
	Internal surveys	Media broadcasts/reports
	Market Research	Journals
	Personal Networks	Trade shows
	Planning documents	Professional networks
	Financial documents	Industry Experts and Analysts
		Suppliers / Customers
		Company reports
		Consultants
		Trade Associations
		Professional Institutes

Table 2.1. Typical sources of information (Codling, 1992)

Codling (1992) and Andersen and Pettersen (1996)advise that it can often be tempting to go directly to the more direct and exciting sources of information, but the importance of publicly available data should not be underestimated. For example, the United States Central Intelligence Agency (CIA) organisation performs extensive information collection, gathering large amounts of data on political, economic and military issues in several countries. A former head of the CIA, Richard Helms, recognised that more than 85 % of the intelligence provided by CIA originates from the analysis of public information. (Andersen and Pettersen, 1996)

The following figure shows a classification of several data collection methods as implemented at McDonnell Douglas Aerospace (BMP, 1995).

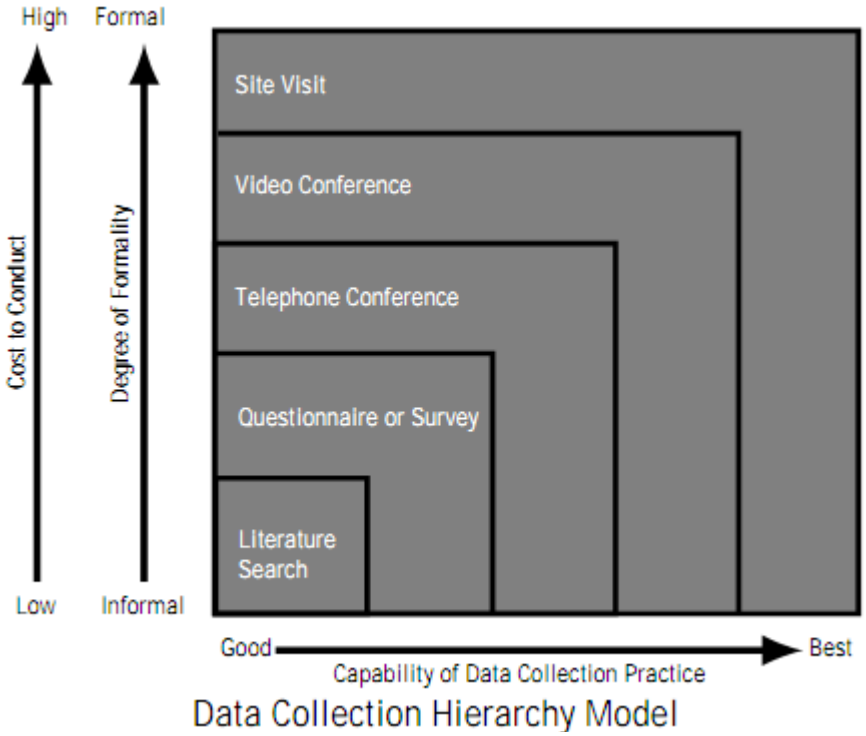

Figure 2.6. Different modes of data collection (BMP, 1995)

Once the different collection methods have been shown, the next doubt would be select the most appropriate one for the study purposes. Zairi (1996) lists the factors that influence this choice:

- *"Time limitations. If the information collection requires to be done in a short period of time, this might eliminate using benchmarking partner personal visits or live interviews".*
- *"Resource limitations, as the different techniques present different resource requirements with regard to financial and human resource aspects".*
- *"Experience, as the researcher usually tends to use the techniques that one is familiar with".*

An interesting tool that is reviewed through all the literature is the use of a questionnaire. According to Andersen and Pettersen (1996), the advantages of using this method include the establishment of a framework that helps sorting and organising the information that needs to be collected, the clear definition of the information requirements and the areas of interest and finally, the construction of the questionnaire represents an excellent opportunity for raising

the participation of the personnel involved in the process that is being benchmarked.

It is a common factor between the reviewed authors that the data that can be obtained can be divided into 2 groups: qualitative and quantitative information.

Quantitative information (metrics, performance measurements) are useful indicators that show how processes and practices are working (Camp, 1995). These metrics will enable the identification of the company's own performance for the selected process to benchmark and define the size of the gap that exists in comparison. Process measurement indicators should be carefully selected, ensuring that the comparisons are made on an "apples-to-apples" basis (Elmuti et al., 1997).If objectives are correctly and accurately defined, there will be less likelihood of diversions or wasted resources.

However, depending on the characteristics and nature of the process that is being benchmarked, some metrics and quantitative data might be not available or non-comparable factors intervene in the comparison (Zairi, 1996).

- *Implementation and monitoring*

The following statement defines the relevance of the last stage of the benchmarking process:

"If benchmarking goes no further than data collection, it has been a waste of time" (Fowler, 1997). All authors are unanimous with this opinion; the success associated to a benchmarking process comes ultimately from the implementation and not from the data.

However, it is also broadly acknowledged that the implementation phase may result not to be easy. Organisations may not know how to successfully translate procedures or ideas (Elmuti et al., 1997). It is stressed (Camp, 1995) that new practices should not be imposed but adapted to the company. In addition to this, a last requirement of benchmarking would be the necessity of evaluate and re-calibrate benchmarking as an iterative process.

Another advice on the implementation phase is "to adapt, not adopt" (Andersen and Pettersen, 1996). "After having observed methods that function very well in

the partner's organisation, it might be tempting to adopt it directly into our own procedures". If so, the fact that there might be certain conditions that make the method work well for the partner might be overlooked. These conditions include market characteristics, industry, organisational structure, etc. The identified methods must be adapted to fit the conditions present in one's own company.(Codling, 1992)

During the implementation phase, it is also need to be reminded (Andersen and Pettersen, 1996) that all changes are painful to those affected by and the psychological effects that such implantation might have on the human resources should be considered. Miller et al. (1992) suggests that the best way of easing this discomfort, and increase the probability for success, is to let the personnel affected by the changes to take part in the decisions that are going to be made by permitting their representation in the benchmarking team.

2.1.4. Best practices and benefits

A term which may come out on several occasions when reviewing the literature about benchmarking is *best practices.* Camp (1995) advocates that the best practices are the ones that "lead a company to a superior performance". Zairi (1996) states that best practice comparisons are the ones that potentially spark improvements that may provide the most significant rewards and returns.

As a further development of this definition, Codling (1992) advises that such "best" practices depend on the nature of the process and the requirements of the company and it could vary depending on these. For example, when buying a new car, the characteristics of the "best car" may differ depending on the subject (family with children, company use), purposes and the available resources. This concept can be illustrated with the following figure, which represents Codling's statement.

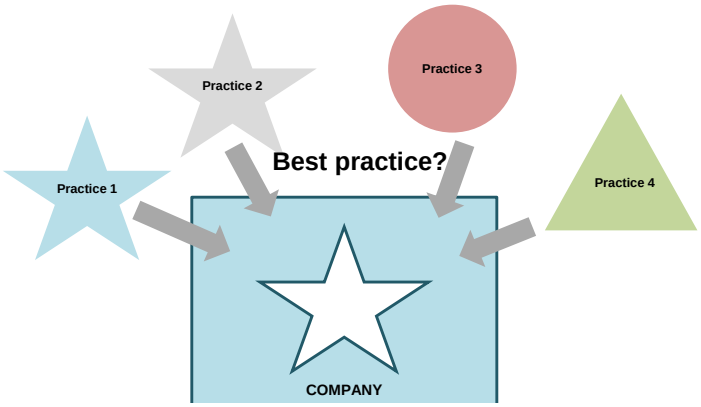

Figure 2.7. Search for the Best Practice.

When evaluating the benefits that the benchmarking process may bring to an organisation, the reviewed authors provide several of them. According to Elmuti et al. (1997), this process can support the strategic planning and encourage the development of new performance and productivity measures. Furthermore, Camp (1995) advises that an approximate image of a company's situation within the industry can be obtained through this method and such; taking advantage of such awareness for enhancing the strong points and reinforcing the weaknesses.

2.2. MEDICAL DEVICE VALIDATION

The literature review of the basis and practices of medical device validation practices starts, logically, with the definition of the elements of this title.

According to Nishihata (2003), a medical device is generally defined as:

“An implant and equipment to be used either to achieve disease diagnosis, medical treatment, or disease prevention or to influence the physical structure and function”

As it can be seen, this definition covers a wide range of categories, starting from scissors and other minor surgical equipment, which represent small risk to human function; to intravenous catheters, dialysis devices or pacemakers, with a high risk and responsibility to human function and life (Nishihata, 2003).

On the other hand, for the validation part, we may recur to the U.S. Food and Drug Administration (FDA), the regulatory agency responsible for supervising the public health related issues in the United States and the main (in terms of influence) regulatory organism within the medical device global industry, who defines it as a “method for assuring that a product manufactured satisfies the design required, the specification established and the reproducibility of the results” (FDA, 2011).

Comparing these two definitions, we can foresee that the elements implicit in both contexts are tightly linked by the existing requirements and normative that regulate their reason-to-be.

Prior to the review of the different concepts involved in validation and process validation, the industrial context will be introduced with the following figure (PTC, 2008); which illustrates a generic medical device development process showing the process involved in the development of a new product, the stages throughout this product advances and the functional departments in charge of the activities of each stage.

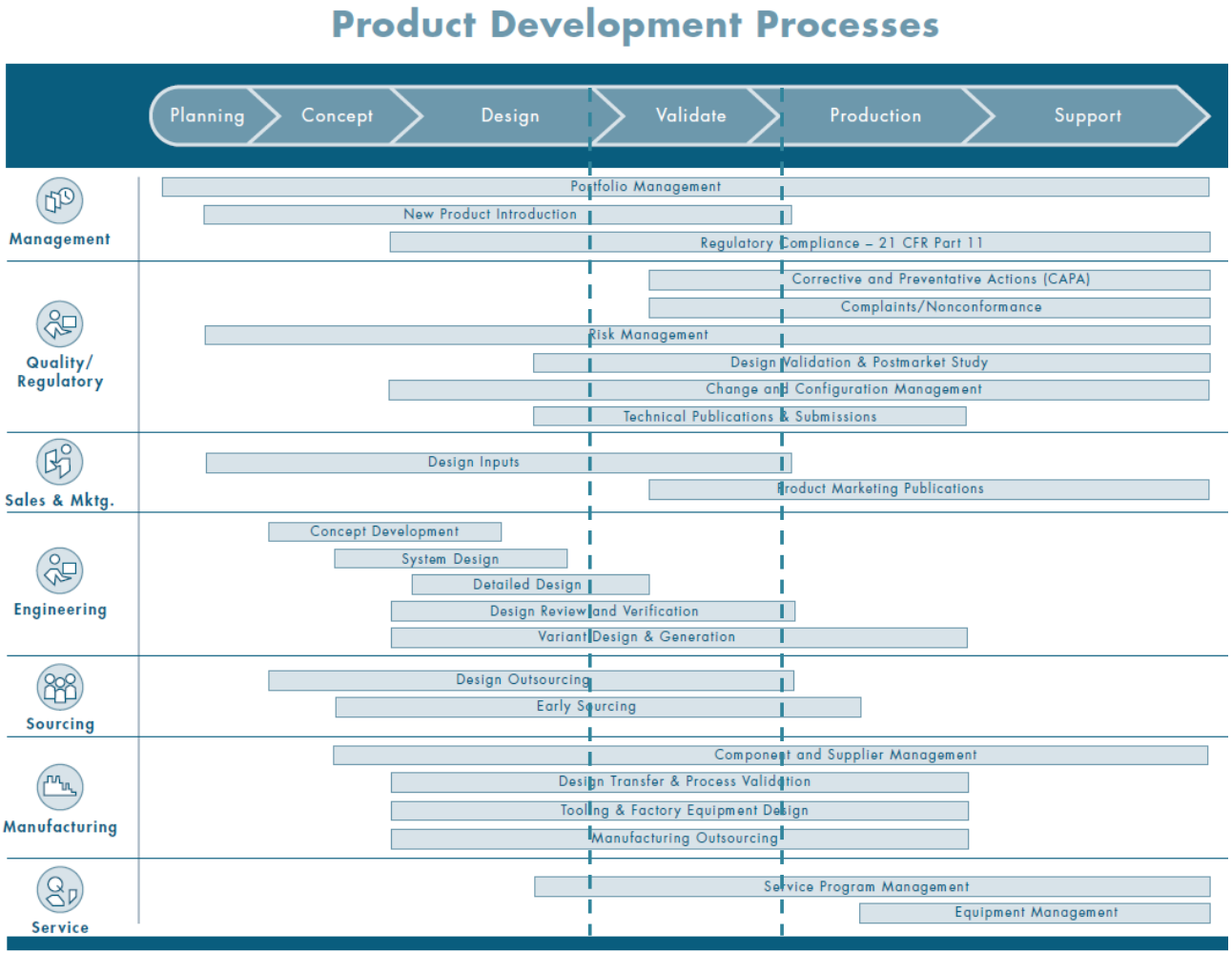

Figure 2.8. Product Development Process (PTC, 2008)

2.2.1. Validation principles

By performing a quick overview on the different industry regulations and quality standards, it can be pointed out that process validation is a basic requirement in heavily regulated industries, such as automotive or aerospace (Weese, 1998). In the case of medical device manufacturing, both the International Organisation for Standardization (ISO) and the United States Food and Drug Administration (FDA) require process validation as a regulatory requirement (Dixon et al., 2006).

In order to explain the reason of this requirement, some previous general concepts will be introduced. The first one will be the assurance of product's quality. Quality control is a vastly treated and reviewed concept and by referencing some of its experts, it could be introduced as assuring a product's services, cost control, production, delivery, safety and other performances (Dale

and Tidd, 1991) or by the costs related to the lack of quality, which will eventually result in society's losses caused by that particular product after its delivery (Taguchi, 1989).

Assurance of a product quality consists of several factors, such as selecting quality parts and materials, defining an adequate design or controlling the process and final testing (Juran, 1974). Due to the complexity of medical products, the total control of these different features and the routine testing of the end-product often are not sufficient to assure product quality. Some of the tests have a limited sensitivity and in other cases only destructive testing would show that the manufacturing process was adequate (Kuba, 2003).

Within the production of a product, some quality goals are required to be reached, which are listed in 3 principles: (1) "quality, safety and effectiveness must be designed and built into the product"; (2) "quality cannot be inspected or tested into the finished product" and (3) "each step of the manufacturing process must be controlled to maximise the probability that the finished product meets all quality and design specifications". This is why validation is a key element in assuring that these quality assurance goals are totally met (FDA, 1987).

These concepts can be summarised as follows: the product that results from a process should be verified to demonstrate that it meets the specified requirements. For the requirements that can be verified, a verification stage will be established (inspection, test, etc.). For the requirements that cannot be fully verified, a validation process will be required. (O'Leary, 2010)

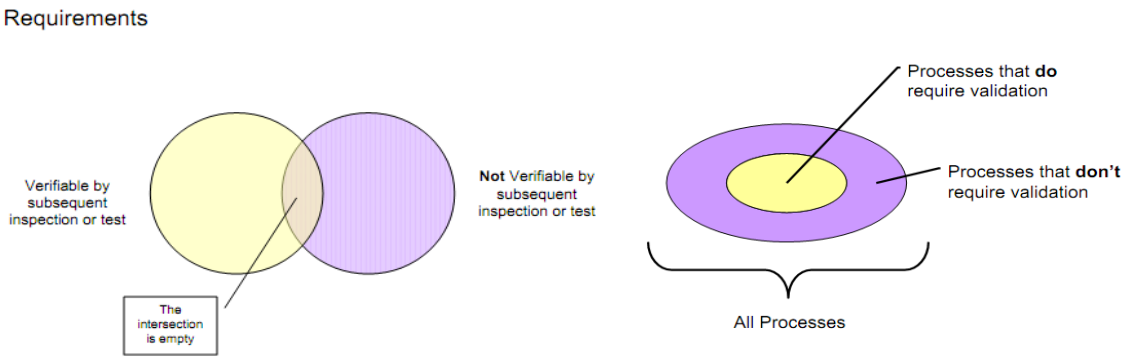

Figure 2.9. Requirements verification and validation (O'Leary, 2010)

The next question that may rise from this definition might be w*hich processes should be validated*.

A general answer for this question can be found on FDA's Quality System Regulations Manual (21 CFR Part 820 QSR) (FDA, 2008), which states that validation should be performed in the following cases:

- *"Routine end-product test have insufficient sensitivity to verify the desired safety and efficacy of the devices."*
- *"Routine end-product test do not revel all variations in safety and efficacy."*
- *"Clinical or destructive testing would be required to show that the manufacturing process has produced the desired product or result."*
- *"Process capability is unknown or it is suspected that the process is barely capable of meeting the specifications".*

In order to illustrate on a better way these conditions and provide some specific examples, a reference should be done to the Global Harmonization Task Force (GHTF), a group of representatives from medical regulatory authorities with the objective of standardise medical device regulations across the world. According to this organisation, the following processes shall be validated:"sterilisation, clean room environment conditions, sterile packaging, heat treating, plastic injection moulding or laser welding" (GHTF, 2004).

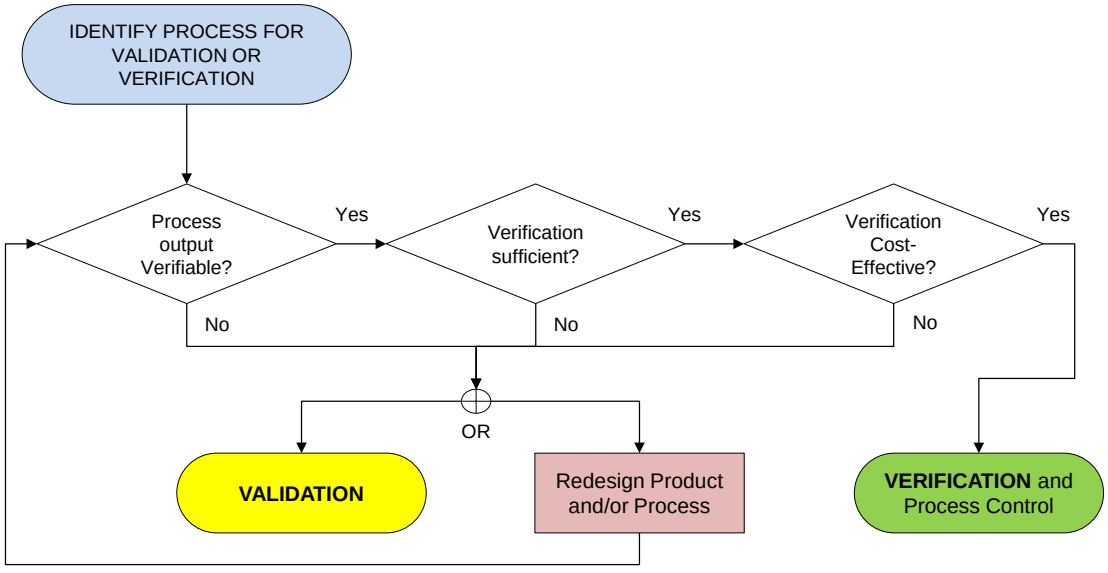

Figure 2.10. GHTF Decision Tree: What requires Validation (GHTF, 2004)

A more general description could be found on the abovementioned 21 CFR Part 820 QSR (FDA, 2008), which states that routine end-product test that have insufficient sensitivity to verify the desired safety and efficacy,

Finally, a last question that should be answered is: “What are the main differences between a common process and a validated process?” Recurring to O’Leary (2010), a typical process within engineering is composed of:

- *Process specifications or requirements (predetermined)*
- *Product specifications (predetermined)*
- *Work instructions*
- *Suitable Equipment*
- *Monitoring and measuring procedures*
- *Product verification*

In the case of validated processes, they also have:

- *Process parameter controls*
- *Qualified operators*
- *Additional record-keeping requirements*

2.2.2. The validation process

Continuing with the FDA definitions, under its Good Manufacturing Practice (FDA 1987; FDA 2011) the term validation process is clearly stated as “establishing documented evidence which provides a high degree of assurance that a specific process will consistently produce a product that meets predetermined specification and quality attributes” (FDA, 1987).

More recently, the FDA updated this definition in the following revision of the Process Validation Guidance (FDA, 2011), defining process validation as “the collection and evaluation of data, from the process design state throughout production, which establishes scientific evidence that a process is capable of consistently delivering quality products”.

At this point, in both definitions, a critical concept of the validation process is introduced, the terms “documented evidence” and “collection and evaluation of data”. As it will be seen later, all the activities related to documentation

(generation, record, traceability) are the key foundation where all the process relies on.

Quoting back the FDA, it is important that the manufacturer prepare a written process that specifies all the procedures to be conducted, capable of collecting and reflect accurately all the required information (FDA, 1987).

Returning to the central subject, the following figure represents the different stages and key milestones of the validation process of a medical device.

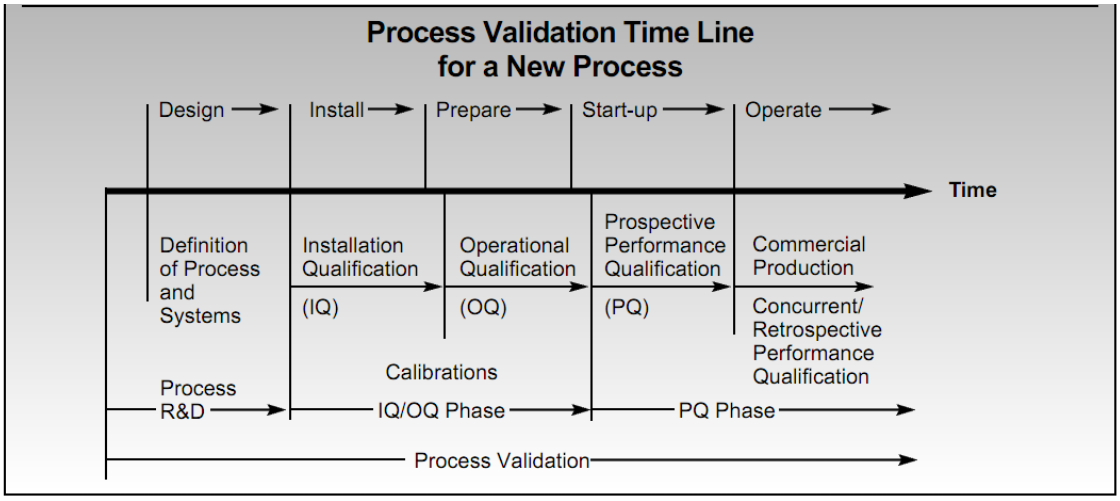

Figure 2.11. Medical Device Validation process (Tejal, 2011)

Three key stages can be appreciated in this process are according to Dixon (2006):

- Installation Qualification (IQ), “where the key aspects of the equipment installation, supplies, calibration, maintenance and operator training are established”.
- Operational Qualification (OQ), “which demonstrates that the equipment consistently operates to specification under normal conditions, including: testing of alarms, software function, machine consistency and extremes of operating ranges”.
- Performance Qualification (PQ) “produces product within specification when operated under the defined conditions”.

The process start with the development of the (design), which is applicable for both the product, the manufacturing process (tooling) and the test methods,

which should include accuracy for manufacture and testing and safety for preventing contamination (Nishihata, 2003).

The core purpose of the IQ is to show that the equipment and facility used to manufacture, measure and test the product is maintained and calibrated as required (Stockdale, 2010). In addition to this, it provides the opportunity to evaluate the specific installation and process conditions that can prove valuable over the programme. For example, if a process is not yielding the same dimensional stability after some time, installation qualification can be tracked to obtain the circumstances of the problem. By documenting the initial settings of the installation, the investigation to determine the root cause of the rejects will be simplified (Stockdale, 2010).

The following bullet-points, by O'Leary (2010), summarises the IQ phase:

- *"Equipment must meet specified requirements"*
- *"Equipment should be installed so it can be operated and maintained."*
- *"Limitations and tolerances are easily known by the operator"*
- *"Work Instructions are available"*
- *"If the equipment has a measuring function, include the calibration schedule".*

The objective of the OQ is to evaluate and define the manufacturing process. Through the use of analytical processes, engineering studies and statistical and dimensional evaluations, one can identify areas of concern that need to be addressed early in the programme (Stockdale, 2010). Definitions from the relevant normative and regulatory bodies may include "establishing documented evidence that the process is effective and reproducible" (FDA, 2008) or "establishing by objective evidence that the process control limits and action levels which result in product that meets all predetermined requirements" (GHTF, 2004).Again, it is pointed out the stress made on establishing documented evidence.

The Determination of Experiment (DOE) is used to define which process parameters affect specific dimensional responses, the influence on the response and the interactions between them; establishing the optimum process

window and its respective influence on each dimension. From these studies, the predicted dimensional outcome can be confidently defined. During the DOE, a series of experiments are carried out and the influences are evaluated statistically (Dixon, 2010).

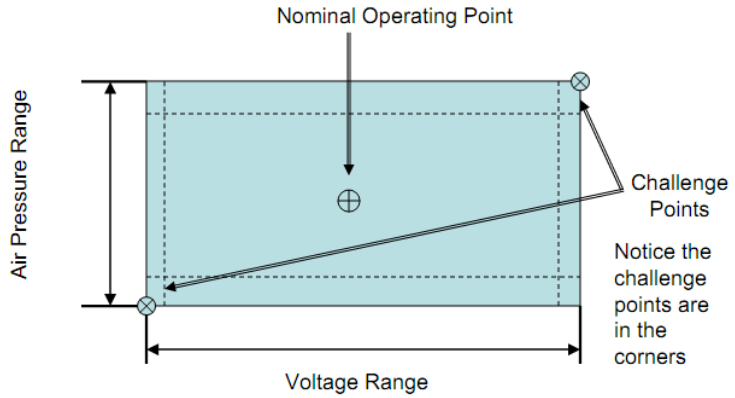

Figure 2.12. Operating points example: DOE for the optimal dimensional process window (O'Leary, 2010)

These process limits will then be challenged and evaluated. The challenges consist of three dimensional runs: low, high and nominal process challenge runs. Each run is equal in run time and evaluated for dimensional, functional and cosmetic considerations in relation to the product specifications and tolerance. The results may demonstrate conditions that do not meet the desired acceptance criteria, in which case the process tolerance, mould or specification needs to be modified and if necessary, the processes re-run to verify conformance. (Rifino, 2003)

A description of the Performance Qualification (PQ) can be given by the GHTF (GHTF, 2004), which defines it as "establishing by objective evidence that the process, under anticipated conditions, consistently produces a product which meets all predetermined requirements. In other words, it consists in demonstrating that the process, under anticipated conditions, consistently produces conforming product".

Once that the different stages of the process validation of medical devices have been described, the next point would be explaining how these process is actually carried out in practice. A summary of these actions are given by O'Leary (2010):

- *Determine the need to validate*
- *Determine what to validate (IQ-OQ-PQ)*
- *Write a Validation Protocol*
- *Conduct the Protocol and collect the data*
- *Analyse the data*
- *Improve the process, based on the data and analysis*
- *Prepare a report*
- *Keep documentation as a Quality Record*

Finally, some controversial opinions of the pharmaceutical industry about the validation process are worth to be mentioned in this literature review. As Johnston (1995) points out, *"*it (process validation) has been considered that the blind, bureaucratic approach to validation followed by some companies is a needlessly expensive process that achieves nothing more than a temporary reprieve from the regulatory authorities*".*

Many medical device manufacturers consider validation and other regulatory requirements as a "dead weight or burden". While some companies have developed a "mature approach to regulatory compliance and have acquired an integrated approach and methodology, many other companies in the sector only consider the validation aspect once the main elements of product and process have been completed" (Johnston, 1995). "If it is faced from this perspective, meeting the established regulations might become a paper generating exercise and a drain on resources" (Baseman, 2012). "However, these requirements should be taken as an opportunity to increase process understanding, ensure that processes are operated under optimum conditions, improve quality and reduce costs"(Dixon et al., 2006).

Finally, an update to the process validation approach has been introduced within FDA's latest document revision (FDA, 2011), where as a complement to what has been explained until now, a product life-cycle approach is considered, as it can be appreciated on the following figure.

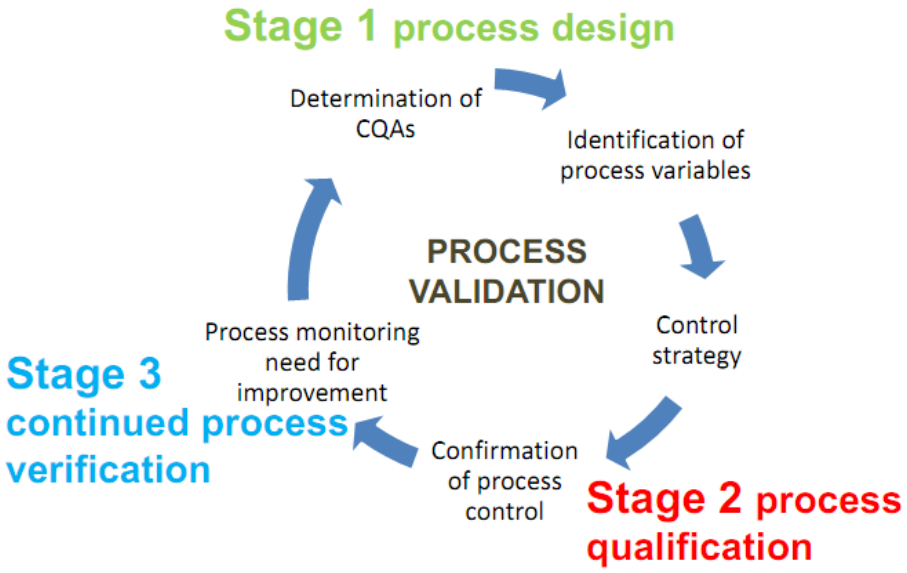

Figure 2.13. Process Validation: Life-cycle approach (Baseman, 2012)

The first stage is highly focuses on Process Design, in order to build and capture knowledge and understanding on process capability and variability from its development phase. The Design of Experiments to identify and establish the process parameters and sources of variability; and the risks assessment aim to minimise and prioritise efforts, are classified into this step. (Baseman, 2012)

Stage 2, Process Qualification, comprises the most part of what have been introduced on the previous paragraphs of this section. During this stage, the process design is confirmed as being capable of reproducible commercial manufacturing (FDA, 2011). Activities of this stage include, as abovementioned, facility and equipment qualification (IQ) and process performance qualification (OQ, PQ).

Finally, the loop is closed by Stage 3 with the Continuous Process Verification, where on-going assurance is gained during routine production that the process remains in a state of control (Baseman, 2012).

With this new life-cycle approach, process validation should not be considered any longer just as a milestone, becoming now a continuous process of valuation (Long et al., 2011). These steps contribute to “know the process”, “know the variables”, “have confidence before going into commercial production” and create vigilance through monitoring and continuous improvement.

The challenges created on the medical device manufacturing organisations require these to expand their current scope of validation by reaching further upstream into development and downstream into day-to-day manufacturing (Long et al., 2011). It is commonly agreed that this will foster better communication from development through production. In order to face successfully this new challenge, the author suggest medical device companies to perform gap analysis of their current state of validation programmes and compare it with the future state based on the new guideline (Long et al., 2011). These assessments will provide a better position to organisations to create action plans and procedures for the new policies, as well as identifying any further resource or training requirements.

2.2.3. Quality Assurance role in the validation process

The International Organisation for Standardization (ISO) defines Quality as the "measure of excellence or state of being free from defects, deficiencies and significant variations*".* When applying this concept to manufacturing, Dale et al. (1991) states that it consists in the strict and consistent adherence to measurable and verifiable standards to achieve a uniformity of output that meets the requirements established by the customers or users. Juran (1974) defined Quality Assurance as the activity of providing to all the parts concerned the evidence required to establish confidence that the quality function is being managed adequately.

As defined previously by the relevant authorities, the purpose of process validation is to show that a specific process will do what it is purposed to do (FDA, 1987; FDA, 2011; GHTF, 2004).

Quality Assurance in medical device companies embodies the effort to ensure that the products have the reliability, safety and efficacy in performing as it is intended to do (Kuba, 2003).

During the last years, this quality awareness has been stressed as companies seek world-class status for their operations defining QA programs focused on the following factors: certifying suppliers, setting standards for customer satisfaction (both within and outside the organisation) and incorporating several

process controls (i.e., Statistic Process Controls) in manufacturing operations (Cheng, 1994; Kumar, 2008)

The activities and responsibilities of the Quality Assurance department within a medical manufacturing organisation are (Beckford, 2002; Rifino, 2003):

- Establish raw material specifications and their acceptable limits: All raw materials are tested before use and these must meet quality standards and specifications, as well as their limits set. External contractors may perform these tests, but QA will ensure that the laboratory procedures are properly followed and documented, with the end objective of ensuring that no raw material is released improperly.
- Product specifications and their acceptable limits: QA responsibilities are the same as for raw materials and final products. All finished products (including components and sub-assemblies) are tested to determine if they meet the required quality standards.
- Product and process stability: stability programmes are performed to determine whether or not the product or component will be manufactured properly and maintain its quality characteristics through its operational life.
- Training: Responsibilities associated with process validation and Quality Assurance relies on the training of the personnel involving in the manufacturing and testing activities. These personnel are trained to carry out the standard procedures required by validation documentation.
- Documentation: Quality Assurance is responsible for generating all the documentation directly related to the process validation (protocol, report, data collection, etc.) in order to meet one of the main objectives of the process, *to establish documented evidence*. Other responsibilities include the release of manufacturing related documentation (procedures, work instructions) and other quality specific records.
- Process Validation: This activity is concerned with controlling the manufacturing process, ensuring what procedures must be performed and under what conditions they must be carried out and establishing documented evidence that a process is reproducible and it will consistently produce a product meeting the specified requirements.

Rifino (2003) advocates that process validation should be considered the main tool of Quality Assurance because it not only involves the activities of different organisational units but also centres on proving that the process is under control. It provides documented evidence that the quality function exists for the manufacturing process.

2.3. VALIDATION IN THE AEROSPACE SECTOR

The term *validation* within the aerospace industry context has a broad range of definitions and meanings, as contrast of the accurate definition given in the pharmaceutical and medical device industry. Despite sharing the same philosophy on its basis, it has no standardisation and its definition may vary depending on the sector (aviation, space, etc.) or the regulatory authority consulted.

Throughout this section of the literature review, different approaches to validation in the aerospace industry will be introduced in order to establish and framework for the research activities.

2.3.1. Process Validation in aerospace

This section will emphasise in the process validation concept, which is focused on the validation of the different manufacturing practices and it has been considered as the most related one to the medical device process validation.

In aerospace industry, the validation of a process is regulated by the Aerospace Quality Standard AS9100, clause 7, sub-clause 5, section 2, validation of processes for production (SAE, AS9100 Rev. C).

According to this section, in special manufacturing and production processes where verification or test is not possible or feasible, the validation of such process should be performed (i.e., composites, critical components, new manufacturing solutions, etc.). (SAE, AS9100 Rev. C)

As an example of the application of this clause, these are the quality requirements that the aircraft manufacturer Embraer requires for its suppliers:

7.5.2 VALIDATION OF PROCESSES FOR PRODUCTION AND SERVICE PROVISION

OPR (7.520.02)	Supplier shall establish procedures for controlling of special processes, including but not limited to: **1 – Qualification or initial approval** – Special Processes shall be qualified or approved before use. Supplier shall keep available for EMBRAER review the following data: *a)* Identification and address of the facility; *b)* Identification of the special processes and applicable specification number; *c)* Report of process parameters controls (temperature, pressure, concentration, pH, hardness, conductivity, etc) according to the limits and frequency specified in the specifications; *d)* Calibration standards list (including calibration reference procedures and calibration frequency); *e)* List of qualified personnel; evidences of their qualification (training, knowledge, experience, skills); *f)* Qualified materials list used in the process; **2 – Qualification maintenance** – Special processes shall be maintained through periodic verification. Periodic verification shall consist of monitoring the special process parameters at in interval established in the process specification requirements. **3 – Flow down of the requirements** – Supplier shall flow down applicable requirements and control of special process performed by Subtiers. Supplier control of Subtiers shall include: qualification, maintenance, control of nonconforming product and corrective action.

Figure 2.14. EMBRAER Quality Requirements for Suppliers (Embraer, 2010)

The Federal Aviation Administration (FAA), a regulatory organism of the U.S. Department of Transportation in charge of regulating and oversee all aspects of civil aviation in the United States, on its *Guidelines to Minimize Manufacturing Induced Anomalies in Critical Rotating Parts* (2006) document, defines the process validation *as "*a procedure in which it is demonstrated that the manufacturing process delivers parts and product consistent with the form, fit and function required by the design of the part to meet its Service Life*"*(FAA, 2006). According to the FAA, two approaches to Process Validation are used within the aerospace manufacturing industry:

- Part Specific Process Validation (PSPV)
- Generic Manufacturing Process Validation (GMPV)

In PSPV, a part is evaluated against its design requirements and subsequent production is controlled to deliver product consistent with the evaluation (FAA, 2006)

In GMPV the manufacturing methods that are identified as being sensitive, or in other words, that requires a high level of control in the manufacturing process to

meet the design requirements are controlled by specifications and/or validated parameter limits. The GMPV ensures that any product manufactured within the parameter window will meet the design requirements (FAA, 2006)

The FAA describes the procedure on the following table as a “route” to Process Validation for an engine component.

Step	Who	Activity		How / Comments
1	Engine Design	Identify parts which must maintain a high level of integrity to avoid hazardous engine effects and designate them as CRITICAL, FLIGHT SAFETY PART or LIFE CONTROLLED PART.		FMEA of the engine leads to part classification. The critical nature of the part should be conveyed to all parties concerned with manufacturing the part.
2	Validation Team	Review all part features and identify the features made by Sensitive Manufacturing Processes.		PFMEA or other disciplined method should be used to help identify Sensitive Manufacturing Processes. It is generally accepted that the feature Manufacturing Process and fatigue life should be considered in the identification process.
3	Validation Team	Validate the Manufacturing Process for those features identified in step 2.		The Process Validation can be a combination of: - PSPV - GMPV
3.1	Manufacturing engineer	**PSPV:** Define Manufacturing Process	**GMPV:** Define parameter limits	Based on validated manufacturing methods.
3.2	Validation Team	Establish fatigue capacity	Investigate the fatigue behaviour or parameter limits including consideration of the most adverse combinations	By fatigue test using part, sub-element or specimen which captures material, Surface Condition and geometry, Or Metallurgical evaluation where experience defines an acceptable material Surface Condition Or A combination of the above.

Table 2.2. Route to Process Validation (FAA, 2006)

Finally, this section is concluded with a case-study which will expose how process validation is carried out in the aerospace sector. This real case is described in the Best Manufacturing Practice: Centre of Excellence website as a best practice performed by the aerospace and defence company Lockheed Martin – Tactical Aircraft Systems (BMP: CoE website, Lockheed Martin).

According to this database, Process Validation is used by Lockheed Martin “to meet the requirements of test environments, customer demands, concept and design review baselines and design standards, ensuring this way the accuracy,

repeatability and reliability of the process through analysis and independent verification" (BMP: CoE website, Lockheed Martin)

The Process Validation "includes simulation and modelling, test validation plan and Production Readiness Assessment; which consists in assessing the factory and depot test equipment, production tooling, test procedures, calibration procedures, preventative maintenance plans and equipment operating instructions" (BMP: CoE website, Lockheed Martin). As it can be appreciated, there are clear similarities with the processes performed within the medical device validation.

The benefits for Lockheed Martin that Process Validation approach presented consisted in "a reduction of test debug time, faster achievement of full-rate production, lower production support costs, verification of readiness of the production line, early availability of process variability data, verification of product testability and producibility and efficient production test flows". (BMP website, Lockheed Martin)

Because all process validation methods are integrated, "unnecessary test are eliminated, the number of test equipment required is reduced, the production bottlenecks are identified early in the manufacturing cycle and production costs are minimised" (BMP website, Lockheed Martin).

2.4. CROSS-INDUSTRY APPLICABILITY

Finally, at this last section of the literature review, the procedures and practices that were originally created in the aerospace industry and were later adopted by the medical sciences sector have been exposed. It requires to be pointed out that previous publications about this subject were very limited, resulting in a potential gap that should be fulfilled.

Owing to this fact, one of the contributions of this research project would be providing a framework and a set of initiatives that would allow current practices implemented in aerospace sector organisations to be translated and adapted to a medical device manufacturing company.

2.4.1. Quality Systems framework

A first approach could be made in this applicability evaluation exercise by comparing the ISO quality system requirements for both industries on the process validation related area.

On one hand, the International Standard which specifies the quality requirements for the medical device manufacturing sector is the ISO 13485:2003; which is based on the ISO 9000 quality standard series, by some additions and deletions it harmonises the existing requirements within the different authorities present in this industry.

On the other hand, the quality standard for aviation, space and defence organisations worldwide is the AS 9100, being the Revision C the latest version. The main objective of this standard is to set a framework based on terms of confidence between suppliers and manufacturers (Graham, 2007). First published in November 1999 by the Society of Automotive Engineers (SAE), it was the first globally acknowledged system that addressed both military and civil aviation needs. Developed by a special advisory committee of ISO and other international quality groups, it contains the ISO 9000 quality standard series requirements with additional requirements which are specific to the aerospace industry.

Clause	Requirement	ISO 13485:2003	SAE AS9100:2009 Rev. C
	Validation of Processes for Production and Service	**Validation of Processes for Production and Service**	**Validation of Processes for Production and Service**
	The organisation shall validate any processes for production and service provision where the resulting output cannot be verified by subsequent monitoring or measurement. This includes any processes where deficiencies become apparent only after the product is in use or the service has been delivered	Same	Same Note: This processes are frequently referred as *special processes*
7.5.2	Validation shall demonstrate the ability of these processes to achieve planned results	Same	Same
	The organisation shall establish arrangements for these processes including, as applicable a) Defined criteria for review and approval of the processes, b) Approval of equipment and qualification of personnel, c) Use of specific methods and procedures, d) Requirements for records and, e) revalidation	Same	Same, except for: a) Defined criteria for renew and approval of the processes, *qualification and approval of special processes prior to use,* c) Use of specific methods and procedures, *control of the significant operations and parameters of special processes in accordance with documented process specifications and changes*

Table 2.3. Quality Systems Comparison (ISO 9001:2008, ISO 13485:2003, SAE AS9100:2009)

As it can be seen, at first sight, there are no big differences in the requirements of process validation from the quality standard point of view, other than the prior approval before entry into service in aerospace (no retrospective validation) and tighter process parameter controls.

2.4.2. Aerospace Reliability applied to Biomedicine

The most subject-related publication is a paper titled “Aerospace Reliability Applied to Biomedicine” by Lalli and published in 1972.

Through this article, the author suggests that the quality and reliability procedures used by the National Aeronautics and Space Administration (NASA) on their space rocket program applied on medical equipment may result highly beneficial. Lalli (1972) establishes along this article the several similarities that both sectors share and sets some basic-points for further development activities.

The purpose of this paper by Lalli was to evaluate “the methodology developed by NASA to achieve equipment reliability”. According to the author, there are many obvious differences between the space and medical areas, “and much that is done to achieve reliability of space equipment is not directly applicable in

the biomedical area. Much of the methodology should be of value". (Lalli et al., 1972)

In this paper, "the Space Electric Rocket Test project is used as an example of NASA application of reliability and quality assurance methods" (Lalli et al., 1972). By performing a direct comparison it is exposed "how the same methods can be used in the development of instrumentation and complex systems for use in medicine".

As it is pointed out by the author, both NASA and the medical industry are involved in the design, production and operation of complex and critical equipment. "These systems must operate accurately and reliably. Failure can cause economic loss; even worse, it can result in the loss of human life" (Lalli et al., 1972). This way, NASA has developed an extensive reliability and quality assurance methodology that could be used as the bases for an appropriate program for medical instrumentation. Such a program should be aimed at improving equipment performance, reducing failures and absolutely minimising risks of personal injury or death (Lalli et al., 1972).

This research paper showed that a survey in some hospitals of the Detroit area disclosed many disturbing things about the medical devices:

- "Few pieces of equipment are properly maintained"
- "Simple calibrations and adjustments are not made"
- "Dust is allowed to build up inside the chassis causing components to overheat"
- "Few defibrillators accurately produce the amount of energy they are supposed to"
- "Most monitoring oscilloscopes and electrocardiographs have a substandard frequency"

In addition, medical equipment was found to contain the following defects:

- "Low quality parts were used in construction"
- "Planning in the placement of equipment was poor"
- "Equipment was not adequately protected from its operating environment"
- "Equipment was misused by being operated by untrained personnel."

“To solve similar problems in achieving highly dependable equipment performance, NASA developed an extensive methodology for improving, maintaining and verifying design reliability and product quality of space-program hardware” (Lalli et al., 1972)

This space-related methodology was based on the application of two existing engineering disciplines: 1) reliability, and 2) quality assurance. (Lalli et al., 1972)

According to the author’s definitions, “reliability engineering is concerned with design and testing tasks in product development to ensure that the product is properly designed to perform the assigned task without failure” (VERIFICATION). On the other hand, “Quality Assurance is concerned with various control methods and qualification testing to ensure that the product delivered is manufactured as designed” (VALIDATION) (Lalli et al, 1972)

Regarding this last aspect, the author provides an interesting statement related to the resources used during this stage: In quality assurance, “the best-designed product is only as good as the people and materials finally used to make it” (Lalli et al., 1972)

Another relevant stage within high complex products is the review of the specifications and requirements. As the author details, “specifications explain just what is required in each component in either case” (Lalli et al., 1972). The usual tasks required to be performed by quality-assurance engineers in this control activity are “1) drawing review 2) configuration review 3) procurement document review 4) vendor survey 5) fabricated article review 6) component identification system 7) preservation, packaging, handling, storage and shipping review 8) training and certification of personnel” (Lalli et al., 1972)

The next steps taken for the evaluation of the Flight Status Review by NASA provides several aspects for ensuring the mission success. According to the American Space Agency, a flight component is considered to be flight ready only if the criteria given below are met (Lalli et al., 1972):

1) Fabricated to the latest released specifications
2) Meets all test requirements
3) Date of fabrication, source, serial number and history are identified

4) “History does not contain repetitive repair, rework or modifications”
5) “The life-limited equipment is identified”
6) “Stable operation history without test anomalies”
7) “Failures have been analysed and corrective actions taken”
8) Corrective action has been inspected and tested to assure performance
9) Condition not degraded by handling or storage
10) “The replacement components are handled like flight items”
11) “The launch-site activities are carefully planned to maintain readiness”

Despite sharing the same principles and motivation behind, flight-readiness status in aerospace terms is not clearly comparable “on a direct one-to-one basis” to the medical device sector, but the eleven criteria provided on the previous paragraph define “the **care-before-use** philosophy of quality assurance”. The same philosophy translated to “concrete well-planned control activity is obviously needed in equipment for use on human patients” (Lalli et al, 1972).

According to the author, the second part of the quality assurance tasks is testing the product according to the following subdivisions (Lalli et al., 1972):

- *Inspection*
- *Acceptance*
- *Operational*

During the inspection, the elements that are embarked are checked ensuring that all components are manufactured to the specifications and identifying critical parameters. In order to carry out these activities, skilled and experienced personnel, and extensive training, are required (Lalli et al., 1972)

In addition to inspection, the reliance on the manufacturer’s inspection is not enough to ensure product performance and acceptance tests are required to help on the assurance of the performance (Lalli et al., 1972)

Finally, after passing the acceptance tests, components are assembled into the final product and final tests are run. This integral testing provides the opportunity to fully assess the operation of the final product under the environmental conditions and expected operational modes (Lalli et al., 1972)

Finally, the conclusions of this paper provide some advices relating to the validation process methodology and lessons learned from space projects. “The methodology must be prevented from generating a *paper blizzard*” (Lalli et al., 1972). As the author highlights, it is critical to keep the paperwork simple and “encourage simple language and forms”. It is important to point out the fact that “paper cannot replace sound simple engineering evaluation and judgement”. However, the author warns that “improving the methodology does serve to reduce the frequency of human or material failures, but obviously it will not completely eliminate them” (Lalli et al., 1972).

In the end, a final recommendation from the author (Lalli et al, 1972) it is exposed which clearly fits with what other regulatory authorities (FDA, 2011, Long, 2011) has stated later on its industry guidelines: it is essential to monitor and control the manufacturing and test processes and to maintain close adherence to specifications, parts must be standardised as much as possible and good housekeeping practices must be followed at all times and places. The system can be costly, but it can save much more (Lalli et al., 1972)

2.5. RESEARCH GAP

Despite several relationships and links between the aerospace and the medical sector have been found within the literature review, some knowledge gaps and improvement areas have been identified:

- There is no specific information regarding which specific practices and procedures require to be developed for addressing effectively the validation stage.
- There are no analysis related to the resource infrastructure and investment required for developing a fully reliable and efficient process validation phase.

This research project aims to address these knowledge gaps by identifying the best validation practices within aerospace sector and provide the required procedures and resources for their translation and implementation within a medical device manufacturing organisation.

2.6. SUMMARY

In this literature review chapter the key elements, terms and concepts that the research thesis will cover have been introduced. It has been demonstrated that the benchmarking process is considered as an improvement tool for the organisations and its structured approach and stages have been outlined. In addition to this, the regulatory framework of the project has been introduced with the presentation of the validation concept and how the different sectors (aerospace and medical) cover it, and providing particular details on the “process validation” practices and the role of quality assurance along this stage. Consequently, a link between these two sectors has been established and finally, the research gaps on the literature have been identified.

3. RESEARCH METHODOLOGY

This chapter describes the methods and techniques used to conduct this research project, giving a general overview of the approach to this study.

The research approach for this project can be defined as a qualitative study and the author used several research tools, techniques and activities during this period.

An essential part of the study was to assist the company's Quality Assurance department to perform the process validation for 2 different medical devices. This also included the implementation of new techniques which were chosen together with the company's management board.

3.1. APPROACH

As it has been shown on the Literature Review chapter, when facing a benchmarking process, several approach and study methodologies can be adopted. Depending on the author, this process may be composed by a different number of stages.

The selected approach, despite sharing the main philosophy of the benchmarking processes proposed by the literature, does not follow any of them in particular.

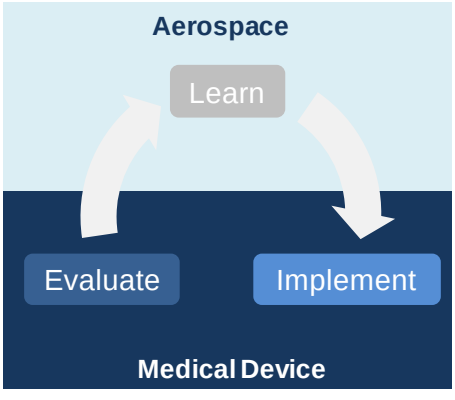

Figure 3.1. Research approach.

At first glance, it can be appreciated that two of the three process boxes are located on the "Medical Device" side. This implies that the main activities and

"driving force" of this research will be focused on evaluating and developing the procedures of JEB, leaving the other process as an information source and improvement tool.

- ***Evaluate*:** The first step will consist in realising *Where we are*, *Where we want to go* and *How are we going to achieve our destination*. As a result of this stage, the key parameters and specific improvement areas will be obtained.

- ***Learn*:** This word represents the core and end-objective of the benchmarking study; to identify and learn the best practices that players from a different industry sector are using for solving the common-nature problem.

- ***Implement:*** The meaning that relies behind this word is related to a pro-active attitude. Once the previous phases have been successfully completed, it is time to get into action and apply all the outcomes obtained in the previous stages.

Basing on these three principles, in the following lines a more specific and detailed guideline of the project's programme is given, describing the main activities and results of each stage.

3.2. RESEARCH PHASES

The Figure 3.2 illustrates the structure of the research methodology selected for this research project.

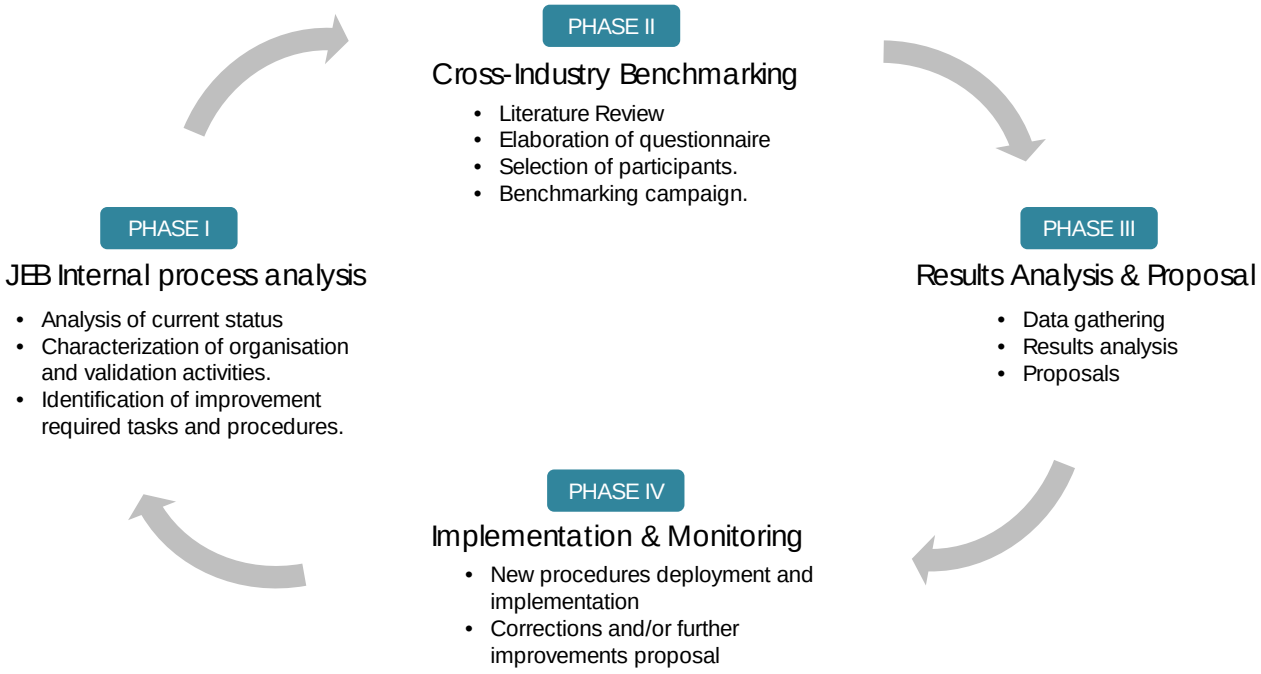

Figure 3.2. Research Project Phases

3.2.1. Phase I: JEB internal analysis

Due to the characteristics of the required information, a qualitative analysis was performed on the current practices, challenges and problems that the company was facing during the process validation phase. This analysis was based on semi-structured interviews with the relevant personnel (designers, engineers, managers, customers) involved in these activities and the author's field experience during this stage. These interviews were designed to capture information and workers opinion relevant to the different activities during process validation, including their role's responsibilities, critical milestones or the resources available for performing the different tasks. In addition to this, the company internal quality procedures, standards and resources allocated for process validation have been reviewed with the objective of ensuring that the newly developed procedures are totally integrated within the practices of the organisation.

3.2.2. Phase II: Cross-industry benchmarking study

In order to capture the leading practices related to the validation stage, a benchmarking study was undertaken within the aerospace sector. This study was carried out through several techniques and sources, including an extensive

literature review, the consultation of benchmarking databases, corporate websites and publications, and seven direct, semi-structured interviews. The questionnaire and interviews were based and developed in order to capture the information related to the main improvement areas identified on the internal analysis.

3.2.3. Phase III: Best practices analysis and proposal

At this stage of the study, a qualitative analysis was done on the outcomes and findings of the benchmarking study. Based on the information gathered on this study and taking into account the improvement requirements detected on Phase I; a list with the new practices proposal was created and validated by panel of experts.

3.2.4. Phase IV: Implementation and monitoring

In this phase, the new practices implementation guidelines were provided in order to integrate the identified best practices within the medical device manufacturing company. The opinions and recommendations from the previous experts' panel, the expected benefits, complexity and resource requirements of the new procedures were considered for generating these guidelines.

3.3. SUMMARY

This chapter has introduced the research methodology followed for this project. Based on an Evaluate-Learn-Implement approach, a four-phased methodology has been developed for achieving the aim and objectives of this study. The activities of the first phase are focused on identifying the improvement areas of the organisation, the leading practices of the aerospace sector are evaluated through the benchmarking campaign of the second phase, resulting in a list of proposals, once they have been analysed and validated, and concluding with the new procedures implementation guidelines.

4. COMPANY INTERNAL ANALYSIS

This chapter describes the internal evaluation of the current validation process and activities of the company. For the purpose of this study, a total understanding of the business processes and validation procedures was required.

During the research period, the author was based at the company premises collaborating closely with the Quality Assurance Department, the area responsible for medical manufacturing process validation, and working on the validation process of several surgical device projects.

4.1. DATA COLLECTION

Sources of information:

1. JEB Quality Management System procedures
2. Semi-structured interviews with company employees
3. Author's day-to-day work experience in medical validation

4.1.1. Company Quality Management System procedures

As a first contact and in order to familiarise with the validation process and other related procedures, the company's Quality Management System was reviewed to get a clear picture of the activity logics. JEB is certified in ISO 9001:2008 Quality Management and ISO 13485:2003 Medical Device Quality Management Systems.

4.1.2. Interviews

Another valuable source of information for drawing the current status of the company was the several semi-structured interviews carried out through the whole research period.

In order to conduct these interviews, a questionnaire for the organisations internal analysis (Appendix A) was used. The structure of this questionnaire was:

- General Information
- Process validation
- Resources

The first part of the interviews contained general information questions relevant to the role within the company, years of experience and key functions and responsibilities in the department.

The second part was focused on the specific tasks and activities during the medical device process validation stage. Opinions regarding the procedures, workflow, performances and involvement of the interviewee during this stage were asked.

Finally, the last part of the questionnaire included questions related to the allocation of resources and any further resource requirements and considerations associated to this particular stage.

In order to validate the capacity of the questionnaire in capturing the desired information, 3 sample interviews were made with the operators involved in the medical section, for testing purposes. The outcomes of the test proved its total suitability and success in gathering the desired information.

A total of 10 employees from different departments and positions within the company were interviewed, as it is summarised in the following table:

Area	Role
Management	- Managing Director - Production Manager
Quality Assurance	- Quality Assurance Manager - Quality Assurance Engineer
Production / Manufacturing	- Mould shop Manager - CNC area Manager - Manufacturing area assistant - Tool room operator - Test operator
IT department	- IT Department Manager

Table 4.1. Internal Analysis interviewees

4.1.3. Work experience

Finally, the author, as a member of the Quality Assurance Department, has been involved in the several tasks and activities related to the development of two new designs of surgical devices, the definition and update of quality procedures and the assessment of best resource allocation, acquiring useful and first-hand information.

The experience accumulated during this time period includes:

- Drafting and generation of validation related documentation
- Carry out protocols and reporting
- Samples data collection & testing
- Technical documentation research
- Feedback from OEM and customers
- QMS procedures update

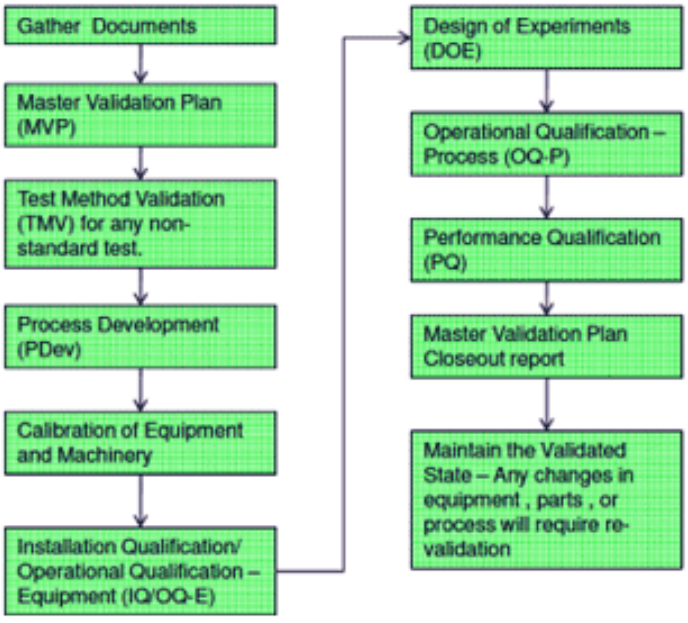

Figure 4.1. Process Validation Flow Chart (FDA, 1987)

4.2. DATA ANALYSIS

A qualitative analysis was performed once that the relevant information has been collected and classified, as it can be summarised on the following flowchart.

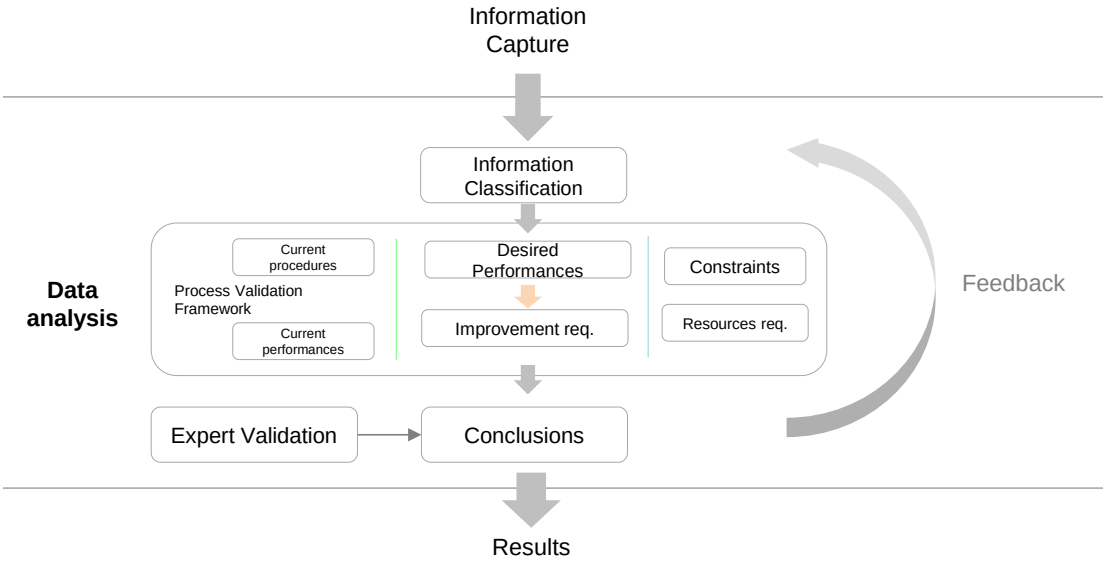

Figure 4.2. Internal Data Analysis

This analysis was focused on evaluating the current status and comparing it to the desirable one, identifying the improvement areas and always taking into account those aspect of the process in which a poor level of performance would affect the following elements:

- Product quality
- Product reliability
- Product traceability
- Time
- Costs
- Installations and equipment
- Customer's satisfaction

In order to perform this analysis, several constraints related to the process validation particularities, customer requirements and available resources were considered. Finally, relevant workers and players provided opinions and

feedback along the process and the outcomes of the analysis were validated by a panel of experts.

4.3. RESULTS

In this part of this chapter, the results and findings of JEB Internal Analysis are described. Due to the characteristics and similarities shared by these results, it has been decided to separate and differentiate the outcomes of the internal assessment according to their nature and 2 categories have been established, procedural related improvement and resource requirements.:

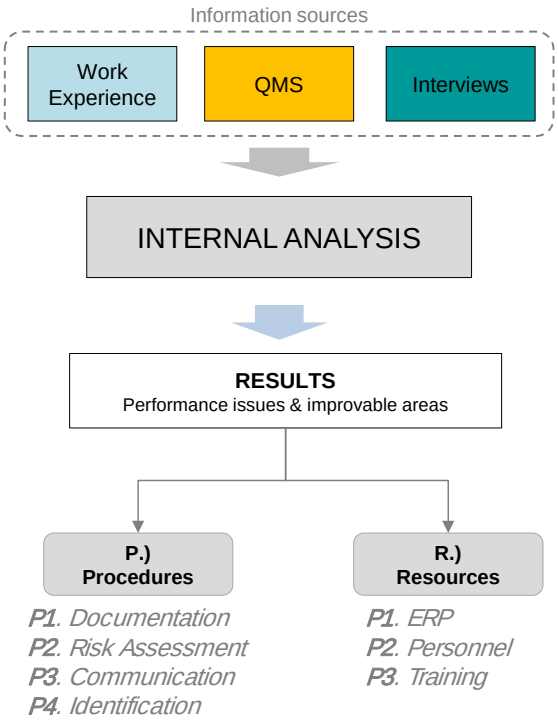

Figure 4.3. Problem and issues classification

- ***(P)****Procedures:* issues related with the work flow in place, instructions and orders that may affect to the overall performance of the process validation.
- ***(R)*** *Resources:* problems related with the lack or non-efficient assignation and distribution of resources (i.e., human resources, time, material, equipment) at each stage of the process validation.

4.3.1. Documentation management

This has been identified as a critical point within the validation stage. As it is requested by the Regulatory Authorities, in this particular case the FDA, all medical companies are required to maintain a secure, comprehensive and centralised system to manage all quality procedures, product documentation and manufacturing procedures, as well as tracking all the changes made (FDA, 2008). In addition to this, it is also expected that the documentation management system is capable of identifying all the documents impacted by quality events and product changes.

Validation Protocols and Reports are fully generated on a word processor (MS Word) file. The validation related documentation contains several attachments which may be presented in different file formats (images, pdf's, CAD drawings, etc.). The integration of these files into a unique document results in a non-efficient and time-consuming process.

Considerable amount of time is dedicated to deal with an inadequately structured and configured validation documentation system. This time is non-productive, as the activities required to manage and sort out these database are not value-adding and do not contribute to the overall success of the process validation.

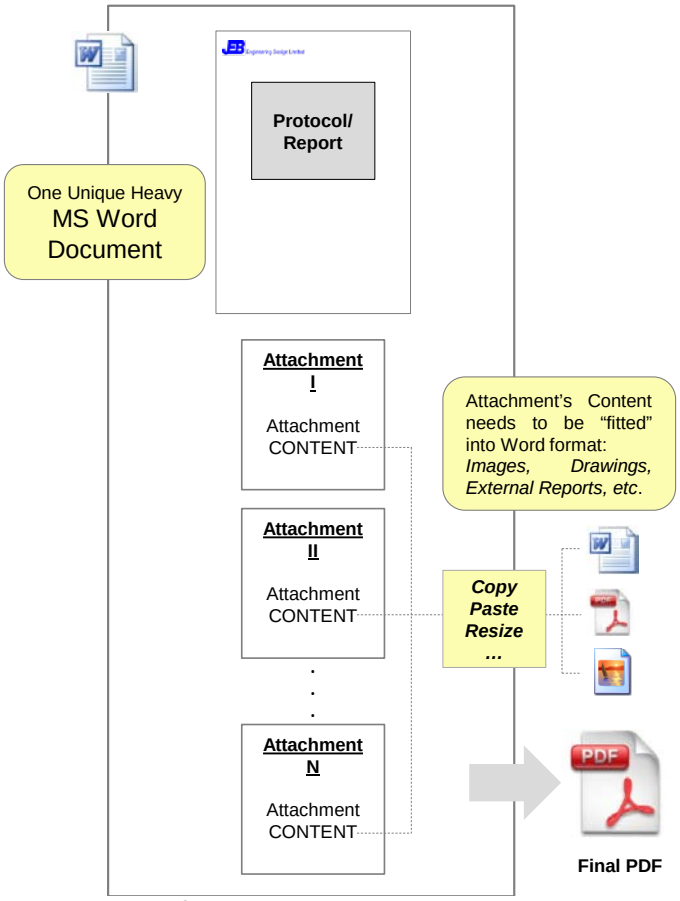

Figure 4.4. Document structure

In addition, documents are not correctly structured and configured, they do not exploit all the advantages of documentation software, making more difficult and tedious the protocol and report drafting process.

Finally, some difficulties have been found with the distribution and revision control of documents and drawings that should be solved to avoid possible future non-conformances.

4.3.2. Risk assessment

A risk assessment analysis (pFMEA) is one of the customer's requirement prior to the completion of the PQ.

Although this activity is currently covered by the company procedures, the actual process does not follow the provided guidelines; resulting in considerable deviations and approval issues, delaying the final stage of the validation and acting as a *bottle-neck.*

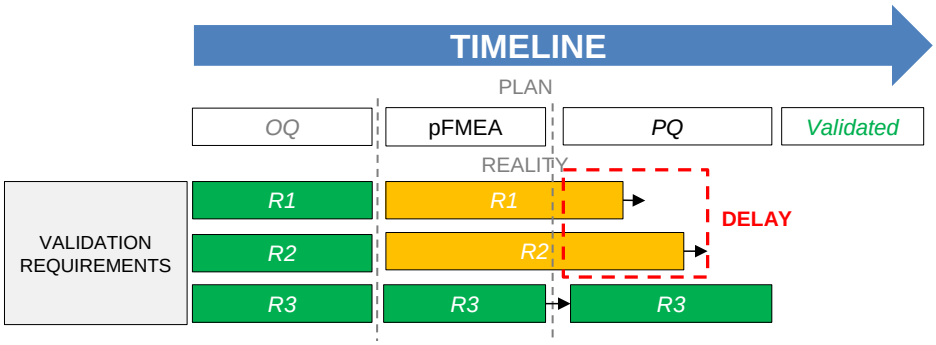

Figure 4.5. pFMEA – OQ Transition

4.3.3. Communication

Communication methods and procedures need to be developed within the company. It has been observed that some orders and requests procedures (production runs, test activities, calibration, engineering change requests, etc.) are not totally effective, resulting in unnecessary delays and potential causes of confusion and errors.

It has been also detected that there is a communication disconnection between the Quality Assurance Department and other functional areas within the organisation, generating an obstacle or barrier. Documentation are not in a standardised format, wording or either location; resulting in possible difficulties in interpreting the commands, not providing or prioritising the appropriate resources to resolve quality issues and, consequently, impacting the result of the product.

Figure 4.6. Communication scheme

Communications with the customer is not as fluent and easy as desirable; there are no standard procedures in place for validation related documentation and

requirement discussion, amendment or review, resulting in some occasions in a highly non efficient and confusing activity.

Communications with the customer are mainly managed by e-mail and conference calls. In addition to this, at the present there is a limitation with the size of the file and documents that can be sent enclosed in the messages.

Despite not being a current major issue, validation related document file-size is constantly increasing and this may become a major problem in the future.

4.3.4. Identification and traceability

Despite not recording any major issues or non-conformances, it is has been suggested by the customer and external audits that the tool and calibration databases, component identification and traceability (parts, raw material, tooling, etc.) should be improved.

Procedures developed in this field will be focused to meet the requirements provided by the FDA, which states that medical device manufacturing companies shall maintain a system to track all materials and associated suppliers used in production, in order to ensure the quality of the final product. (FDA, 2008)

In addition to this, a current objective of the organisation is to step forward and implement a barcode or RFID technology based solution. A case-study and implementation feasibility analysis is suggested to be performed before taking any further decision.

4.3.5. ERP software

Although there is an Enterprise Resource Planning (ERP) system in place in the organisation (SYSPRO), it is not fully implemented within all the departments and divisions of the company.

The total implementation feasibility of an ERP solution has been suggested by external auditors to be evaluated as an improvement in the IT structure of the company.

4.3.6. Personnel

During some periods of the validation process, a considerable amount of activities are accumulated, resulting in workload peak-demands that may overcome the personnel availability.

4.3.7. Training

Training in validation related software (i.e., Statistical Process Control Software) and other computer skills (e.g. ERP) should be considered for all the personnel involved in process validation.

The training and qualification offer available for the personnel should be expanded, as well as the tools and resources related to them: facilities, material, offer, trainers, IT network, etc.

4.4. VALIDATION OF RESULTS

In order to validate the results obtained from the internal analysis, a workshop involving several experts and stakeholders across the company responsible for the development and manufacturing of medical devices was organised.

This expert's panel was composed by:

- Managing Director
- Quality Assurance Manager
- Design leader Engineer
- IT Manager
- Test lead operator

4.5. SUMMARY

As a summary for the internal analysis of the sponsor company, the target and development expectations are condensed in the following bullet-points:

- Achieve a highly efficient Documentation Management System and reduce the amount of time and work-load spent on non-value-adding activities, such as documentation system corrections, amendment and control.
- Develop a reliable validation process monitoring system in order to obtain a real-time status of the process, enabling better control of the workflow, provide accurate quality information to the decision-makers, better resources allocation and gaining transparency.
- Set up a dynamic communication procedures between the different players involved in process validation, focused on assuring the correct and efficient information collection and sharing.

The following table summarises the results of the internal evaluation of the company's process validation current practices performed during the first stage of this research project.

PERFORMANCES	P1	Documentation
	P2	Risk Assessment
	P3	Communication
	P4	Identification
RESOURCES	R1	ERP
	R2	Personnel
	R3	Training

Table 4.2. Internal Analysis Results: Improvement areas.

Despite these minor issues; all of them related with resource management, performance level and process efficiency; it can be concluded that the overall valoration of the current practices in process validation is “Good or Very Good”, as stated by current customers and external parties.

It can be pointed out that no issues were found in relation to the manufacturing techniques or test procedures, which would affect the product reliability, resulting in serious non-conformances on the process validation and major complains from the customer.

5. BENCHMARKING STUDY

5.1. INTRODUCTION

This chapter describes how the benchmarking study for the identification of the best practices within the aerospace sector relating to process validation was performed.

First of all, this section establishes the partner selection criteria, which was based on the considerations defined during the definition of the research scope. Then, it details the data collection methods used and its different sources. Once the information was collected, the analysis of the findings and outcomes of the study was performed, resulting finally in a set of practices that were proposed to the company for their implementation within the organisation procedures. However, prior to this integration step, the set of proposals were evaluated and validated by a panel of experts based on the knowledge of the internal procedures of the company, industry and work experience.

5.2. COLLABORATORS SELECTION

As defined in the scope of this research project, this benchmarking study will consist in a cross-industry evaluation which will focus on capturing the leading practices within the aerospace sector regarding the process validation activities.

In Figure 5.1, it can be appreciated a concise scheme that illustrates the abovementioned criteria.

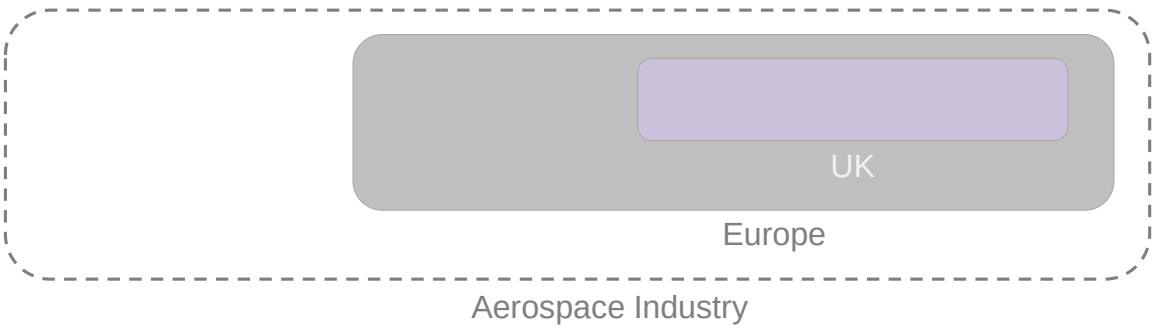

Figure 5.1. Desired information capture framework

In first place, the study boundaries for the collaborators were set within the UK aerospace and defence manufacturing industry. However, by following the benchmarking literature review, which states that it is not always possible to obtain the desired information within a predefined and immobile area (Zairi, 1996; Codling, 1992), these limits required to be widened and other aerospace organisations in the European Union were considered. It was decided that if only limited information could be gathered from the previous range, collaborators scope limits could be opened again and any aerospace industry company across the world could be considered for the purposes of the benchmarking study. Finally, in a last iteration, in the eventual case that no information at all could be gathered, other close-related industries would be considered.

5.3. DATA CAPTURE

Once the collaborators selection criteria was established, the next step of the benchmarking study consisted of defining the best data collection methods according to the purposes of this research project.

Prior to the introduction of the different information capture methods, the characteristics and nature of the data that this research project required was evaluated. Owing to the particularity of the study, focused on learning the leading practices from a sector (aerospace) and translating them into a company which operates in another one (medical device) (Camp, 1998), it was concluded that the qualitative approach would be the one that fitted the best for the purposes of this project.

In contrast with quantitative research methods, which are focused on the elements that can be measured and directly compared, qualitative methods involve subjective and opinion driven information, where observations are tested in order to derive a conclusion and build a solution (Rolstadas, 1996).

Different data capturing tools and methods were developed focused on gathering qualitative type information.

Figure 5.2 illustrates, with the same idea-behind as previously showed in the Literature Review section, in a pyramid-shaped diagram, the different benchmarking data collection methods and their valuation according to two different criteria; the resource and investment requirements to perform the study and the value and relevance of the information that could be obtained through them.

Figure 5.2. Information capture methods (Andersen and Pettersen, 1996)

Due to the characteristics of the information that was being sought, the particularities of the research project, the time and resource constraints and other external factors, such as the availability or willingness of the potential collaborators to take part in the study; not all of these methods were used by the author for the purposes of this research. Particularly, only the public available resources and live interviews were considered.

5.3.1. Publicly available information

The data collection methods used for this research that can be classified into this segment are:

- Literature: books, journals, papers, articles, specialised magazines, etc.
- Conference papers and presentations
- On-line Benchmarking Best Practices databases
- Professional association websites and forums
- Corporative brochures and websites

- Technical reports

5.3.2. Interviews

A series of live interviews with different participants from the aerospace sector were undertaken for this research project. These collaborators were chosen according to different criteria such as their role within the organisation, years of experience, business activities of the company, level of involvement within process validation activities, willingness to take part in the study and their availability.

A first contact was made via e-mail and/or telephone in order to set up an upcoming meeting, live conference call or on-site visit, whenever this was possible.

Due to the characteristics of the information given, involving organisation internal procedures and details, for the benefit of confidentiality, none of the participants and/or the respective companies involved in these interviews are named. The following table provides a brief description of each of the participants.

Company	Area	Activity	Role	Years of experience
A	UK	Aerospace 1st Tier supplier.	Design Team Leader	14
B	UK	Aviation Maintenance Services	Quality Assurance Engineer	10
C	Europe	OEM	Quality Assurance Engineer	8
D	Europe	OEM	Manufacturing Engineer	6
E	Europe	Aeronautical 1st Tier supplier and Consulting Services provider	Consultant Engineer (Structural design department)	6
F	Europe	Technology Consulting Company (Aerospace)	Consultant Engineer (Product life-cycle)	7
G	World	Technology Consulting company (General)	Consultant Engineer (Technological risks)	4

Table 5.1. Benchmarking Interview Participants

The benchmarking interviews were conducted using a semi-structured questionnaire (see Appendix II), which can be classified into three main information areas:

- Introduction

- Process Validation
- Resources.

The introduction part encompassed general information questions aimed at capturing broad information about the participant and his role and responsibilities in the organisation.

The process validation part focused on the practices and procedures employed by the interviewee and his/her organisation in the achievement of the different requirements and deliverables within the validation stage. Questions involving the main difficulties found along the validation stage or the human resources, such as team organisation and role assigning for the activities of this phase were also included.

Finally, the last part of the questionnaire was intended to provide a general idea of the different means, tools and resources available for performing the prior activities.

5.4. KEY FINDINGS

Information was collected and documented conveniently, building a consistent knowledge database.

The Table 5.2 summarises the results and key findings of the benchmarking study and provides an overall opinion of the sources and the quality of the data gathered for each of the information areas defined at the Internal Analysis stage.

		Doc.	Risk	Comm.	Id.	ERP	Staff	Train.
Partners	UK			●	●	●		●
	Europe	●	●	●	●	●	●	●
	World		●			●		
	Other	●						
Methods	Visit	–	–	–	–	–	–	–
	Interview	↑	↓	↓	~	↑	↓	↑
	Survey	–	–	–	–	–	–	–
	Public Information	~	↑	~	↑	↑	~	↑

↑ Very useful ~ Useful ↓ Barely useful – Not performed / No results

Table 5.2. Benchmarking Study Summary Table

At first glance, it can be appreciated that where a method resulted to be “weak” in obtaining the desired information in a specific area, this was properly covered by another one, resulting in a successful combination of data gathering methods

Going further on, it can also be pointed out the fact that, although being defined as a highly helpful and accurate information capturing method, live interviews could not provide useful (and usable) data in some areas which can be considered as “delicate” regarding the privacy and confidentiality of the information, involving organisation’s internal procedures, capacities and resources.

It should also be highlighted the important role of the publicly available information, which provided good quantities of useful data for the purposes of this study and filled up those areas where live interviews did not provide any sort of information.

Finally, as the green arrows indicate in the abovementioned table, there were some cases that, despite the amount of detailed data provided, due to the particularities of the company or its business environment (size, budget, project characteristics, special regulations, etc.) and the impossibility of translating any

of these conditions; the information resulted not very useful for the purposes and the scope of this research project.

On Table 5.3, the main outcomes of the benchmarking study are outlined.

BENCHMARKING STUDY RESULTS	
Reference	*Outcome*
P1: Documentation Management	
P1.1	- Independent modules The different elements/entities that compose one document are created separately and they shall be treated as independent to each other. The final and definitive document file is then assembled and created when all the sections are completed.
P1.2	- PDF role in the process The PDF type file acquires more relevance within the documentation workflow, not only for final deliverable documents, but on a daily work basis. PDF editor software is crucial for a good management of these resources.
P1.3	- Interactive Masterlists In the organisations with no ERP implemented in the evaluated departments, documentation masterlists are widely used in order to keep organised all the relevant files. As a value-adding feature to this, according to the consulted literature review, references and hyperlinks are utilised with time saving and organisational purposes (Garretson et al., 2005). This method has been proved to be very helpful as well when large revisions of the documentation systems are carried out or quality audits are undertaken.
P1.4	- Documentation Management System (DMS) Four out of seven of the participants interviewed showed that within the organisation a DMS module as an add-on of their ERP was in

BENCHMARKING STUDY RESULTS	
Reference	*Outcome*
	place for the generation, editing and management of all the relevant documentation. By working this way, the time spent in documentation administration related tasks are taken off the user and avoiding non-value adding activities.
P2: Risk Assessment	
P2.1	- Use of FMEA All the participants confirmed that this risk assessment tool was widely used at some stage during the validation phase of a new design, resulting in a helpful method for detecting possible errors, failures and risks. It also encourages the creation of a teamwork environment where different roles and position involved in the project gather together to discuss the possible setbacks on the product development flow. However, little or no further procedure related details could be obtained through these interviews.
P2.2	- FMEA scoring criteria When recurring to the publicly available resources, the literature review performed for this research permitted to compare the sponsor company's current FMEA scoring criteria to other organisations in the aerospace industry. Moving within the same similarities area, where direct comparisons could be attempted to be done, these proved that the current criteria in place is aligned to the best-in-class practices of the aerospace and defence industry.
P2.3	- FMEA Documentation/Templates In a parallel way to the comparison of the scoring criteria, templates from the available literature review were evaluated. These comparisons showed that despite some minor modifications, a common structure and functionality is shared with the ones recommended by the consulted authors. Effective documentation provides the outcomes of the FMEA

BENCHMARKING STUDY RESULTS	
Reference	*Outcome*
	traceability of the evaluated requirements during the manufacturing process; allowing the quality management department to trace eventual problems effectively and mitigate the identified risks.
P2.4	- FMEA procedures No practical details for the FMEA procedures were obtained from the live interviews with any of the participants. The sponsor company's FMEA framework was compared to other procedures available in the literature. It was found that some variations in the pre and post analysis meetings, as well as the resources (time, software, teams) invested in this process may lead to sound improvements in the current work flow. In particular, it needs to be highlighted the figure of the "Analysis Conductor" or "Facilitator", who is identified as the responsible of managing the process and enhancing the effectiveness of the analysis. This role shall exceed in organisation, participation encouragement and discussion management skills (Dyadem, 2003)
P2.5	- FMEA software As a result from the interviews, in three of the organisations consulted dedicated software for the FMEA stage is used and widely extended, resulting in a dynamic and user-friendly process where participants are able to concentrate in the analysis rather than in the documentation generation. In the other four, according to the interviewees, due to the characteristics of their projects, the number of analysis required for the process and the extension of these; a standard MS Excel based spread-sheet template proved to be sufficient for their purposes.
P3: Communication	
P3.1	- On-line Video-conference calls Four out of the seven consulted participants, when meetings or conference calls are required with external branches of the

BENCHMARKING STUDY RESULTS	
Reference	*Outcome*
	organisation or customers, in order to deal with major updates, changes or critical reunions are required to be held; on-line live video-conference calls are set up for these purposes. Taking advantage of the current status of software, hardware resources and internet connection properties, several service providers and platforms are available for hosting these events. It is commonly agreed that these have been resulted in increased efficiency, time saving, constructive and positive experiences.
P3.2	- Review Stages Down the workflow of the documentation draft and generation process, several review stages are established prior to the approval release (BMP: CoE website, Lockheed Martin; Hasson et al., 1997). In these reviews, different parts of the department responsible for the document generation are involved in with the objective of assuring the accuracy, error-free, quality and correction of the documents produced.
P3.3	- "In-cloud" services It is considered as a new data and information sharing method as a reliable alternative to the common ones based on Intranet server based services.
P4: Identification and traceability	
P4.1	- Shop floor data collection Five out of seven participants stated that shop floor data collection methods were widely used across their organisation, being the job cards or variations of this concept the most common method. Particular procedures and examples for these data collection method are also covered by the extensive literature review performed (Watts, 2008).
P4.2	- Bar-codes As a main input method for the abovementioned shop floor data collection method, bar-coded systems was used by all the organisations of the interviewees.

BENCHMARKING STUDY RESULTS	
Reference	*Outcome*
	Benefits resulting from bar-code implementation include the elimination of operator key strokes, elimination of record-keeping errors, improved work environment, reduced cycle time/efficiency (Raytheon, 2005)
P4.3	- RFID technology RFID technology allows information to be stored in tags that are attached to components providing the opportunity to transform the mean that data related to products and equipment is gathered and analysed in real-time. Within the four companies that are directly involved in manufacturing and maintenance activities, keeping track and located the vast array of specific tooling and jigs in their facilities represents a big challenge. When performing a 100% tool check manually is non-feasible, automatic identification technology based in RFID was concluded as the best solution.
R1: ERP	
R1.1	- Total Implementation All the participants of the interviews assured that an ERP solution was implemented within their organisations. In addition to this, total implementation was an actual fact within all the departments related to validation processes (manufacturing, production, quality assurance, procurement) According to the collaborators and the literature review (Parry et al., 2003), the main benefits from ERP total implementation are having a greater control and visibility of the manufacturing related activities, real-time access to accurate data, improved forecast, better resources allocation and cost management
R2: Personnel	
	- Human resources Depending on the characteristics of the organisation analysed and/or interviewed, a diverse range of answers were obtained regarding the

BENCHMARKING STUDY RESULTS	
Reference	*Outcome*
	availability and distribution of human resources, the assignation of responsibilities and the specific tasks and activities of the departments and roles involved in process validation.
R3: Training	
R3.1	- Training catalogue All of the organisations have implemented a training catalogue where different courses, trainings and workshops are offered to their employees, which are able to consider and select the appropriate one according to a set of specific factors, such as their level, skills or shift availability. In addition to this, it has been regarded the importance of the role of the trainer, being motivation and communication skills critical for an appropriate connect and knowledge transmission.
R3.2	- On-line training resources Two of the organisations have incorporated on-line corporative tools for personnel development. This way, the responsibility of skills and capacities development is transferred to the own individuals. The e-learning framework and catalogue is available on the corporate intranet, where employees can access to their specific set of skills and select the desired training course.

Table 5.3. Benchmarking Study Results

Regarding the development area R2: Personnel, it requires to be highlighted that it resulted unsatisfactory and no relevant results were obtained from the benchmarking study and the posterior analysis due to a various set of reasons, including the differences in relation to the size of the companies interviewed and the sponsor company, the functional structure and the particular characteristics of the projects.

5.5. DATA ANALYSIS AND PROPOSALS

The stage that follows the information collection and documenting is the analysis of the outcomes of the study; which is focused on obtaining, from this outputs list, a set of elements and practices that could be successfully translated to the sponsor company own procedures.

For this exercise, two different sets of factors have to be taken into account:

1. Implementation feasibility and benefits expected.
2. Organisation internal factors.

In the first group, the following information, perspectives and criteria have been considered for this analysis:

- Consulted literature review
- Reports and previous area related publications
- Participants professional experience

On the other hand, regarding the factors associated to the organisation, a totally different group of parameters had to be considered:

- Time and material resources available
- Engineers, operators and other employees' implication
- Management level commitment
- Customer requirements and expectations
- Regulatory authorities' compliances.

As a result of this, a set of scores related to the benefits expected from the implementation and its complexity (defined as the amount of effort required or type of resource needed) have been established in order to evaluate each of the outcomes of the benchmarking study. On Table 5.4 the results of the assessment are summarised.

BENCHMARKING RESULTS ANALYSIS				
	Ref.	*Finding*	*Benefit*	*Complexity*
P1 Documentation	P1.1	Independent modules	4	1
	P1.2	PDF role in process	4	2
	P1.3	Interactive masterlists	4	2
	P1.4	DMS	4	4
P2 Risk Assessment	P2.1	Use of FMEA	-	-
	P2.2	FMEA scoring criteria	-	-
	P2.3	FMEA Documentation/Templates	5	1
	P2.4	FMEA procedures	4	2
	P2.5	FMEA software	2	4
P3 Communication	P3.1	On-line Conference calls	3	2
	P3.2	Review stages	5	2
	P3.3	In-cloud services	4	2
P4 Identification	P4.1	Shop Floor Data Collection	5	3
	P4.2	Bar-codes	4	4
	P4.3	RFID technology	1	5
R1 ERP	R1.1	ERP Total implementation	2	5
R3 Training	R3.1	Training catalogue	4	3
	R3.2	On-line Training resources	4	5
(Benefit 1=Low, 5=High; Complexity 1=Low, 5=High)				

Table 5.4. Benchmarking outcomes analysis

A first conclusion that can be withdrawn from this matrix is what it is called as the “instant winners”, those practices which share a green-green shade on their valoration columns: by their integration, a wide range of benefits are expected with a little resource and effort investment required.

5.5.1. Documentation Management

As it can be appreciated on the previous matrix, results related to this area were found within the extensive literature review, corporate website visits and live interviews, being the later the one which provided the most useful resources for the purposes of this project.

Regarding the documentation management practices, all the entities analysed share the philosophy of keeping a clear, structured and user-friendly documentation system in order to provide a powerful tool for all the reporting and information generation related activities.

As a common characteristic of all the organisations within the aerospace company, documentation management (protocols, technical reports, drawings) plays a critical role in keeping ordered and updated all the documented evidences involved in the development of a product.

An efficient process validation revolves around a structured and well-based documentation system, owing to the fact that these files will give evidence of meeting all the requirements given by the customer and regulation authorities, being these elements the one which would be reviewed if any issues are raised during the lifecycle of a new product.

The main proposals for this area are summarised in the following bullet-points:

- New documentation structure; commencing with process validation related files and progressively implementing across other departments and functional areas of the organisation.
- Masterlists with hyperlinks
- Update / Procurement of documentation edition and management software
- Quality control Database: review and update QMS documentation procedures. Documentation revision control. QMS should be published electronically on the intranet for accessible consulting.

In order to comply with possible future regulations, the documentation system should be provided with controls to ensure integrity, accuracy and reliability of the information, especially the documented evidences related to process validation. Moreover, the system shall provide some type of audit trail to prevent and detect un-authorised creation, addition, alteration or deletion or records.

5.5.2. Risk Assessment

The interviews proved what the literature review had previously stated, the fact that the Failure Modes and Effects Analysis (FMEA) is a practice widely implemented within aerospace companies and owing to its success it has been gradually adopted by other sectors, such as the medical device industry.

Following the guidelines provided by the literature review, a new template for the FMEA analysis is proposed in order to capture all the information required, provide more dynamism to the evaluations and enhance the achievement of results.

In addition to this, the sponsor company's procedures relating to this risk assessment process should be considered to be updated and the figure of the Facilitator or Champion introduced.

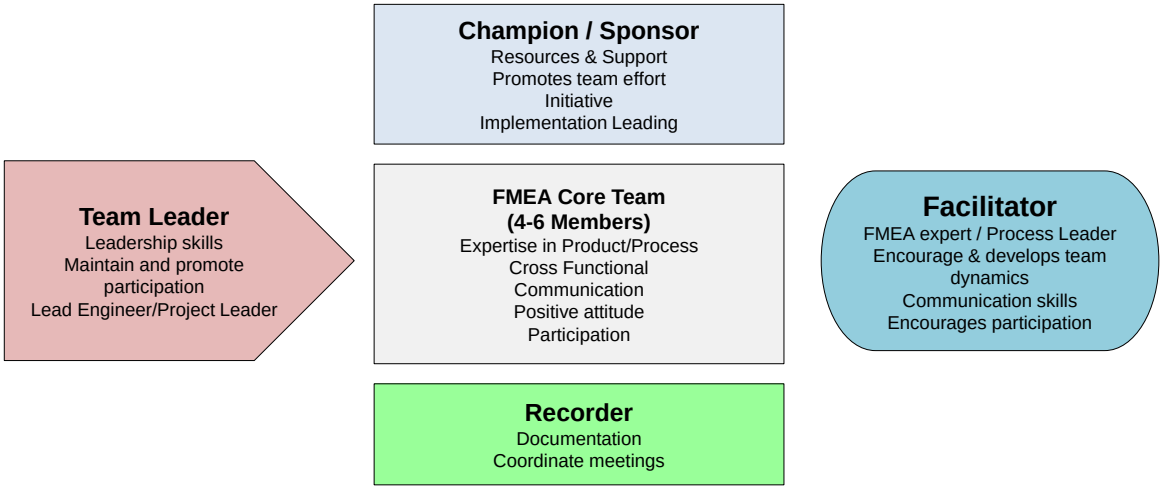

Figure 5.3. FMEA Analysis Panel (Northrop Grumman, 2012)

5.5.3. Communication

With the aim of improving the communication framework within the sponsor organisation, from the outcomes of the benchmarking study two different fronts were identified for this purpose:

1. Procedures review, gap analysis, improvement opportunities and update
2. Resources allocation

Procedures updates proposed include:

- Team meetings and panel analysis review prior to critical points in the schedule, non-conformances or any major changes to the product.
- Additional review stages prior to the release of any documentation.
- Regular (weekly) Project status review meetings at critical stages of the schedule, major deliverables, high concentration of activities.
- Regular (weekly, monthly) advisory circulars with project status, summary, upcoming events, etc.
- Quality Management System manual, procedures, instructions made more accessible to the employees.

Resources:

- Web based “in-the-cloud” information sharing applications
- Video-conference calls technology
- Quality Management System Intranet

5.5.4. Identification and traceability

In terms of improving the identification and traceability aspects, the first milestone should be the implementation of shop floor data collection methods to capture the different parameters involved in the process, which would provide, on one hand, a more accurate image of the manufacturing workflow and efficiency indicators, and on the other hand, it would meet the FDA requirements for full-traceability system, providing information from way back through the production process, including operator, machine, lot, material batch, inspection reports or raw material supplier.

A shop data collection method enables information from the factory floor to be collected and collated electronically. As each operation or activity is performed, the relevant information is captured by the operator.

- Estimated times for jobs and operations
- Quality tolerances
- Labour and quantity costing
- Automatic job receipt, material issue, lot and serial number entry

- Real time information and validations

A step further on the development of the shop floor data collection methods, considering a mid-term scenario, would be the implementation of a bar-code based system, which would enhanced the data capturing capacities by reducing cycle times, increasing operator's efficiency and avoiding mistakes originated by hand-writing.

The higher costs comparing to bar-coding solutions, the need to re-structuring and re-engineering the process, and above all, the current characteristics of the sponsor company's manufactured devices, lead to consider RFID systems as a non-feasible solution, at present.

5.5.5. ERP

The total implementation of an ERP solution within the company would assist in centralising all current systems into one database within the network, providing the ability to manage almost all the department key activities.

Particularly, the area concerning the process validation, the Quality Assurance module, would allow to define procedures, tests, audits than can be triggered directly within the system, capturing and processing the specific data. In addition to this, it will also contribute to the system full traceability, enabling the automation of looking back through production (machines, operators, inspection reports, raw material supply, etc.) activities; instead of the current hand-operated and time consuming tasks.

However, during the analysis stage, it has been concluded that the cost involved in implementing the ERP solution into the Quality Assurance department, responsible for process validation activities; plus the costs related to the personnel training and module development required to replace the current system would be huge. As a result, the total implementation of the ERP across the department is discarded for the short and medium term.

5.5.6. Personnel

Due to the particularities of this resource area, unsatisfactory and no relevant results were obtained from the benchmarking study and the posterior analysis. The reasons that lead to this outcome included the differences in relation to the size of the companies interviewed and the sponsor company, the functional structure and the particular characteristics of the projects.

5.5.7. Training

According to the interviewees, despite the infrastructure, financial resources and other elements, the success of an organisation depends finally on the capacities of their human resources and their development within the work environment.

This way, training and personnel development are key factors that any company must consider when facing new challenges and improving their performances.

Back to the literature review, it was previously stated that one of the factors that difference between validated and non-validated processes is “Qualified Operators” (O’Leary, 2003).

This highlights the relevance that personnel training (and qualification) plays within the process validation.

Following the analysis, recommendations and results from the benchmarking study, a corporate skill development program is proposed to the sponsor company, which should cover the essential skills learning, advanced developments and corporate culture.

Currently, regarding the process validation activities, only an ISO 13485:2003 training course is given by the department. Following the outcomes of the benchmarking study, a wider catalogue of workshops, courses and activities are proposed:

- IT skills (General, documentation, Statistical analysis, etc.)
- Introduction to regulatory framework (FDA, GMP, GHTF, etc.)
- Risk assessment
- Quality culture

5.6. VALIDATION OF RESULTS

The objective of this section is to validate the obtained results in the previous benchmarking study through a relevant method and looking for its implementation within the sponsor company.

Once the benchmarking study was performed, a continuous process was carried out involving several personnel from the sponsor company in order to validate the results obtained.

For the results validation purposes, two different workshops were carried out involving a group of experts from different department, roles and management levels across the company.

As a first step, five key experts were identified for an initial validation of the outcomes of this phase. This panel was composed by the Quality Assurance department manager, a quality assurance engineer, the production manager, the design leader engineer and the IT department manager. Their previous experience and opinions created a first opinion for the validation of these outputs. It requires to be highlighted that when defining and developing new procedures, it is crucial to validate and authenticate the practices with the organisation and its employees in order to ensure that the requirements are met and no conflicts arise from their implementation.

For final validation of the results, the principal members of the team involved in the medical device process validation stage reviewed its application and the different procedures and resources were assessed to ensure agreement. This panel included a manager, two engineers from the Quality Assurance Department, the medical devices test lead operator, the design engineer and the managing director of the organisation.

This process was done with both management level positions, in order to secure integration with the organisations procedures, and also with the specific product validation teams and operators, in order to guarantee the usability and applicability of the solutions.

5.7. SUMMARY

This chapter has described the benchmarking campaign process, giving an overview to the main activities carried out in order to collect the necessary information, the analysis of the outcomes and key findings of this study, the generation of a proposals list and its final validation by a panel of experts composed by members from different departments, roles and management levels across the organisation.

6. IMPLEMENTATION

6.1. INTRODUCTION

Due to the diverse nature of the practices, procedures and solutions resulting from the benchmarking study, these elements have highly different set-up requirements, both in time and resources, generating a diverse group of actions and milestones required for their effective implementation and monitoring within the company.

The effective implementation of new practices and ways of working is not an easy road, as demonstrated by previous experiences. From the literature review, the following figure depicts the results of a benchmarking study in relation with the process improvement within an organisation. From the number of responses allocated to each of the reasons, it can be appreciated that the majority of the interviewees consider the *lack of human resources to implement changes* as the primary source (Dolan, 2003) of improvement issues, followed by the *acceptance of results by the departmental managers*.

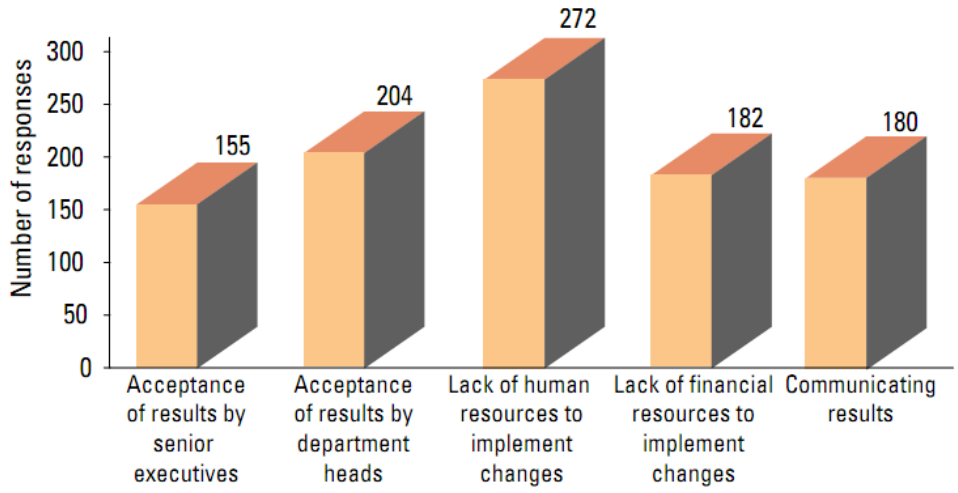

Figure 6.1. Benchmarking Survey: Process Improvement Problems (Dolan, 2003)

This section, which will assess the implementation feasibility of the proposals, is divided into 2 groups:

- Short term recommendations
- Long term considerations

The first group will be formed by those practices and procedures which will provide improvements in a short period of time and are associated to a small amount of resource investment requirements. As it has been mentioned before, the “instant winners” are classified into this group.

On the other hand, the long term recommendations are the ones which would require higher levels of time, financial or other type of resources, in other words, a great commitment from all the parts involved, for their proper implementation; or those in which associated benefits and expectations would not be appreciated in a short period of time.

6.2. SHORT TERMRECOMMENDATIONS

This section includes the different practices which implementation and integration within the company’s procedures are expected to provide the best results and improvements on a short term scenario; while a low amount of resource investment would be required.

Due to this, during the research period of this thesis, some of these practices have been effectively implemented and monitored, providing useful information and proving correct some of the results of this study.

6.2.1. Documentation system management

New documentation generation and management related practices have been effectively implemented during this research project period.

It has been demonstrated that the new framework provides the capacity to achieve time reductions of up to 90% in the generation of process validation related documentation; by spending little resources in software purchasing and training.

In order to illustrate these new procedures and approaches, Figure 6.2 describes the new documentation structure for the validation related protocols and reports, showing how each element of the file are managed prior to their approval release.

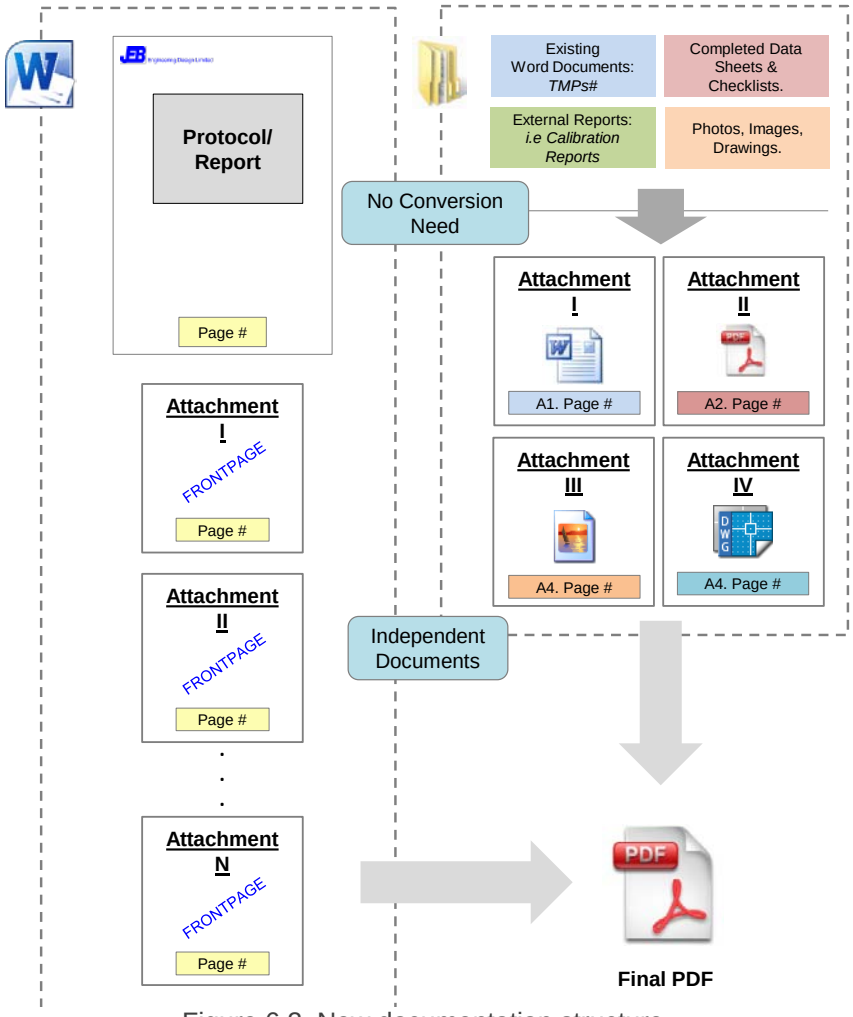

Figure 6.2. New documentation structure

6.2.2. Identification

The implementation of “Job Route-cards” provides the ability for shop floor data-collection within the manufacturing process, which will result in clearer and more accessible information for the subsequent process validation stage.

At the end of this research period, first steps have been taken towards the implementation of this procedure within production. A template for the Shop Floor Data Collection card has been validated by the engineers and operators involved in the manufacturing process. The content and data-fields of the card has been linked to the information database through the current production ERP system, assuring the accuracy of the data and providing performance metrics, transparency and full-traceability.

6.2.3. Communication procedures

One of the factors identified in the benchmarking analysis which has enhanced the efficiency and quality of the validation process and other related ones in the company is the update of the flow of communication and information within the relevant department.

This is way this area required the most immediate action at the manufacturing company, hence it is highly recommended that the flow of information between the departments involved in process validation, quality assurance and production, in particular shall be improved.

In order to address this challenge, several modifications were made during this research project period:

- Update of internal procedures: e.g. confirmation meetings acting as “checkpoints” before major changes during the work-flow, intermediate and final review stages for newly produced documentation.
- Implementation of new communication channels: improvement of current IT infrastructure, implementation and use new on-line collaborative software tools and “in-the-cloud” services.

6.2.1. Risk management

During this research project period, FMEA related procedures and work-flow were updated in order to address the outcomes of the benchmarking study. For example, Figure 6.3 shows an updated template for the FMEA analysis, which contributed in simplifying the process, minimising the time spent on documentation activities and enhancing this risk assessment process within the organisation.

In addition to this, the number of participants and different roles involved in the several analysis performed along the project was increased; resulting in more opinions and point of views for the different requirements evaluated in this process.

Although, in a first moment, this resulted in an increment of the time spent on the meetings, the extra-resource investment resulted very useful.

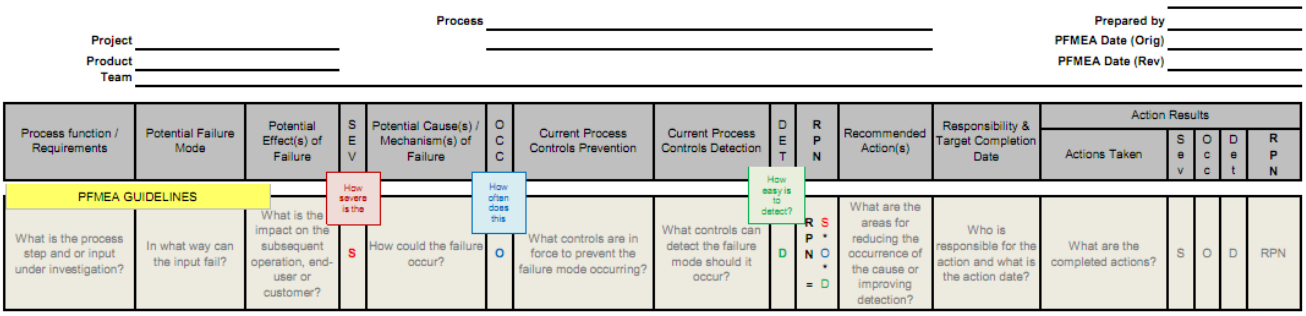

Figure 6.3. FMEA Template

6.3. LONG TERM SCENARIO

In a similar way to the previous section, this one covers the practices which implementation and integration within the company would require:

1. High amount of resources investment, effort, time or analysis due to its complexity, and/or;
2. Benefits would be only appreciated after a reasonable period of time after the integration of such practices

This way, a long-term scenario picture is depicted, requiring great commitment in both terms of resources allocation and management level consideration.

6.3.1. ERP

As it has been pointed out in along the benchmarking study, a total implementation of ERP system across the organisation would improve the efficiency and create an enhanced visibility of the different actions during the validation stage, providing transparency to the quality related issues, increasing the reliability of the documentation management, reducing risks and removing non-value adding processes to improve the efficiency of the department/s.

However, opinions from the expert panel and external parts consulted reveal that the total implementation of the ERP solution across the relevant department/s involved in process validation might be an area which would require further assessment due to the huge investments associated.

6.3.2. Training

The amount of resources required for developing a training course catalogue moves this proposal to a long term scenario.

6.3.3. Identification: Bar-code system

The total implementation and successful integration of the previously mentioned Shop Floor Data Collection Cards will act as a trigger for the adoption of a bar-code based capture solution and enabling the maximum optimisation of this resource.

6.4. SUMMARY

This chapter has described the recommendations and considerations that need to be taken into account in order to implement the identified best practices within the organisation. Depending on the benefits expected, the time-frame considered, the complexity and the resources required, two different groups have been created.

7. DISCUSSION AND CONCLUSIONS

7.1. INTRODUCTION

This final chapter describes the conclusions of this research project, showing the main research results, outcomes and potential benefits for the sponsor company and the related industrial sector community.

A final evaluation of the research methodology is made and the subsequent findings and achievements of this project are summarised.

In addition to this, the assessment of the contribution to knowledge is depicted based on the completion of the initial aim and objectives of this research project and the knowledge gained through its several phases.

Finally, the applicability of the research results is evaluated and it is concluded with the discussion and recommendation of potential related work and projects in this area.

7.2. METHODOLOGY DISCUSSION

The qualitative research methodology selected for this project has proved successful in capturing the required information to sketch and define the approach to the solutions for the defined objectives at the start of the project.

First of all, the literature review has been helpful in identifying the first elements that should be considered when facing a benchmarking study and cross-industry practices translation project, highlighting the importance of selecting the right methods and participants and providing an adequate number of case studies, previous benchmarking databases and specific practices.

The sponsoring company internal analysis reviewed the organisation current practices, procedures and available resources for the process validation stage. This analysis provided the assessment of the current status, identified the improvement areas and defined the scope and considerations for the benchmarking study.

This extensive review was complemented with a cross-industry benchmarking study, which evaluated the process validation practices in the aerospace industry and the different procedures, resources and particular characteristics involved at this stage. In order to carry out this study, semi-structured questionnaires were adopted as the best tool for capturing the qualitative information and it can be concluded that these have been very efficient methods for this purpose, acquiring the opinion and information given by different representatives across the sector. The variety of roles and participants consulted provided several options of facing the same problem and permitted the definition of a wider scheme of solutions. In order to check that the obtained solutions were the most appropriate ones, complete validation of the outcomes was performed with experts' opinion.

Finally, the implementation within the organisation's internal procedures of the results of this study was carried out, providing some practical real-life experience to the outcomes of this research. Due to time and resource considerations, not all the proposals were integrated in the sponsor company by the end of this period.

The main limitations of the followed methodology for this research project were, first, the lack of any quantitative analysis or numerical method for comparison, which would have permitted a more accurate evaluation of the different practices and/or resources used during the validation stage. In addition to this, for the benchmarking study, the use of other available methods, such as on-line surveys or more on-site live visits would have provided a wider range of information and further richness for the purposes of this study.

7.3. RESULTS DISCUSSION

The aim of this research project was *to perform a benchmarking study of the best practices within the aerospace sector for the development of an efficient process for the validation of medical devices.* This aimed was achieved through a four-stage methodology focused on completing the four objectives established at the beginning of the research project.

- *Evaluate the current procedures for medical device manufacturing, looking for gaps and improvement areas.*

This objective was completed through the internal analysis stage, which identified the improvement areas for the sponsor company, as it has been described through the company internal analysis chapter (section 4) of this thesis.

- *Perform a cross-industry benchmarking study in order to identify the best practices for the validation process.*

The benchmarking study took into account the outcomes of the internal analysis and identified within the aerospace sector the best practices for the process validation stage, resulting in a set of procedures and resources that will contribute to the improvement of the performances of the organisation, as it has been described through the benchmarking study chapter (section 5) of this research project thesis.

- *Carry out validation, embedding assessment and implementation feasibility analysis of the identified methods.*

The results of the benchmarking study were evaluated and new practices and procedures were validated by a panel of experts formed by different key roles within the organisation and the process validation phase, resulting in a list of implementation proposal for the sponsoring company.

- *Develop a set of guidelines for the implementation of the new practices*

This objective was achieved by generating a set of guidelines for the proposals implementation, as it has been exposed through the implementation guidelines

on the section 6 of this thesis. Two different groups were identified, the short term recommendations, which would provide benefits and improvements on a short time scenario with a little amount of resource investment; and the long term considerations, which expected improvements and/or complexity required longer times or larger amount of resources.

7.4. CONTRIBUTIONS

This research project puts into light a key aspect of the current industrial practice that affects to multiple sectors. Due to the increasing complexity of the products and the wider offer available, the medical device manufacturing organisations admit the importance of successful product development and the necessity of its optimisation. Within this process, the validation stage plays a crucial role that requires to be addressed before the production and commercialisation of the newly developed solution.

The outcomes of this research project are based on an analysis of the leading practices of process validation across the aerospace industry and promotes the identification of:

- The key points and procedures within the process validation stage in order to ensure the manufacturing of highly reliable and quality products.
- The practices, knowledge and resources required to optimally address each activity through process validation.
- The interactions and exchanges between these factors and how they shape and modify the process validation.

In this way, appropriate procedures and resources required to make these happen are potential sources for the efficiency in the process validation stage.

It has been demonstrated that organisations operating in the aerospace and defence industry have mainly adopted automated management solutions within the four main activity areas; documentation management, quality management, product and programme management and review process, resulting in dramatic improvements in the business performance and compliance with their relevant Regulatory Authority requirements.

On the other hand, medical device companies, while still delivering the required compliance, are still using combinations of paper-based processes and discrete IT solutions. The sponsor company uses a robust and consistent process validation strategy which has been proving to be successful when dealing with customer's requirements; but the inadequate definition of some procedures result in a loss of valuable resources in non-value adding activities. Although correct decisions were made regarding the major points in process validation, the derived and subsequent activities were not optimised.

The thesis pointed out the relevance of the configuration management related tasks within an organisation and its influence on the major activities of the business.

7.5. FUTURE WORK

It can be said that the principal limitation of the adopted approach was the lack of a quantitative or numerical analysis, due mainly to the diverse characteristics of the elements that were being compared. However, once particular areas have been highlighted in process validation, a numerical method for rating the different parameters involved may be helpful in assessing the effectiveness the adopted practices.

As a further development of the previous statement, by dealing with specific case studies, such quantitative analysis and direct comparisons and measurements could provide more accurate data regarding the different improvements obtained from their implementation.

Further research activities could be performed within the new process validation framework recently released (2011) by the FDA, evaluating and addressing the new challenges that medical companies need to face and the internal updates of the organisation associated with these changes (philosophy, procedures, resources, etc.). In a similar way to the aim of this thesis, learning from aerospace and implementing into medical device manufacturing; the research of how aerospace companies perform within the product life-cycle approach environment would provide key findings for its further implementation within the FDA's 2011 approach framework.

Finally, the scope of the benchmarking could be varied by evaluating the validation related practices within the medical device manufacturing sector or it could be potentially enlarged to consider a greater range of companies and sectors involved, adopting a broader and global approach.

7.6. CONCLUSIONS

Non-conformances, delays and different setbacks are frequently expected in the validation programme of a new product within the aerospace and medical device industry due to a range of reasons, such as configuration management, communication or resources.

Aerospace and medical device manufacturing companies are required to automate compliance and quality processes to meet the relevant Regulatory Authority requirements, while improving business process performance and compliance integrity.

This research identified issues in the process validation stage of a new medical device manufacturing programme. It also identified best practices from the aerospace sector based on an external study. In addition to this, it also highlighted the desirable resources required for undertaking these practices in a reliable way. Finally, this study provided the guidelines for the implementation of the identified practices and desirable resources.

The resulting proposal defines a structured set of tools, practices, resources and capacities that should be improved within the organisation in order to face successfully the different requirements and challenges along the path of the process validation.

The ultimate objective of this is to enable the organisation, and any other interested companies, to reduce the time to market of their products, reduce the associated costs while assuring the product quality and meeting the customer and regulatory requirements.

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APPENDIX A – INTERNAL QUESTIONNAIRE

INTERNAL QUESTIONNAIRE

(JEB ENGINEERING QUALITY DEPARTMENT)

This document is a sample of the semi-structured questionnaires used for the Internal Analysis in order to collect information regarding the internal procedures and passed to engineers, operators and/or other employees involved in the process validation for medical devices.

Each interview/visit required preview personalisation of the set of the questions asked based on the role of the subject and its involvement along the process flow.

INTRODUCTION

Name:

Job Title:

Years of Experience/ in the Company:

Can you describe your key responsibilities within medical Process Validation?

……..…..

……..…..

……..…..

What are the key functions of the Department where you work?

……..…..

……..…..

……..…..

Which individuals/What elements (both internal and external) do you interact with in order to perform your job?

……..…..

……..…..

……..…..

Could you please provide, a brief description, of a typical day in your work-day within the department?

……..…..

……..…..

……..…..

(Optional) If you have worked for other departments, how would you compare them to Quality Assurance Department? (Procedures, resources, responsibilities, work environment)

……..…..

……..…..

……..…..

What Responsibilities would you assign/release to the Quality Assurance Department?

……..…..

……..…..

……..…..

How would you define the current Quality Management System? (Manual, Procedures, Instructions, etc.)

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……..…..

……..…..

*** * ***

PROCESS VALIDATION

How would you describe the current Process Validation system?

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……..…..

……..…..

Could you please identify the Strength and Weaknesses?

……..…..

……..…..

……..…..

From the different stages of Process Validation, which one would you consider as the easiest one? The most difficult? Why?

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……..…..

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Regarding the company internal procedures, would you change or update any of them?

……..…..

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……..…..

What Reviews/Control Procedures are in place within your activity area?

……..…..

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……..…..

What changes would you think that may improve the current process? What changes would you make to the Process? (Procedures, practices, resources, strategy, etc.)

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From the list given, which changes do you consider that are required to be urgently done?

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What are your key milestones regarding a Process Validation?

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……..…..

……..…..

Could you identify any part of the process which supposes a burden for the achievement of those milestones?

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……..…..

……..…..

Do you work with key milestone reviews or regular meetings to the best and worst practice experienced on a validation project?

……..…..

……..…..

……..…..

Can you describe any major or recurring problems/issues resulting from current practices of validation?

……..…..

……..…..

……..…..

What would you consider as the organisation's best practices? (Name 5 of them, please)

……..…..

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……..…..

Is there anything else that you wish to add or discuss?

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RESOURCES

Which are your communication channels with other workers when performing Process Validation?

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……..…..

If unlimited resources were assigned to the Process Validation stage, which 3 things would you improve/acquire/change/delete first?

……..…..

……..…..

……..…..

If only one element could be applied to the current process, which one would it be if the objective is to reduce the time spent on Process Validation?

……..…..

……..…..

……..…..

What Tools/Software/Media do you use for the Process Validation related activities?

……..…..

……..…..

……..…..

Which capacities/abilities do you consider as the appropriate ones/most helpful ones when facing a Process Validation project?

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……..…..

……..…..

Would you consider / Would you be interested in Training Courses/Workshops if offered?

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* * *

THANK YOU VERY MUCH FOR YOUR TIME AND CONSIDERATION

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APPENDIX B – BENCHMARKING QUESTIONNAIRE

BENCHMARKING QUESTIONNAIRE

This document is a sample of the generic semi-structured questionnaires used for the Benchmarking Study in order to collect information regarding the procedures within the aerospace sector regarding product validation and verification activities.

This questionnaire is a common template and questions may vary.

Each interview/visit required preview personalisation of the set of the questions asked based on the role of the subject and its involvement along the process flow, so the content of this document may vary between interviews and interviewees.

INTRODUCTION

The objective of today's interview is to discuss practices of process validation within your organisation.

First of all, I would like to thank you for your time and consideration.

Your identity (or your company's) will not be revealed and all the data and information provided will be used for the purposes of this research project only and shall be treated with the strictest confidence and privacy. It will not be directly quoted or passed/sold to any third parties.

This interview is structured in three main areas:

1. Introduction
2. Process Validation
3. Resources

It shall begin with general questions concerning your job activities, tasks, responsibilities and role within the validation and verification stage.

Continuously, more specific questions will be asked regarding the practices and procedures followed within your organisation.

Finally, this interview will conclude with some questions concerning the resources available for carrying out those tasks mentioned on the previous section.

Again, thank you very much indeed for your time and collaboration.

* * *

Name: ……..

Job Title: ……..

Years of Experience/ in the Company: ……..

Previous experience / Career: …….

What is your role within the organisation?

……..…..

……..…..

……..…..

What department do you work for? What are the main responsibilities / functions of this department?

……..…..

……..…..

……..…..

Which individuals / other departments / parts (both internal and external) do you usually collaborate with in order to perform your responsibilities?

……..…..

……..…..

……..…..

Can you describe your key responsibilities within medical Process Validation?

……..…..

……..…..

……..…..

Could you please provide, a brief description, of a typical day in your work-day within the department?

……..…..

……..…..

……..…..

What Responsibilities would you assign/release to your current Deparment?

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PROCESS VALIDATION

How is the Validation & Verification stage of the products performed at your organisation?

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……..…..

……..…..

Could you please define/quantify how your involvement is in V&V process within your organisation?

……..…..

……..…..

……..…..

How would you describe the role of V&V within the development of a new product?

……..…..

……..…..

……..…..

How would you define the status of the V&V activities that are performed at your company?

……..…..

……..…..

……..…..

What individuals or functions are involved through the stages of process validation?

……..…..

……..…..

……..…..

Please, describe briefly a typical “Process Validation” procedure within your company.

……..…..

……..…..

……..…..

What practices / procedures / resources are in place in order to assure traceability / identification of the elements involved within product development?

……..…..

……..…..

……..…..

What Reviews/Control Procedures are in place within your activity area?

……..…..

……..…..

……..…..

What changes would you think that may improve the current process? What changes would you make to the Process? (Procedures, practices, resources, strategy, etc.)

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……..…..

From the list given, which changes do you consider that are required to be urgently done?

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Which Risk Assessment tools do you use in your organisation?

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(Optional) Do you carry out FMEA at any stage of your process?

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……..…..

(Optional) Could you describe the FMEA procedures within your organisation?

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……..…..

Could you identify any part of the process which supposes a burden for the achievement of those milestones?

……..…..

……..…..

……..…..

Do you work with key milestone reviews or regular meetings to the best and worst practice experienced on a validation project? How are these performed?

……..…..

……..…..

……..…..

Can you describe any major or recurring problems/issues resulting from current practices of validation?

……..…..

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……..…..

Could you describe the primary causes of setbacks / delays / non-conformances / other problems during the validation process and activities?

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……..…..

What would you consider as the organisation's best practices? (Name 5 of them, please)

……..…..

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……..…..

Is there anything else that you wish to add or discuss?

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*** * ***

RESOURCES

Which are your communication channels with other workers when performing Process Validation?

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……..…..

……..…..

How would you describe your Documentation system? Would you change any of it? If so, what, why?

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……..…..

……..…..

What the average time you spent on creating documentation for validation activities?

……..…..

……..…..

……..…..

How would you describe your IT infrastructure? Strength, Weakness? What would you improve / change?

……..…..

……..…..

……..…..

If unlimited resources were assigned to the Process Validation stage, which 3 things would you improve/acquire/change/delete first?

……..…..

……..…..

……..…..

If only one element could be applied to the current process, which one would it be if the objective is to reduce the time spent on Process Validation?

……..…..

……..…..

……..…..

How many people are assigned to your department? How many of them participate directly in validation process activities?

……..…..

……..…..

……..…..

What Tools/Software/Media do you use for the Process Validation related activities?

……..…..

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……..…..

Which capacities/abilities do you consider as the appropriate ones/most helpful ones when facing a Process Validation project?

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How is Training / Human Resources development programme performed in your company?

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THANK YOU VERY MUCH FOR YOUR TIME AND CONSIDERATION

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