CRANFIELD UNIVERSITY

MOYOSORE ADENIJI

A BENCHMARK STUDYOF THE INDEPENDENT QUALITY VALIDATION TECHNIQUES OF PRODUCT DESIGN AND DEVELOPMENT

SCHOOL OF APPLIED SCIENCES

MSc THESIS

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ABSTRACT

As we move ahead in the 21^{st} century, quality validation techniques need to be based on principles of long term safety as consumers are now more aware of safety issues surrounding product design and development and globalisation has brought about competition within the manufacturing industry. Quality is seen as a reality for all manufacturing organisations and if quality standards are ever compromised, the immediate benefits in terms of cost savings, efficiencies and enhanced profitability are often lost. The study aims to capture and analyse the industrial best practices of independent quality techniques to evaluate and validate product design and development.

The project introduces various techniques used in testing hardware components of products and what the pros and cons of these testing techniques are. Due to the information that was to be gathered during the research process, an inductive approach was taken. This approach consisted mainly of five major phases; the literature and industrial research, data collection & analysis at the sponsor company, the benchmark study, the final proposal and validation of the project by experts at the sponsor company.

Academic literature and various online resources were consulted and reviewed to identify the various hardware testing techniques and for overall insight into the common issues and challenges faced by manufacturing organisations involved in the use of the identified testing techniques. Comparisons were made between academic literature and reality in industry. The results revealed that the sponsor company was operating within the best practices of the manufacturing industry and conclusions were drawn from the entire study stating that although the sponsor company was operating within the best practices, there was room for improvement. The documented benefits of the testing techniques will provide factual information to the senior management team enabling them make strategic decisions on the new techniques that could be implemented into their hardware testing plan.

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GLOSSARY OF TERMS

AET	Acoustic Emission Testing
DFMEA	Design Failure Mode Effects Analysis
ECT	Eddy-Current Testing
EMC	Electro-magnetic compatibility
IQV	Independent Quality Validation
LPT	Liquid Penetrant Testing
MPT	Magnetic Particle Testing
NDT	Non-Destructive Testing
NVH	Noise, Vibration & Harshness Testing
PA	Product Assurance
PDM	Product Data Management
PLM	Product Lifecycle Management
OEM	Original Equipment Manufacturer
QFD	Quality Function Deployment
RT	Radiographic Testing
TMP	Test and Maintenance Program
UT	Ultrasonic Testing
VES	Visteon Engineering Services
VSM	Value Stream Mapping
VT	Visual Testing

1 INTRODUCTION

This chapter introduces the reader to a brief description of the background and nature of research presented in this thesis. The aims and objectives are presented accordingly and the research process is summarised. Furthermore, the methodology is presented and the chapter concludes with the structure and contents of each chapter of the thesis.

1.1 Overview of the industrial problem

Product quality is a significant factor in achieving higher customer satisfaction. This is a major concern for organisations and a major requirement for competitiveness in today's global market. One necessary condition for the realisation of quality and the creation of value added is quality measurement and control. This is an important function to ensure the fulfilment of given customer requirements. The purpose of the marketing quality control is to determine whether the quality system is performing at optimum levels from an operational point of view (Zineldin, 2005). In the current market conditions, products have to be delivered to global standards defined by ever-changing market demands, safety regulatory guidelines and consumer preferences.

In a world such as this, virtually every end-user product manufacturer faces the prospect of high costs, schedule delays and marketplace failures. In most cases, mistakes are caused by incompetence which means that organisations have to carefully consider the validation techniques adopted to test products in every product development program. The research described in this thesis was conducted in collaboration with several companies and the sponsor company that kindly participated in the study.

The sponsor company is a leading global supplier of automotive systems, modules and components to global vehicle manufacturers and the automotive aftermarket. The company was formed in 1997 as an auto parts supplier of Ford Motor Co and is headquartered in Van Buren Township, Michigan. The span of the manufacturing processes and innovative materials at the sponsor company are adaptable to customer timing and specifications. Compliant with the automotive industry's standard for quality, QS 9000 and certified for ISO 14001, the sponsor company’s manufacturing facilities characterise the standard for environmental management. With the ability to deliver according to a manufacturer's needs, whether through *in-line vehicle sequencing*, *off-line vehicle sequencing* or establishing a *focused factory* near a vehicle manufacturer's assembly facility, the company can help the automaker meet their needs more efficiently.

In the early stages of production and throughout product development, highly developed facilities aim to improve the way by which customers’ vehicles respond to a variety of climatic changes and driver inputs. Customer needs are met throughout the development process by providing testing tools which improve vehicle reliability, responsiveness, and sturdiness, before the products reach the marketplace. The state-of-the-art testing facilities mimic real-world consumer-use patterns and provide automotive vehicle manufacturers with data that can improve durability and product robustness.

The motivation for this research stems from the highly dispersed global economy which makes meeting consumer needs very demanding and challenging. There is a need to build on the existing research in the field of independent quality validation (IQV) techniques within product design and development. This MSc individual thesis project will carry out a study related to the available industrial best practices and benchmark them against the current practices at the sponsor company to identify opportunities for improvement. The project will be performed through the following aim and objectives.

1.2 Thesis aim and objectives

The aim of the thesis is:

To capture and analyse the industrial best practices of independent quality validation techniques to evaluate and validate product design and development

The project aim is achieved through the following technical objectives:

i. Synthesize the best practices of independent quality evaluation and validation techniques of product (hardware) design and formalise the required background theory for the project through extensive literature review and industrial research.

ii. Design a closed questionnaire to capture current practices of independent quality validation techniques and defining opportunities for improvement by mapping VES AS-IS model against the identified industrial best practices.

iii. Identify suitable companies from various industrial sectors to participate in a benchmark study from. Analyse collected data to identify the best practices.

iv. Map the best practices identified from VES against the captured industrial best practices in order to identify opportunities for improvement.

v. Validate the proposed roadmap through expert judgements within Visteon.

1.3 Thesis structure

This thesis presents the research across seven chapters. This brief introduction to the thesis will now conclude with an overview of the thesis content.

Chapter 1 – Introduction

This chapter has provided an overview of the thesis and the nature of the research and benchmark study presented within it. The chapter also sets the scene for why the project was undertaken by the sponsor company. It also gives a brief introduction into what Visteon as a company do; in terms of products and services, how long the company has been in operation and what the manufacturing and testing facilities are like within the organisation.

Chapter 2 – Literature Review

This chapter presents a review of academic literature that considers quality and the perception of quality validation techniques in product design and development processes. The chapter also looks at some of the different testing techniques that are used in the manufacturing industry to validate hardware components.

Chapter 3 – Research Methodology

This chapter details how the project was executed and outlines the selection and justification of the methodology used to answer the research questions.

Chapter 4 – Independent Quality Validation (AS-IS) Model at Sponsor Company

This chapter details the state at which VES was operating before the project commenced. This was captured and documented.

Chapter 5 – Benchmark Study

A closed questionnaire was developed to carry out a survey, which was administered to aid the identification of the most widely used testing techniques in the manufacturing industry. This chapter presents the study that initiated the research and pulls together the different validation techniques that were identified and matches them against the current practices at the sponsor company.

Chapter 6 – Discussion of Research Findings

This chapter brings together the findings from conducting the online survey, the research activity and the benchmark study.

Chapter 7 – Conclusions and Recommendations

This chapter concludes the thesis by pulling together all the theory and reasoning and arrives at a decision based on findings from the literature review and benchmark study that were reviewed as a whole. The strengths and weaknesses of the research are discussed and the chapter concludes with suggestions for future research work.

2 STATE OF THE ART ON PRODUCT DEVELOPMENT, PRODUCT LIFE CYCLE MANAGEMENT AND NON-DESTRUCTIVE TESTING TECHNIQUES

Product development practices have evolved over recent years as product cost; quality and time-to-market have each become progressively important (Minderhoud and Fraser, 2004). The purpose of the literature review is to present the research subject area of independent quality validation techniques and to understand the importance of different techniques in different industry sectors within manufacturing. One of the aims of this review is to identify through journal papers and books, the different independent quality validation (testing) techniques available in product design and development.

2.1 Manufacturing and Production Systems

Manufacturing processes are assembled together to form a manufacturing system to produce a desired set of goods where specific inputs and materials are taken by the manufacturing system and value is added through processes, and the inputs are transformed into products for the customer (Degarmo et al., 2003).

2.1.1 Production Systems

The production system services the manufacturing system, using all the other functional areas of the plant for information, design, analysis, and control. These subsystems are connected to each other to produce goods or services, as in figure 2.1.1 (Degarmo et al., 2003).

A production system includes all aspects of the business, including design engineering, manufacturing engineering, sales, advertising, production and inventory control (scheduling and distribution), and, most important, the manufacturing system (Degarmo et al., 2003).

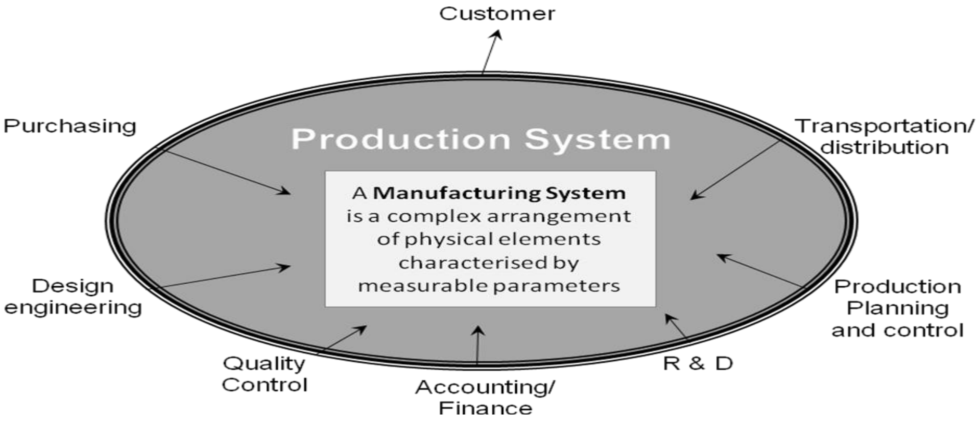


Figure 2.1: Schematic definition of a production system

(Source: Degarmo et al., 2003)

The emphasis of this project is on the testing and validation of hardware components, which is a crucial functional part of the manufacturing process and has to be integrated into the design of a production system. It is represented generally as the Research & Development (R&D) aspect of the system. However the benchmark study carried out through industrial research as a part of this project showed that most organisations refer to the team or department that handles testing as either of these 'Product Assurance' or 'Quality Assurance' or 'Product Verification'.

2.1.2 Manufacturing Systems

Manufacturing systems consist of a sequence of processes and individuals that actually manufacture the required product(s) and are considered as the complex arrangement of the manufacturing elements characterised and controlled by measurable parameters (Black, 1991). The relationship among the elements influences how competently the system can run or be managed. The control of a system refers to the whole manufacturing system which is where the control of the operator is well-balanced relative to the system's objectives, and not merely individual processes or equipment.

Historically, for each phase of industrial and technological growth there has been a parallel evolution in manufacturing information systems. Each phase of development has been trailed by a period of industry stability and systems combinations (Rollins et al. 2003). This emphasizes the relevance of manufacturing systems in product development because according to Narahari and Hemachandra (1995), performance evaluation studies in manufacturing systems have traditionally considered models in which the arrival process and service process are time independent. Real-world manufacturing systems however, are subjected to highly complex and usually time-dependent input workloads.

2.2 Product Lifecycle Management

Market place requirements, technological capabilities and consumer awareness have led to an increase in the demand for complicated and sophisticated products (Rollins et al., 2003). Due to this increase, quality and standards of products are of paramount importance to organisations in the manufacturing industry.

"*Product Lifecycle Management (PLM) is an integrated, information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life, from its design through manufacture, deployment and maintenance – culminating in the product's removal from service and final disposal"* (Grieves, 2006).

2.2.1 Why PLM is useful in industry?

PLM eliminates waste and inefficiency across all aspects of the development process of a product, it pays specific attention not only to the life of a product but also in its manufacture. It is focused on using the power of information to deliberately reduce inefficiencies from the design, manufacture, support, and final discarding of a product. There are proven examples from leading manufacturing companies that are widely adopting the PLM approach, some of which include: Dell, General Electric and General Motors. (Grieves, 2006)

PLM has within its framework the opportunity to increase levels of innovation, functionality and quality (which is where the emphasis lays for the sponsor company of this project), by better organising and utilising the intellectual capital of the organisation. The ability to expand and build creative, more useful, and better products from the same amount of effort will also drive productivity and is a better way of sustenance than cost-cutting. (Grieves, 2006)

Since businesses within all areas of industry are regularly looking for ways to enable more efficient operations, the evolution of the different components of PLM will be useful. However it is important to consider how industry experts define PLM. Marc Halpern, Director of PLM Research for Gartner Group states that PLM systems usually exist in different names depending on latest trends.

In an article by Wong, K. (2006), called *"PLM's Growing Pains"* March Halpern explains that PLM systems are also referred to as Product Data Management (PDM) and CPC and suffer from an identity crisis. The reason for this identity crisis according to the Director is *"What's unfortunate is that there are certain vendors that promote the notion that CAD, simulation, virtual modelling and some support for PDM equal PLM."*

2.3 An Overview of Product Development

Product development may be described as the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product (Ulrich and Eppinger, 2008).

Product development processes have evolved over recent years from sequential technology push/market pull models to more overlapped and integrated processes, employing internal cross-functional teams and early supplier involvement (ESI) to improve time to market (Stalk and Hout, 1991).

It is essential that the designing of product(s) with new or different characteristics that offer new or additional benefits to the customer are a part of every organisation's product development process. It may simply be the modification of an existing product or its presentation, or formulation of an entirely new product that satisfies a newly defined customer want or market niche (Lagrosen, 2002). In parallel, the rapid pace of technology development has led to shorter product life cycles for many product categories, most notably in consumer electronics. Whereas in previous years, the technology development, product development and transfer to volume production for a typical product might have occurred in several phases spread over 10–15 years, now it is common for the same processes to take no more than 2–5 years. (Minderhoud and Fraser, 2004). With this in mind, for every product to thrive in the market, it has to be fit for purpose and safe to use, which leads to the following section on testing of product components.

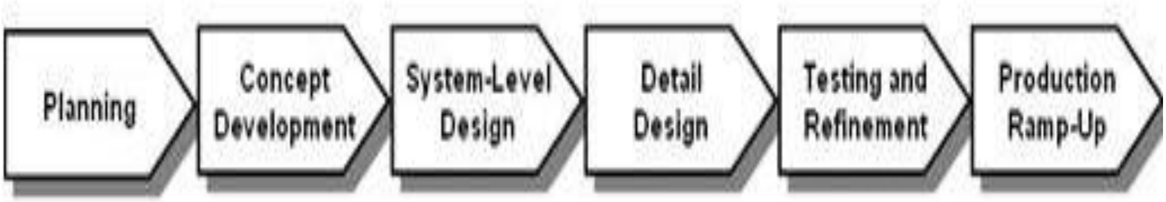


Figure 2.2: The Generic Product Development Process

(Source: Ulrich and Eppinger, 2008)

2.4 Quality Assurance

According to the Oxford English dictionary (12/08/09), quality is defined as "the degree of excellence of something as measured against other similar things".

With the world economy tending to be more global, manufacturing industry is facing tremendous competition in producing products at lower cost, with shorter lead times, with a quicker market response, of better quality and service and more environmental friendly. Based on the author's understanding, the key for manufacturers to survive in the very competitive manufacturing industry is quality, which indicates that manufacturing enterprises have to meet the requirements of all their customers in product development and manufacturing . It is common sense that product quality should be emphasized from the start of a product development process, and quality comes from product design and manufacture, not from inspection. Quality is the characteristic incorporated into a product throughout the entire process. The product development stage mainly determines the quality of the final product. Statistics shows that 40–70% of quality problems stem from poor design (Juran and Godfrey 1999). Product development can determine 70% or more of all manufacturing costs and 80% of a product's quality performance. Good quality at a competitive cost demands that manufacturers switch on quality control at an early stage in the product lifecycle, at the beginning of product development.

Dale and Tidd (1991) define total quality control as an assurance of product quality and services, comprehensive control of cost, production, delivery, safety, environmental protection and any other activities pertaining to performance quality. They identified the following factors as motivations for the development of total quality control based on the outcome of findings in the Japanese markets: environmental, national and business factors, slow economic growth, competition, a lack of effective long-range planning, new products not achieving their target sales values, slow growth in sales and market.

Fujitsu (2007) developed a Test and Maintenance Program (TMP) for verification, mass-production testing and field maintenance to ensure customers can use high-quality hardware products with a high sense of security. The program helps assure product quality throughout the design, manufacturing and maintenance life cycles. Miyahara et al (2007) describe the development policies for Fujitsu's TMP and the technologies employed for design verification, device evaluation, and maintenance support. The TMP's main focus include: high fault detection performance, powerful fault analysis functions and simple operability. The technologies employed for design verification include the test program (TP) which guarantees that hardware is designed in accordance with device and interface specifications by verifying individual functions, combinations of functions, robustness under high stress, Reliability, Availability and Serviceability (RAS) and the hardware performance.

2.5 Testing of Product Hardware Components

Testing is defined as when a set of specifications and methods have been put in place to ascertain whether a product or its components carry out the functionality as anticipated and to see if it is fit for the purpose which the manufacturers intended.

In manufacturing, testing is paramount and any controlled test is better than none, but controlled tests based on realistic service loadings are more informative than simple ones and testing should also be carried out by the vehicle manufacturer, not by the user (Wright, 1985).

Product development involves product planning, design, testing, and refinement. Product planning lays out the functions and performance of a product. Product design puts the plan into practice. Product quality control has to oversee the main activities in product planning and design. In recent years, research in quality control in product planning and design has been focused on planning philosophy, product modelling, product characteristics' definition, quality evaluation, and characteristic optimisation. In the product planning phase, the most important issue is mapping customer requirements to product quality characteristics.

Quality control in the product development process is vital to the final quality of a product. Customer requirements are the groundwork of quality control (Tang et al., 2007). Product development has to be linked with customers through customer demand and quality characteristics. Quality control is an issue that is of great importance in many real-life applications. Error prevention is one of the main targets that industrial and governmental agencies aim for. The following section present different types of non-destructive testing techniques that are used in quality control of hardware components.

2.6 Non-Destructive Testing

Non-destructive testing (NDT) consists of a wide group of analysis technique used in manufacturing to evaluate the properties of a material and component.

A general definition for NDT is an examination, test, or evaluation performed on any type of test component without changing or altering it in any way, in order to establish the absence or presence of conditions or discontinuities that may have an effect on the serviceability of the component. (Hellier, 2001)

Non-destructive Testing (NDT) in the engineering community is normally associated with the objective to detect, to classify and to size material non-conformities; for instance beginning with non-metallic inclusions in steel or aluminium alloys up to 'material defects' like macroscopic cracks. This objective, however, is at the top of the list of activities concerning the number of applications in non-destructive material testing worldwide. Methodologies like UT (Ultrasonic Testing) and RT (Radiographic Testing) or MT (Magnetic Testing) are well introduced in a wide field of product and component examination standards. (Dobmann et al., 1989)

Raj et al. (2007) state that NDT is a term used to represent techniques that are based on application of physical principles employed for the purpose of determining the characteristics of materials or physical components or systems and for detecting and assessing the inhomogeneities and harmful defects without impairing the usefulness of such materials or components. Comparison of the two definitions in this case suggest the same principle; where the product or component being tested is still in a useful state even after tests have been carried out on it.

In the last 15 to 20 years, the NDT technology was also developed for characterising materials, for instance in terms of microstructure parameters, i.e. lattice defects, like distributions and densities of dislocations, precipitates, micro-voids, in order to describe strengthening and/or softening in materials, mainly in metal alloys, but also to measure the applied and residual stresses (Dobmann *et al*., 1989).

In NDT different tests can be applied to the same item, either concurrently or sequentially, and the same test can be repeated on the same sample for additional verification. Sample preparation is hardly required, and the equipment is often portable, permitting on-site testing in most locations.

Raj et al (2007) state that NDT plays an important role not only in the quality control of the finished product but also during various stages of manufacturing and to support the various stages of manufacturing, Degarmo et al. (2003) state that NDTs incorporate the following aspects; some means of probing a material or product, a means by which a flaw, defect, material property or specimen feature interacts with or modifies whatever is probing, a sensor to detect the response, a device to indicate or record the response and a way to interpret and evaluate quality.

2.6.1 Non-Destructive Tests Techniques

In recent times, increased recognition is being given to the importance of NDT in various engineering disciplines at all stages of product development, but before looking at the different NDT testing techniques a brief history into how these techniques were developed is essential. Starting in 1980, the first empirical approaches were developed, to characterise materials in terms of mechanically and technologically defined parameters such as; hardness, hardness depth, yield limit and ultimate strength (Dobmann et al., 1998), and all these were standardised by a destructive procedure. Borsutzki (1998) published that these parameters could be determined also on-line in the steel making process, i.e. in a hot-dip galvanizing line for car body steel sheet production. In this context, micro-magnetic testing is especially suitable because micro-magnetic parameters obtained under magnetic load show many similarities to mechanical parameters derived under mechanical loads. This is why microstructure parameters (lattice defects) impede dislocation movement as well as Bloch wall movement and relationships between mechanical and micro-magnetic parameters are empirically derived by multiple parameter correlation, neural network and pattern recognition procedures (Altpeter *et al*., 2002).

First publications to characterise the materials damage in terms of microscopic damage parameters such as creep damage porosity and fatigue effects were published in Dobmann *et al*. (1993), Dobmann and Seibold (1992). In the meantime further research work was initiated (Dobmann, 2002; Dobmann et al., 2001 a), some characteristic results of which are summarized in the following contribution. They mainly document the maturity of micro-magnetic properties to solve this inspection task.

There are various non-destructive test methods, some of which include;

- **Visual Testing (VT)**

  This method of NDT is thought to be the easiest, simplest, most useful and most widely used technique (Raj et al., 2007 and Degarmo et al., 2003).

  In the book titled *Practical Non-Destructive Testing* by Raj et al. (2007), it is suggested that important details can be collected during VT which would be useful for future analysis and also to decide on the type of NDT to be used for further analysis.

  Degarmo et al. (2003) propose that the human eye is a very discerning instrument and with training, the brain can readily interpret the signals. However, optical aids such as mirrors, magnifying glasses, and microscopes can expand the capabilities of this human eye system. Raj et al. (2007) support this notion as they suggest that VT should be carried out as a complementary method to all other NDT methods and should precede and succeed all other examination and that bore scopes and fibre-optic techniques can provide accessibility to inaccessible locations.

The main limitation of this technique is that only the surface of a product can be examined, but Degarmo et al. (2003) state that this is often sufficient enough to reveal corrosion, contamination, surface finish flaws, and a wide variety of surface discontinuities which is essential in quality assurance and safety for end users.

- **Liquid Penetrant Testing (LPT)**

  Liquid Penetrant Testing is another means of enhancing the capability of visual examination (Raj et al., 2007). It is an effective method of detecting the surface defects in metals and other non-porous materials (Degarmo et al., 2003).

  The principle of the technique as proposed by Degarmo et al. (2003) is described as when a liquid Penetrant containing fluorescent material or dye is drawn into surface flaws by capillary action and subsequently revealed by developer material in conjunction with visual testing.

  The advantages of this technique include; simple, inexpensive, versatile, portable, easily interpreted, and applicable to complex shapes (Degarmo et al., 2003). However, there are limitations that have to be carefully considered. Some of these include; the fact that it can only detect flaws that are open to the surface, surfaces must be cleaned before and after the testing procedure, deformed surfaces and surface coatings may prevent detection, and the penetrant may be wiped or washed out of large defects. It also cannot be used on hot products (Degarmo et al., 2003).

- **Magnetic Particle Testing (MPT)**

  Magnetic, acoustic and ultrasonic techniques are some of the most important rapid non-destructive methods of testing steel. Of these methods, magnetic testing is most successful in industry. Applications of magnetic testing include commercial instruments for the measurement of drawability and hardness of carbon steel sheets. Magnetic Particle Testing is based on the principle that ferromagnetic materials (such as the alloys of iron, nickel, and cobalt), when magnetised, will have distorted magnetic fields in the vicinity of material defects and magnetic particles will be strongly attracted to regions where the magnetic flux breaks the surface. (Degarmo et al., 2003)

  While LPT is effective for the fine surface discontinuities, Raj et al. (2007) suggest that the need remains to detect larger surface flaws, which is met by MPT. Raj et al. (2007) also state that flaws oriented perpendicular to the induced magnetic field are only reliably detectable, hence presenting the challenge to induce magnetic field lines in a given work piece so that they are most likely to be perpendicular to the flaw orientation. MPT is used for detecting the following types of discontinuities in ferromagnetic materials. Table 2.1 shows the different types.

Table 2.1 – Types of discontinuities in ferromagnetic materials

Surface Discontinuities	Below Surface Discontinuities
Cracks and tears	Larger size cracks in various orientations
Porosity	Pores
Shrinkage cavities	Slag inclusions
Voids	Voids
Forging laps	Incomplete fusion
Grinding, corrosion and fatigue cracks	Laminations

(Source: Raj et al., 2007)

- **Eddy-Current Testing (ECT)**

  Eddy current non-destructive testing is a widely used tool in the inspection of conducting materials during manufacture or in service. The technique is based on the analysis of changes in the impedance of one or more coils placed near the work-piece to be tested. It is used to detect and characterise possible flaw or anomalies in the work-piece. (Pichenot et al, 2002)

  Pichenot et al. (2002) present the recent progress in developing eddy current models based on the volume integral method and using the Green's dyadic formalism which has the capability to predict quickly the signal of an eddy current probe used in non-destructive testing. They conclude that models based on the volume integral approach are useful in optimising the design of probes, studying various configurations of control and assessing the impact of perturbation factors by limiting the number of experimental tests.

- **Microwave systems**

  Microwave techniques have historically been used on a laboratory scale. Lasri et al. (1998) considered the characterisation of dielectric materials with the aim of developing original and low-cost microwave testing systems which can replace an automatic network analyser. They achieved this by building a system which can be used to obtain the S-parameters of a material under test. In particular, a system which measures the scattering parameters in thin materials such as textiles, plastics and dielectric substrates to an accuracy of ±0.5dB was conceived. They concluded from their findings that non-destructive testing by means of a microwave system is a good candidate for use in industrial applications.

- **Radiographic Testing (RT)**

  This technique involves the use of penetrating gamma or X-radiation to examine parts and products for imperfections. An X-ray machine or radioactive isotope is used as a source of radiation. Radiation is directed through a part and onto film or other media. The resulting shadowgraph shows the internal soundness of the part. Possible imperfections are indicated as density changes in the film in the same manner as X-ray shows broken bones.

  Radiographic applications fall into two distinct categories evaluation of material properties and evaluation of manufacturing and assembly properties. Material property evaluation includes the determination of composition, density, uniformity, and cell or particle size. Manufacturing and assembly property evaluation is normally concerned with dimensions, flaws (voids, inclusions, and cracks), bond integrity (welds, brazes, etc.), and verification of proper assembly of component pieces.

  http://www.engineershandbook.com/MfgMethods/ndtrt.htm. - accessed 12/08/09

- **Ultrasonic Testing (UT)**

  Ultrasonics is the name given to the study and application of ultrasound, which is the sound of a pitch too high (about 18 kHz) to be detected by the human ear. Ultrasonic waves have a wide variety of applications over an extended range of intensity one of which includes non-destructive testing – a mechanical method, where periodic mechanical stresses are applied to an object. (Blitz and Simpson, 1996)

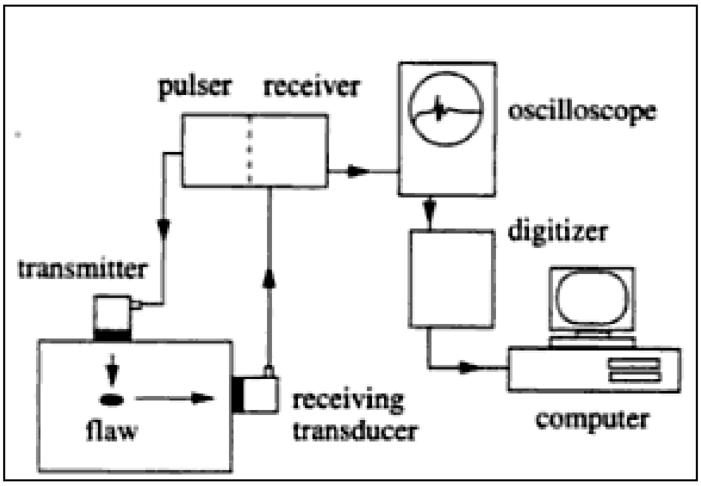


Figure 2.2: Elements of an ultrasonic NDT system

(Source: Schmerr, 1998)

In their book, (Blitz and Simpson, 1996) state that ultrasonic testing involves time of transit (or delay) of the waves, path length, frequency, phase angle, amplitude, impedance and angle of wave deflection (reflection and refraction). The methods of measurement make use of pulsed or continuous waves. In theory, the pulse technique is the simplest of the UT methods consisting of the measurement of and one of the most commonly used.

- **Acoustic Emission Testing (AET)**

  Acoustic Emission (AE) refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material. When a structure is subjected to an external stimulus (change in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors. Detection and analysis of AE signals can supply valuable information regarding the origin and importance of a discontinuity in a material. Because of the versatility of Acoustic Emission Testing (AET), it has many industrial applications (e.g. assessing structural integrity, detecting flaws, testing for leaks, or monitoring weld quality) and is used extensively as a research tool.

Acoustic Emission is unlike most other non-destructive testing (NDT) techniques in two regards. The first difference pertains to the origin of the signal. Instead of supplying energy to the object under examination, AET simply listens for the energy released by the object. AE tests are often performed on structures while in operation, as this provides adequate loading for propagating defects and triggering acoustic emissions. (http://www.ndt-ed.org/EducationResources/CommunityCollege/Other%20Methods/AE/AE_Intro.htm) – accessed 12/08/09

- **Monochromatic Laser Testing**

  Monochromatic light may be described as electromagnetic radiation derived from photon emissions from atoms, which travel as energy wave fronts of different lengths and levels of energy. (http://www.highbeam.com/doc/1G2-3448300393.html - 12/08/09)

  Monochromatic laser light according to Degarmo et al. (2003) can be used to detect differences in the backscattered pattern from a part and a master where the presence or absence of geometrical features such as holes is readily detected. Unlike traditional contact vibration transducers, laser-based vibration transducers, or laser vibrometers, require no physical contact with the test object (Nabavi et al., 2008). The measurement principle of a laser vibrometer is based upon the Doppler Effect. When monochromatic laser light is scattered back from a vibrating target it undergoes a frequency shift proportional to the velocity of the target. This is known as the Doppler Effect. As the target moves towards the light source, the back-scattered light undergoes an increase in frequency. As the target moves away, the back-scattered light undergoes a lowering of frequency. If the target is vibrating, the frequency of the back-scattered beam will be frequency modulated at the so-called Doppler frequency. The Doppler frequency is directly proportional to the velocity of the target. Therefore, tracking this Doppler frequency provides a direct measurement of the target's velocity relative to the motion of the light source. The Doppler Effect can be utilised in systems measuring translational (linear) vibration as well as systems measuring torsional (angular) vibration.

Remote, mass-loading-free vibration measurements on targets that are difficult or impossible to access are typical examples of applications where a laser-based vibration transducer would be the natural choice. Furthermore, the ability to incorporate advanced, miniaturised, optical mirror systems together with the laser source provides automated scanning measurements, where a high number of measurement points can be measured consecutively. Non-contact vibration measurements with very high spatial resolution are possible with such a scanning system and can lead to significant improvements in the accuracy and precision of experimental modal models.

The mono-chromatic laser testing technique also referred to as optical / laser diagnostic is being used by a large well known automotive OEM, whom due to its involvement in this study cannot be mentioned. The company has an optical single cylinder research engine that offers a rapid development tool for obtaining new knowledge associated with new automotive engine technologies. They also state that to obtain full use of laser-based techniques, a maximum amount of optical access is required and must be available with as little disruption as possible. Real time images can be captured using this technology; such as spray dispersion and flame propagation, which enables the advancement of various technologies made possible only through the use of an optical engine.

2.6.2 Advantages & Limitations of Non-Destructive Tests

Non-destructive tests can have a variety of objectives, including the detection of internal or surface flaws, the measurement of a product’s dimensions, the determination of a material’s structure or chemistry, or the evaluation of a material’s physical or mechanical properties (Degarmo, 2003).

The range and sophistication of non-destructive testing techniques now available is capable, with a few exceptions, of finding defects far smaller than those which need to be eliminated from a structure if it is to perform its function satisfactorily (Birchon, 1969).

Birchon (1969) stated that some unacceptable defects would slip through the non-destructive testing processes in 1969, and these errors must be prevented. Raj et al. (2007) then stated that associated with the increased recognition that NDT has received over recent years, is a growing concern about the reliability of the material/techniques used, cost etc. One of the principal causes of unnecessary ambiguity and expense in non-destructive testing according to Birchon (1969) arises from the sophistication of some of the NDT techniques that are available. As a result, the reaction of engineers to non-destructive testing techniques varies between the extremes of blissful confidence in their efficacy, and wary (or even ‘weary’) concern over their uncertainties, limitations, and cost (Birchon, 1969).

This unfortunate situation has arisen just at a time when our increasing precision in non-destructive testing techniques, and our better knowledge of material characteristics and sophistication of design procedures, should enable the gap between non-destructive testing and engineering design to be closed.

2.7 Closing Remarks

The modern manufacturing enterprise is a complicated organisation that is operating in a fast evolving technological environment. In recent times, economic forces and advances in technology is transforming the manufacturing enterprise and the economy worldwide. With this in mind, product development and testing of products and their components are suggested to be the key in any manufacturing enterprise and if not closely monitored, quality assurance of product design and development cannot be achieved.

Testing of hardware components included in any product development process is essential as a safety measure for quality assurance and allows for both surface and internal deformities in hardware components to be identified and facilitates problem solving.

The non-destructive testing methods that were identified in this chapter have been tested and a number of them are being used in a number of the manufacturing enterprises that participated in this study, which in essence validates the study. See section 5 for the analysis of key findings from the study.

3 RESEARCH METHODOLOGY

Research is a way of thinking, and is expertise used in critically evaluating the various aspects of a project which in most cases leads to the understanding and formulating of a theory or a set of principles that govern a particular course of action where developing and testing new theories for the enhancement of a project become evident. Research involves creating new knowledge, identifying a problem (which is a question in the case of this project), gathering data from appropriate sources to help address the problem (interviewing engineers at the sponsor company and visiting the testing facilities used by the sponsor company), accurately recording the gathered information (through the use of the online platform; survey monkey), analysing the collected data, interpreting it, deciding whether or not to gather more information, and drawing up conclusion(s) based on the findings.

The benchmark study aims to identify the best practices of independent quality validation techniques and to incorporate them into a roadmap proposal with recommendations for implementation at the sponsor company. This section outlines a structured approach for investigating and analysing the problem domain of the “A Benchmark of the Independent Quality Validation Techniques of Product Design and Development” project.

The main validation techniques that will be focused on will be the non-destructive testing techniques for hardware (product) components; some of which have been in the manufacturing industry for years and date as far back as the 1950’s (Acoustic Emissions Testing). The benefits and limitations as identified in the literature and industrial research form the basis for the proposed roadmap and recommendations.

Figure 3.1 gives an illustration of the phases which the research methodology followed throughout the course of the project and Due to the type of information that was to be gathered during the research process, an inductive approach was used. This approach consisted mainly of five major phases:

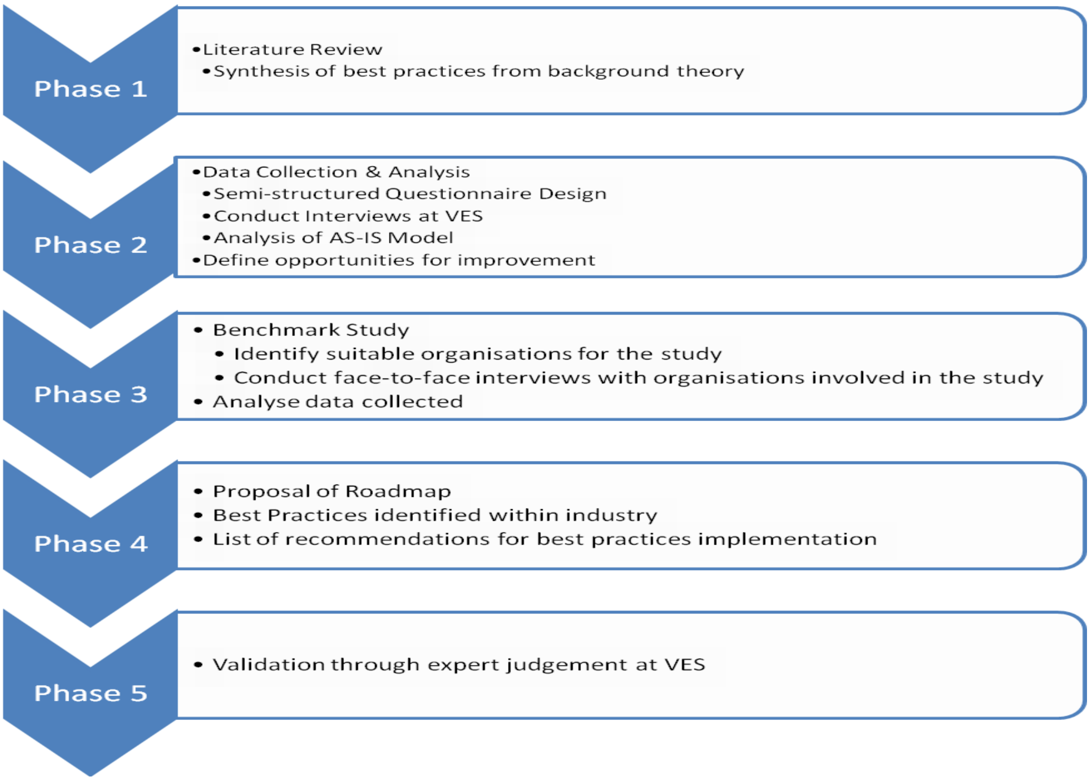


Figure 3.1: Research methodology

Phase 1: LITERATURE AND INDUSTRIAL RESEARCH

- Synthesize the best practices of independent quality evaluation and validation techniques of product (hardware) design and formalise the required background theory for the project through extensive literature review.

- Identify through internet search of journal papers, organisations that are using Independent Quality Validation Techniques in product design and development processes.

- Based on the background theory, design questionnaire structure in order to identify the industrial best practice for Independent Quality Validation Techniques.

Phase 2: DATA COLLECTION & ANALYSIS

- Design a semi-structured questionnaire to capture current practices of independent quality evaluation and validation techniques within VES through interviewing the key engineers and personnel involved in the process.
- Conducting several interviews with key production and testing engineers and personnel involved in the testing and validation processes of hardware components at the sponsor company and other organisations in the manufacturing industry at large.
- Quantitative analysis of data collected in order to identify opportunities of improvements.
- Defining opportunities for improvement by mapping the sponsor company's 'Independent Quality Validation Model' against the identified best practices. In addition to this, a list of recommendations will be given as to how the best practices can be incorporated into the testing and validation processes at VES.

Phase 3: BENCHMARK STUDY

- Design a semi-structured questionnaire in order to identify the industrial best practice for Independent Quality Validation Techniques.
- Identified suitable companies to invite them for the Benchmark Study
- Perform the study through face-to-face or WebEx interviews as well as through Email and internet communications.
- Analyse the collected data to identify the best practices. The data will be also classified according to the industrial sectors.

Phase 4: PROPOSAL

- Map the practices at the sponsor company against the captured industrial best practices to identify opportunities of improvements
- Define a list of recommendations for implementing the identified best practices at the sponsor company.

Phase 5: VALIDATION

- Validation through expert judgment within the sponsor company.

3.1 Scope Definition

It is essential and beneficial to set the boundaries of any project, most especially regarding the research objectives as the issues on testing and validation which this project aims to study have very large scopes.

The scope of the project covers the collection of relevant data from key areas in the sponsor company, by interviewing employees that are involved in mechanical, electrical and hardware testing of product components; benchmarking the sponsor company by an intense and thorough search of the manufacturing industry to identify how other companies are using the best practices in validation techniques to support testing processes; a proposed roadmap and recommendations for the implementation of the identified best practices and validation of these proposals through expert judgement from the sponsor company and the manufacturing industry at large.

The project will require the research student to travel to the sponsor company for data gathering and progress meetings, but will not particularly require that the research student make trips to the participating companies, if information can be gathered either by telephone or via the web.

The project scope does not cover a detailed benchmarking study as there is a time constraint on this type of study in an MSc thesis and the project does not cover the full implementation of the best practices at the sponsor company, but covers a benchmark study of the identified best practices, and analysing the responses received from the participating organisations. The project scope also covers giving all participating companies a copy of the results from the benchmark study, which will include charts, graphs and both qualitative and quantitative results that will be presented in a tabular form.

3.2 Metrics and Timescale

The performance of the project was measured against planned milestones and deliverables. Preliminary key milestones and their estimated dates are stated in Table 3.1.

Table 3.1: Preliminary key milestones and estimated dates

Ref	Milestone	Date
1	Project starts	11/05/09
2	Client Brief approval	28/05/09
3	Draft of Literature Review	12/06/09
4	Visteon AS-IS model	04/07/09
5	Questionnaire	16/07/09
6	Benchmark Study	26/07/09
7	Independent Quality Validation Techniques Proposal	15/08/09
8	Poster Hand-in	21/08/09
9	Poster Presentation at Cranfield	04/09/09
10	Presentation at Visteon	07/09/09
11	Thesis Submission	09/09/09

Detailed breakdown of the project tasks and their timescales are provided in a project Gantt chart as Appendix A.

3.3 Closing Remarks

To summarise, the author has managed to follow through the research methodology and been able to meet the project requirements against the set deadlines. The scope of the project was not compromised and although there was a limit to the amount of time that could be spent on the project, the approach taken has worked well in the execution of this project.

4 THE CURRENT INDEPENDENT QUALITY VALIDATION TECHNIQUES MODEL

This chapter covers the visits made to the sponsor company and how data was collected. Visits to the testing facilities used by the sponsor company were also made and will be detailed in the sub-sections to follow.

4.1 Data Collection with Product Assurance Department at Sponsor Company

To start the project off, an initial visit to the company was made to establish contact with the product assurance team and engineers at the sponsor company that would be participating in the study; to clearly define the industrial problem and scope of the project, visit the testing facilities, agree the client brief and sign the contract. A copy of the sponsor company's *Independent Quality Validation* model was viewed, discussed very briefly and taken away for further study by the author.

Subsequent visits were made to discuss further with product assurance engineers at the sponsor company what the author understood the model to represent, to document the current *independent quality validation* model in detail and to clarify all uncertainties about the model. Additional information such as requirements documents and test specification documents were also provided to the author at this stage for added support.

Due to the fact that the sponsor company subcontracts majority of its testing activities to facilities run by MIRA Ltd, a visit was made to the test sites in Basildon, Essex as an aid for full understanding on the product assurance model for *independent quality validation*.

4.2 The Model

The independent quality validation model for testing product hardware components at the sponsor company is titled *'PA Hardware Validation Test Cycle'* and it includes the detailed steps for the environmental and electromagnetic compatibility testing carried out by the sponsor company on hardware components. For excerpts from the model, please see appendix ‘c’.

4.3 Closing Remarks

Please note that only excerpts from the sponsor company’s ‘independent quality validation model’ are provided and not the full working implemented model. This is to protect the sponsor company’s real model and these excerpts have only been included to support the benchmark study and to validate the project.

5 BENCHMARK STUDY AND ANALYSIS OF KEY FINDINGS

The intention of the survey was focused mainly on identifying the independent quality validation techniques' best practices for testing hardware components in product design and development. This chapter identifies the elements of the benchmark study; it details how the benchmark study for the project was executed in order to achieve success in the project. How the questionnaire used for the survey was designed and how data was collected and analysed for the project is also detailed. Finally the chapter details the results from the survey that was carried out for the study and the key findings that were identified from the study.

5.1 Questionnaire Design

The questionnaire structure was formed based on theory from the academic literature review and the *independent quality validation model* the author was provided with by the sponsor company.

- The questions in section 1 of the questionnaire were included to get general information on the participants (see appendix B).
- The questions in section 2 were focusing on if there was a specific department or team within the participating organisations that dealt with the testing of hardware components and was also trying to ascertain whether or not the participating organisations had well defined IQV models.
- Section 3 questions were focusing on the testing facilities used by the participating companies for physical hardware components testing and trying to identify the activities and tasks included in the participating companies IQV models.
- The questions in section 4 focused on how testing of physical hardware components were initiated in the participating companies.
- Section 5 questions were focused on how the participating organisations plan for the testing of physical components of their product range.
- Section 6 questions focused on how the requirements documents for carrying out the physical hardware tests were developed.

Please see Appendix B for full copy of the questionnaire.

5.2 Results

This section details the analysis of the benchmark study. Some comparisons are made between the responses from the participating companies and the responses from the sponsor company.

5.2.1 Section 1 - General Information

The companies that participated in the benchmark study were; Alstom, Continental, Cranfield Precision, Dytech ENSA SL, Edwards Vacuum, Elektra, Joerns Healthcare, Kodak, Kongsberg Devotek AS, Leyland Trucks, Lodge Cottrell, Lotus Engineering, METSEC, Oclaro, Rotorion, Sperry Marine, TVS motor company. The following analyses give a broad view of the years of experience the personnel at these organisations. Some comparisons will also be made to support and validate points made within the analyses.

Question 1.8 – Number of years in present role?

Figure 5.1 shows the varied number of years that the respondents of the survey have worked. The number of years worked ranged from as little as 1 year to as high as over 20 years. The average number of years participants had been in their present roles was 7 years.

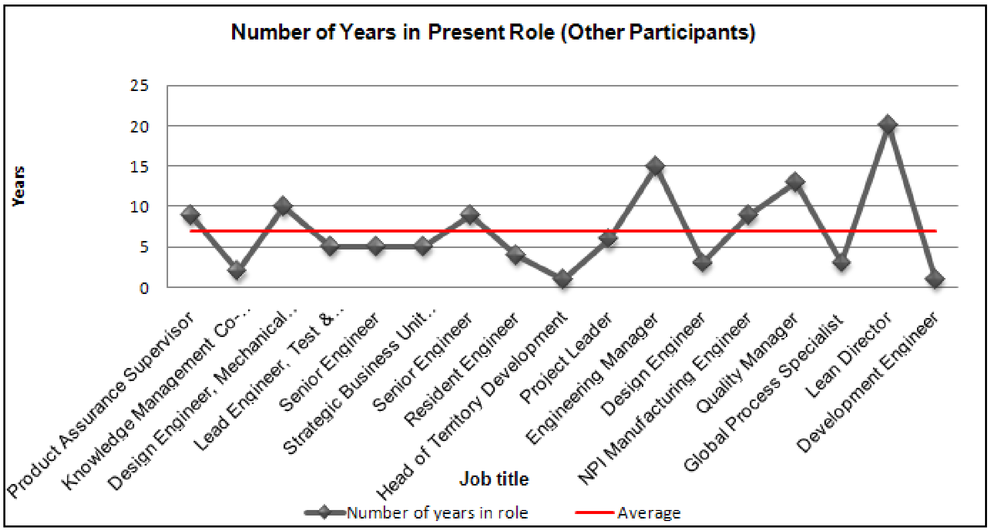


Figure 5.1: Chart showing the number of years participants have worked in present roles

This shows that most of the organisations that participated in the study tend to keep their engineers / personnel in order to preserve knowledge and experience, which is beneficial in the long run as it allows for the quality of service delivered to customers up to standard and in the long run could help gain competitive advantage which in turn could increase market share amongst competitors.

Question 1.9 – How many years experience do you have in the testing of hardware components?

Figure 5.2 shows how many years working experience the respondents of the survey have testing hardware components. The number of years worked in testing hardware components ranged from as low as ‘1 year’ to as high as ‘60 years’. The average years of experience that participants had testing hardware components was ‘17 years’.

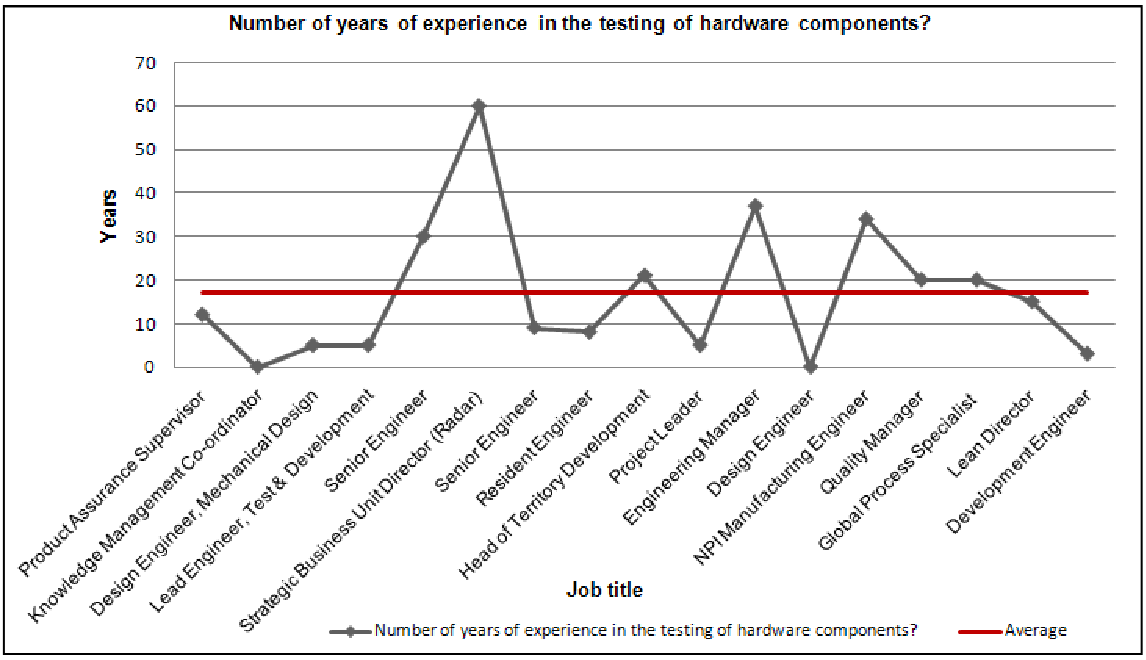


Figure 5.2: Chart showing the number of years participants have worked testing hardware components.

This shows that the participants in the survey have high levels of experience and this supports the previous analysis in question 1.8.

Question 1.8 and 1.9 compared: Number of years in present role vs. Years of experience in testing hardware components.

Figure 5.3 shows the comparison between the number of years participants have worked in their present roles versus years of experience participants have in the testing of hardware components. The study showed that within the industry, there is a vast amount of experience in hardware testing, and that companies are retaining as much of their knowledge as possible, which is beneficial in the long run to the companies as well as potential employees to these companies.

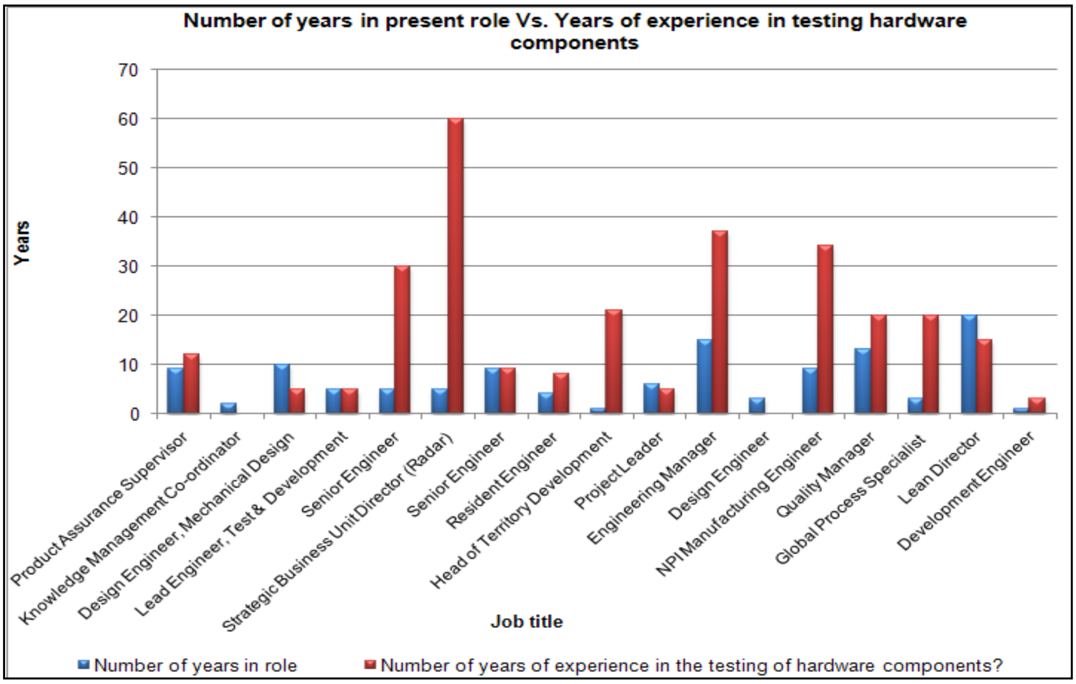


Figure 5.3: Chart showing the comparison between the number of years in a role and the years of experience the participants have in testing hardware components.

Question 1.11 – What manufacturing sector does your organisation operate in?

The study covered a variety of sectors within the manfacturing industry. Figure 5.4 shows the different sectors of the manufacturing industry that participated in the benchmark study. *'33%'* of the companies were from the automotive sector, *'11%'* from the medical sector, *'6%'* from consumer goods, *'6%'* from the electronics sector, *'6%'* from the marine sector, *'6%'* from the manufacturers of vacuum equipment, *'6%'* from the machine tools sector, *'6%'* from power generation & equipment and services, *'6%'* from the telecommunications sector, *'6%'* from the yellow goods and construction sector, *'6%'* from environmental and pollution control and *'6%'* from consumer goods.

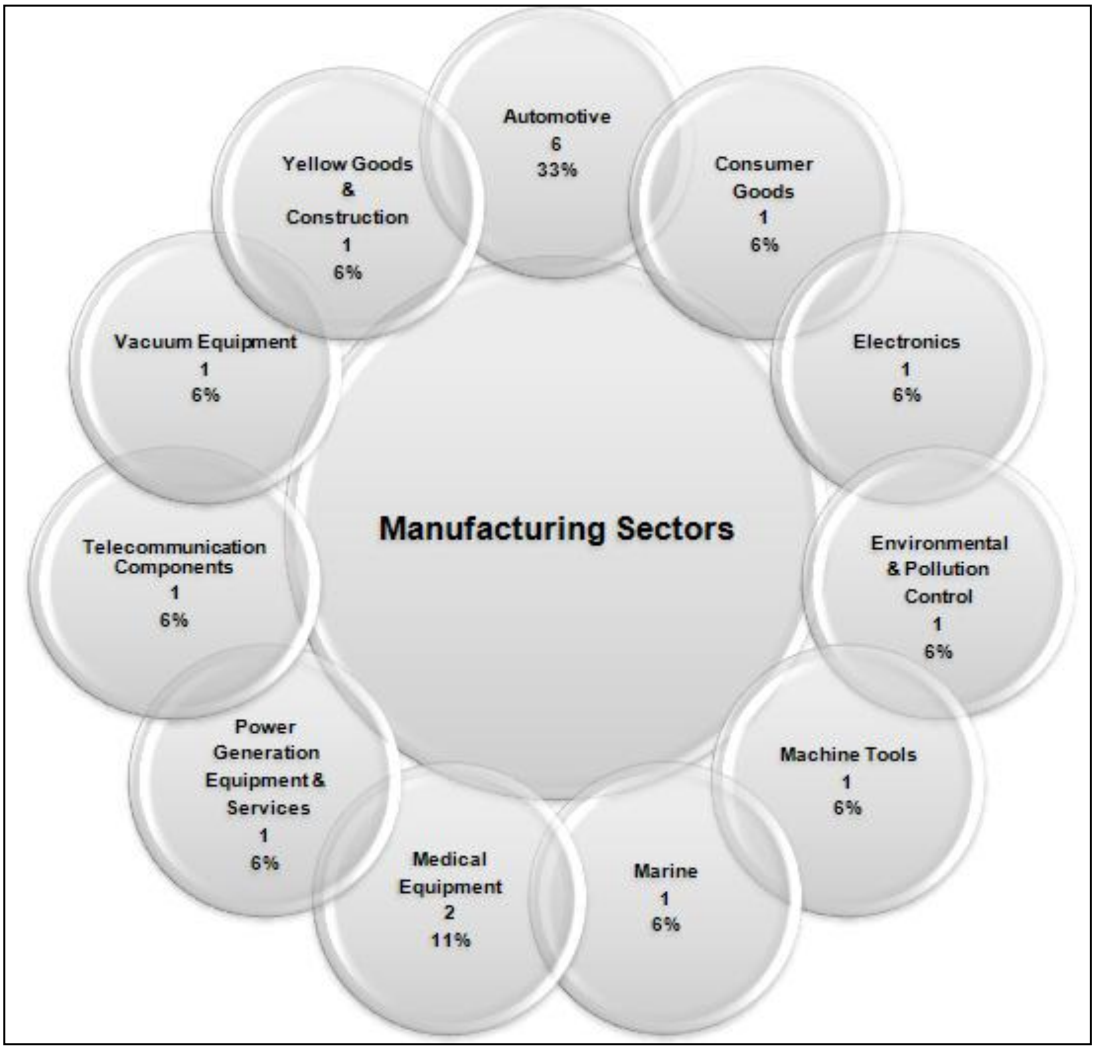


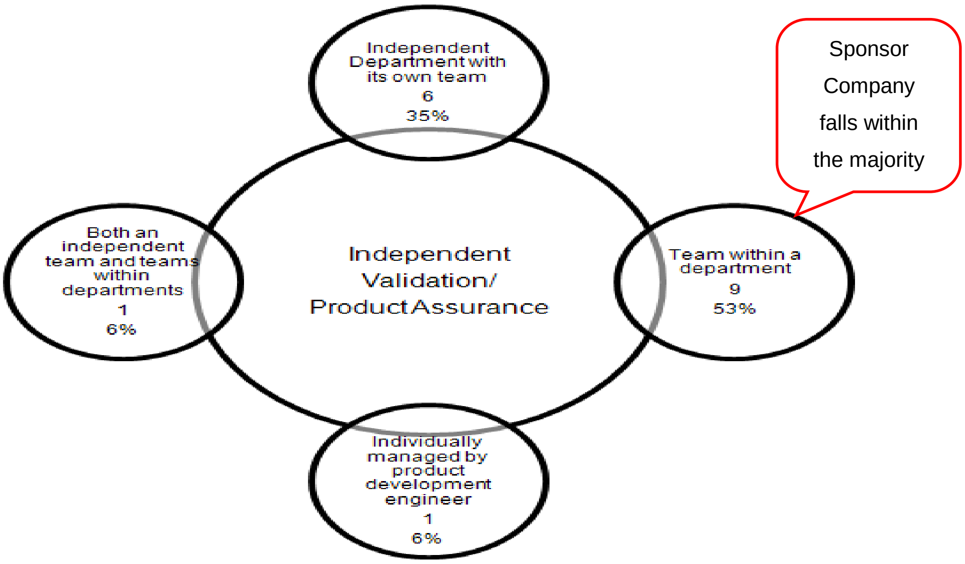
Figure 5.4: Chart showing the manufacturing sectors that participated in the benchmark study

This shows that there was good interest in the subject area and indicates that the area of product quality is still a vital aspect of product development, which could present opportunities to carry out further benchmark studies with these industrial sectors.

5.3 Section 2 – Independent validation product assurance department / team

Question 2.1- The Independent Validation / Product Assurance activities in your organisation include: An independent department with its own team; a team within a department (such as product engineering / product development department); we do not have either a department or team; other (please specify)

The results from the survey showed that '35%' of the organisations that participated have an independent department with its own team, '53%' of the organisations have a team within a department such as product engineering / product development, '6%' of the organisations stated that the independent validation/product assurance activities within the organisation is individually managed by the product development engineer whilst the last '6%' stated that their organisation has both an independent team and teams within departments that handle the independent validation/product assurance activities.



Sponsor Company falls within the majority

Figure 5.5: Chart showing the percentage of independent validation / product activities within the participating organisations

The analysis from this section shows that the sponsor company has a team within a department that is responsible for independent validation / product assurance and so fall within the majority.

Question 2.2 – The name of the department or activities that are responsible for independent validation / product assurance?

The reviewed academic literature showed that typically the department that handles testing within an organisation is usually the 'research and development' department. However the benchmark study showed differently.

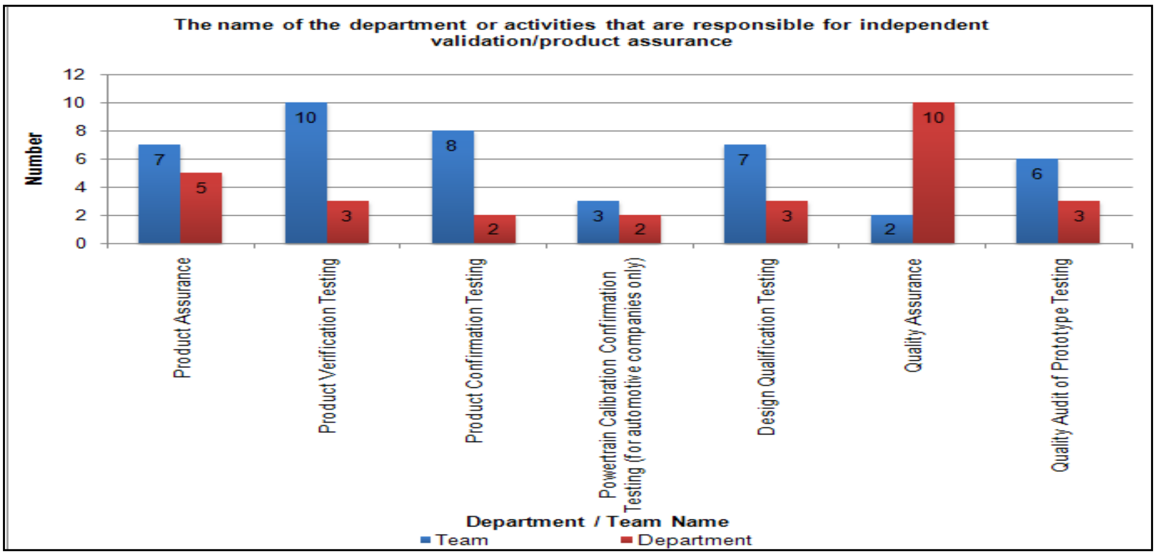


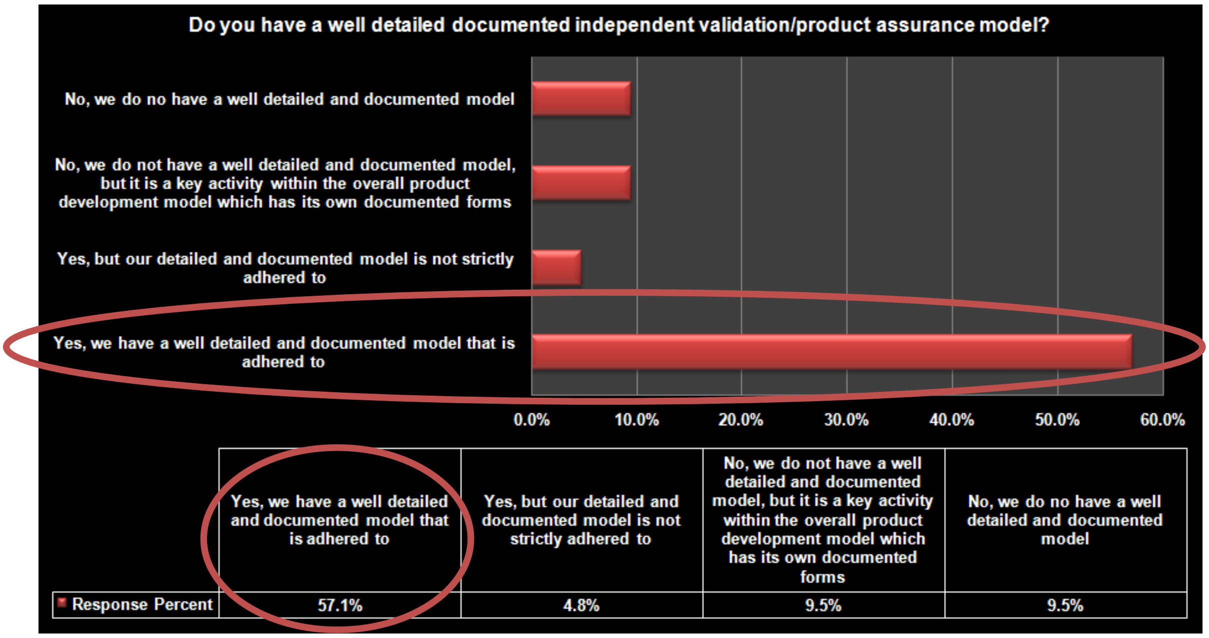
Figure 5.6: Bar chart showing the names of the departments or activities that are responsible for independent validation/product assurance

In figure 5.6, the most popular name for the team that is responsible for independent validation / product assurance is 'product verification testing', where '10' out of the 17 i.e. 59% of the participating organisations selected this option and the most popular department name is 'quality assurance', where '10' out of the 17 i.e. 59% of the participating organisations selected this option.

Question 2.3: Do you have a well detailed documented independent validation / product assurance model?

Out of the 17 companies that participated, '57.1%' responded to having a well detailed and documented model that is adhered to. '9.5%' stated that they do not have a well detailed and documented model, but have independent validation as a key activity within the overall product development model with its own documented forms. '9.5%' also stated that they do not have a well detailed and documented model.

In this case, this could be as a result of the fact that some of the participating organisations are not involved in any forms of physical hardware (product) testing and ‘4.8%’ of the participants stated that they do have a well detailed and documented model, but it is not strictly adhered to.

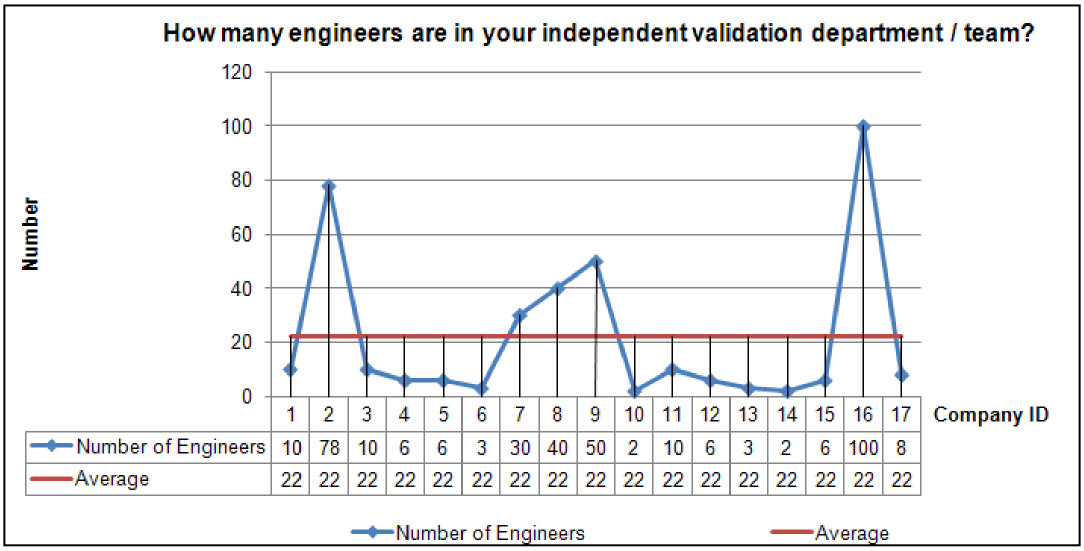


	Yes, we have a well detailed and documented model that is adhered to	Yes, but our detailed and documented model is not strictly adhered to	No, we do not have a well detailed and documented model, but it is a key activity within the overall product development model which has its own documented forms	No, we do no have a well detailed and documented model
🟥 Response Percent	57.1%	4.8%	9.5%	9.5%

Figure 5.7: Chart showing the percentage of organisations that have well detailed documented independent validation / product assurance models

Question 2.4: How many engineers are in your independent validation department / team?

Figure 5.8 shows the varying numbers of engineers the different participating organisations have working within their independent validation departments / teams. The highest number was 100 and the lowest number was 2.



Company ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Number of Engineers	10	78	10	6	6	3	30	40	50	2	10	6	3	2	6	100	8
Average	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22

Figure 5.8: Chart showing the number of engineers in the participating companies independent validation department / team

Question 2.4, 2.5 and 2.6 compared: Number of engineers vs. Number of major and minor projects each engineer handles at a time.

The total sample size was 17 companies originally, with a range of engineers working in their independent validation department / team. The highest number of engineers was ‘100’ and the lowest number was ‘2’ and so on average the number of engineers was ‘22’. The highest number of major projects handled by an engineer was ‘10’ and the lowest was ‘1’. The highest number of minor projects handled by an engineer was ‘30’ and the lowest number was ‘1’. After careful inspection of the data and filtering through to identify typical workload, it was evident that a few of the participants were not within the identified job roles that would know specifically about hardware testing and these participants also had the highest numbers of engineers.

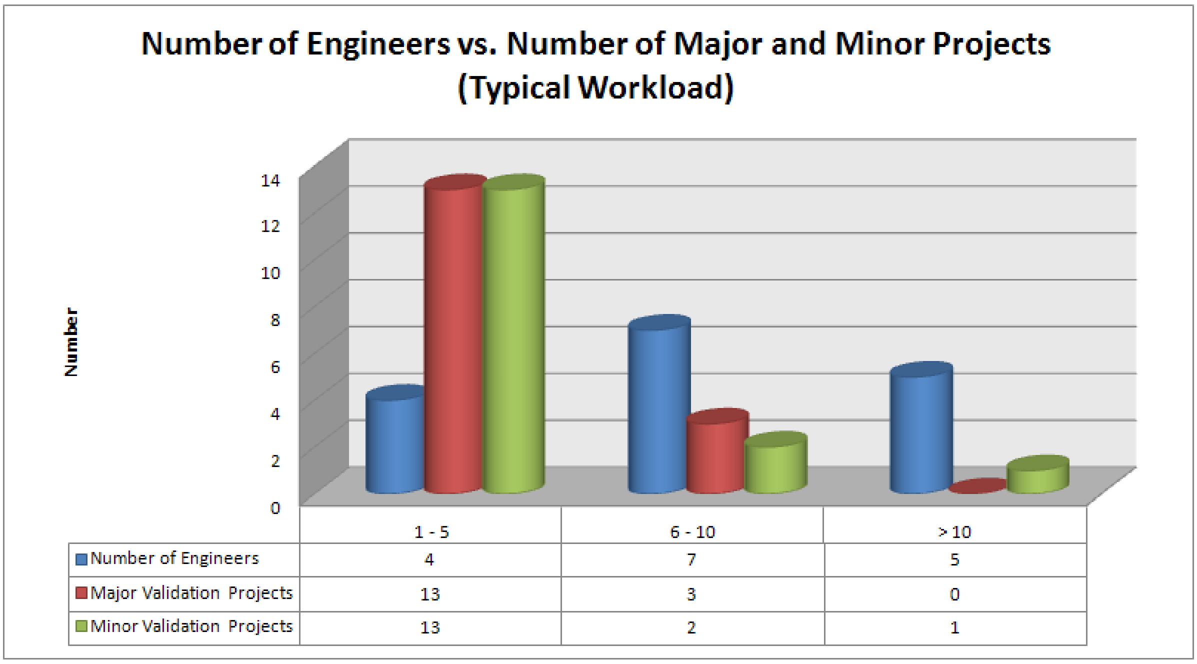


Figure 5.9: chart showing the typical workload of engineers in the participating companies

5.4 Question 3 – Testing Facility

Question 3.1: The physical testing of hardware (product) components are tested in: own facility, sister company testing facility, sub-contractor independent testing facility and we do not do physical testing, we do only virtual simulation & testing (e.g. CAE-FEA, CFD, Virtual Reality).

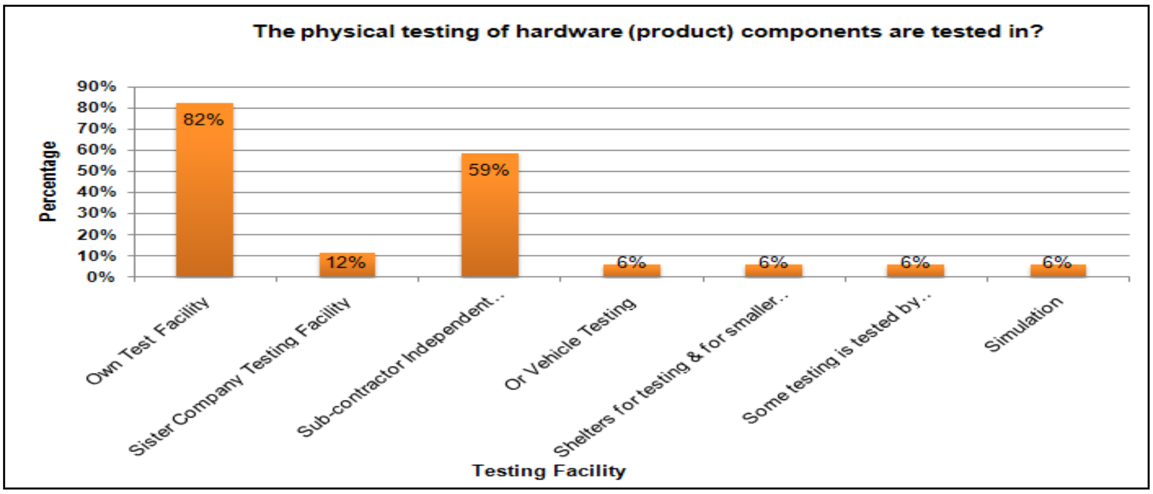


Figure 5.10: Chart showing facilities where physical components are tested

The study showed 82% of participating companies carrying out testing in their own test facility, 12% carry out testing in a sister company's testing facility and 59% sub-contract to an independent testing facility. 4 of the participating companies had their own testing methods which include; Or vehicle testing (6%), shelters for testing or concession processes on production line for small projects (6%), Strathclyde University (6%) and simulation (6%).

Question 3.3: Do you generally classify the physical hardware (product) testing into any of the following?

Of the 17 companies that participated, 12 *always* classify physical hardware testing as *environmental (climatic) testing*, and 6 *sometimes classify* physical hardware testing as *environmental (climatic) testing*. 10 always classify physical hardware testing as EMC, while 3 sometimes and 4 never classify physical hardware testing as EMC. 12 out of the 17 always classify into electrical testing, 3 sometimes and 2 never classify physical hardware testing into electrical testing. 13 always classify into mechanical testing and 4 sometimes classify into mechanical testing. The benchmark study identified 2 other classifications that were not identified from literature. They are; environmental (outside climatic), one participating company stated this and another stated radiation resistance testing.

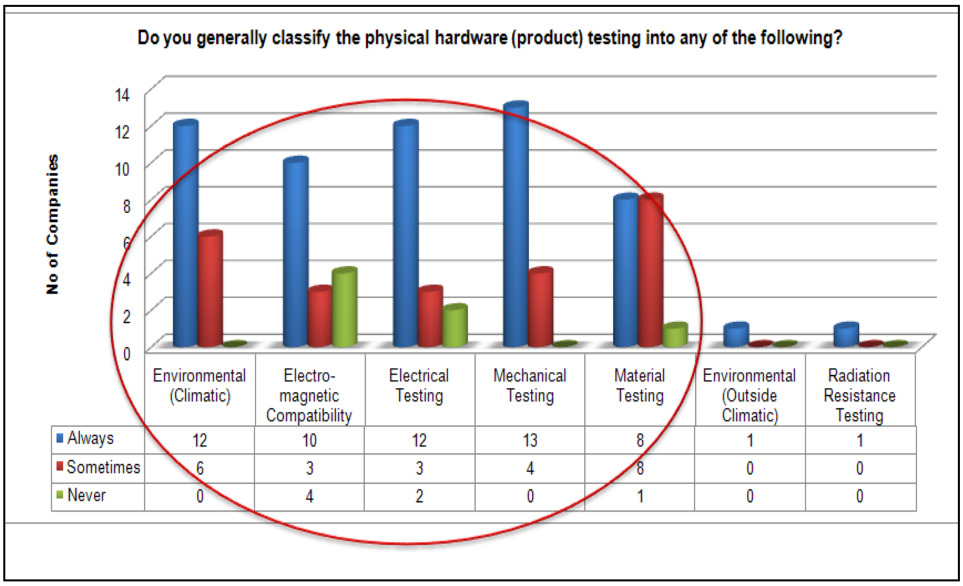


Figure 5.11: Chart showing the classifications of physical hardware testing

Question 3.4: Are any of these specific types of tests carried out on hardware (product) components?

From the literature review, 21 different types of tests that could be administered on hardware product components were identified. They are; *visual non-destructive testing, liquid penetrant testing, magnetic particle testing, ultrasonic testing, radiography, eddy-current testing, acoustic emission monitoring, leak testing, thermography, strain sensing, monochromatic laser testing, electrical resistivity, computed tomography, chemical analysis ad surface topography, aerodynamics testing, durability, fatigue and functional performance, noise, vibration and harshness (NVH) testing, powertrain and emissions testing, proving ground testing, ride and handling testing and safety and structural testing.*

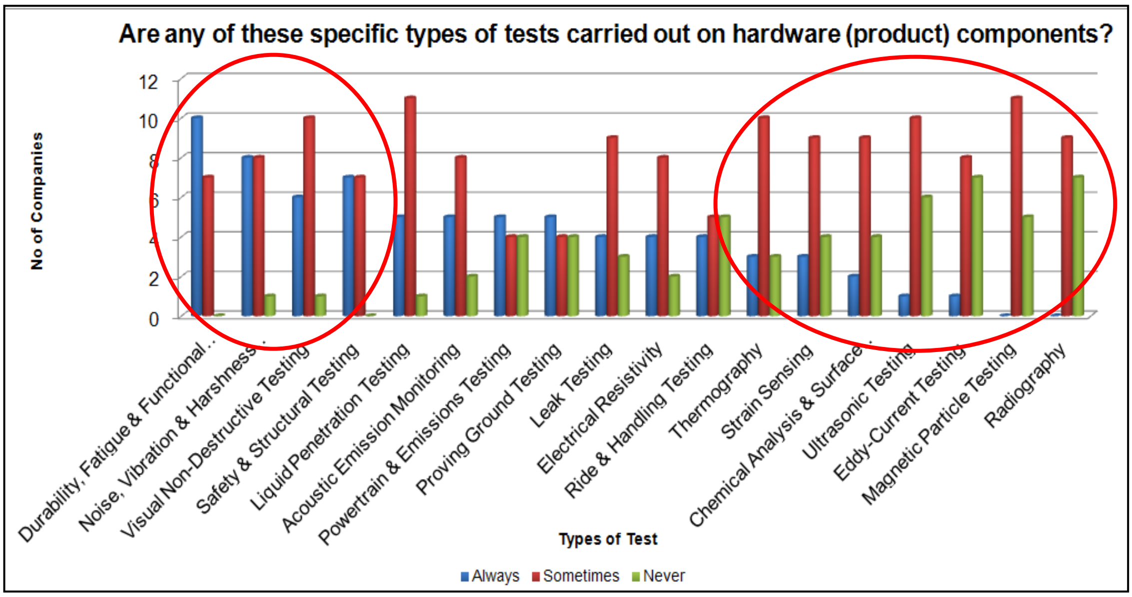


Figure 5.11: Chart showing the overview of responses to the types of tests carried out on the participating companies' hardware (product) components

Figure 5.11 shows the overview of the different specific types of tests carried out on hardware (product) components. Of the 21 types identified, 18 of them have been incorporated into the benchmark study. This is as a result of careful filtering of the responses collected. The study showed in this case that majority (approximately 59%) of the respondents *‘always’* carry out *durability, fatigue and functional performance tests* and the remaining (41%), *sometimes* carry out this test. (47%) *always* carry out *NVH testing* and (47%) *sometimes* carry it out and (6%) *never* carry out *NVH testing.* (35%) *always* carry out *visual non-destructive testing*, (59%) *sometimes* carry out this same test and 6% *never* carry out this testing technique. (50%) of the respondents *always* and *sometimes* carry out *safety and structural testing* which means that if they are more often than not safety and structural testing is usually carried out on hardware components.

Question 3.5 - Which of the following activities / tasks are included in the ‘Independent Quality Validation Model’?

The independent quality validation model at the sponsor company consisted of a number of activities / tasks. The study showed that majority of the participating companies always analyse the test data to define improvement areas for the hardware components design (16 of the 17 companies). 15 of the 17 participating companies always develop hardware test plan, approve test plan for the physical testing of the hardware components, and write test reports. 14 of the 17 companies always define test plan including test cases, and calculate detailed cost estimation of test. 13 always make decisions as to whether testing of the hardware component should proceed or not in their IQV model and also schedule tests. 12 of the 17 always validate their test plans through peer review with departmental colleague(s), 11 always carry out tests, 10 always specify the requirements for manufacturing the required test equipment and 9 always re-prioritise tests as part of their IQV model.

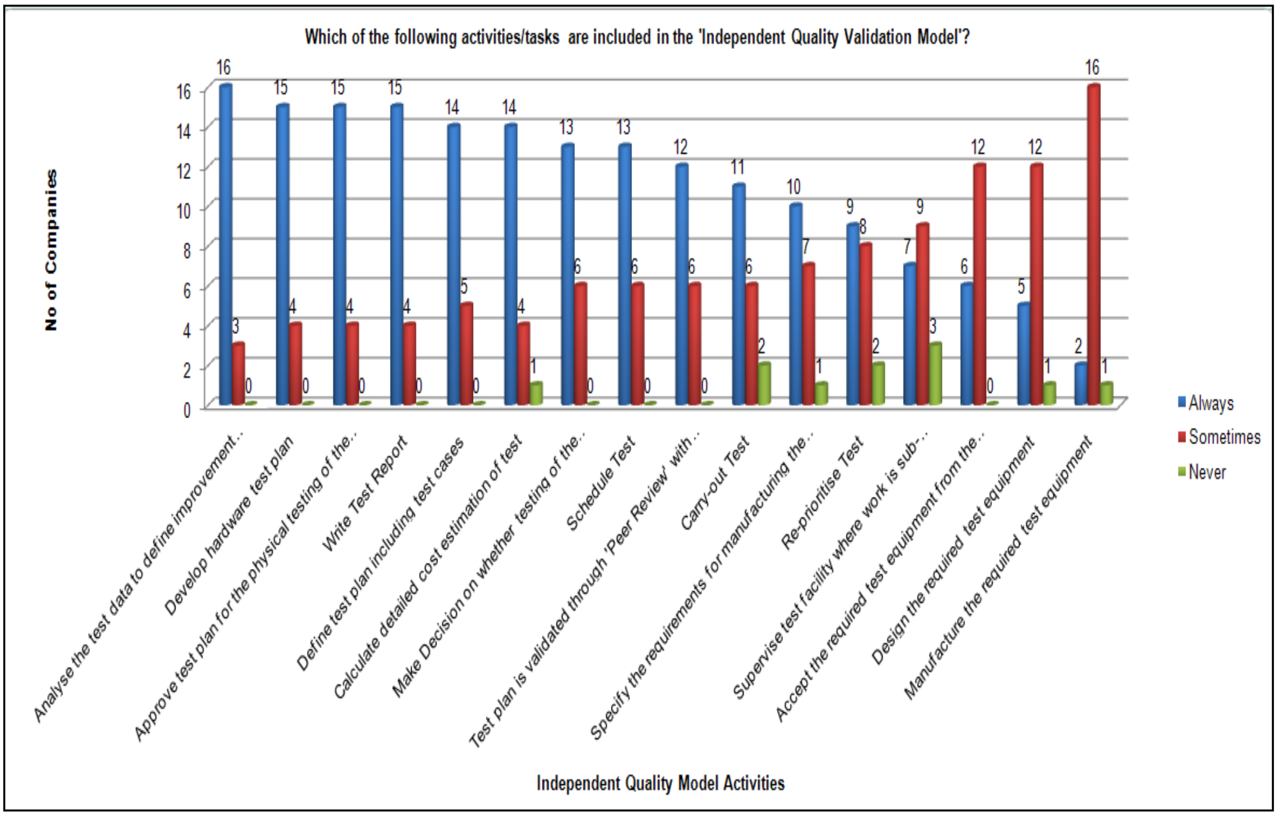


Figure 5.12: Chart showing the activities/tasks included in the participating companies' quality validation model

The study also showed that apart from the majority which fall under the always category, 16 companies sometimes manufacture the required test equipment, 12 sometimes design the required test equipment and accept the required test equipment from the manufacturers' for the physical testing of hardware components and 9 out of the 17 companies sometimes supervise the test facility where work is sub-contracted to.

5.5 Question 4 – Test Initiation Process

Question 4.1 - Who initiates a test request?

The study showed that in majority of the participating companies (approximately 77%) product development project leader initiates a test request, while approximately 53% of companies state that the product engineer initiates the test request.

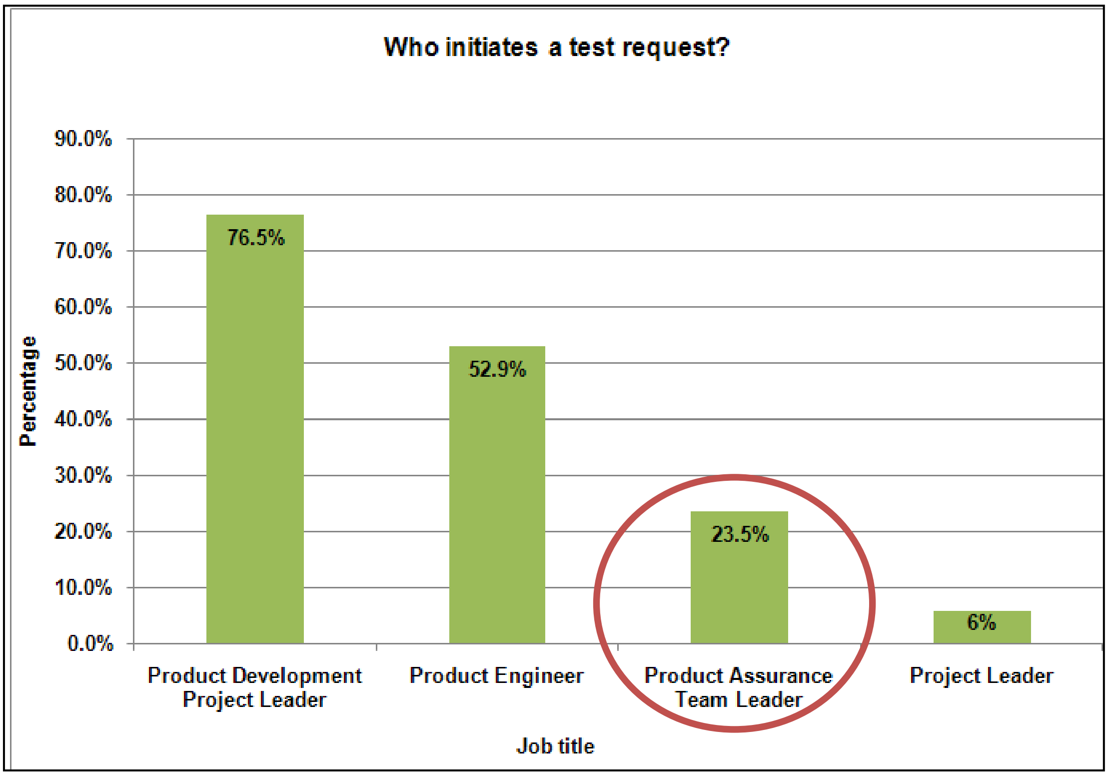


Figure 5.13: Chart showing the employees that initiate test requests at the participating companies

At the sponsor company, the product assurance team leader usually initiates the test request and in the study, only 24% approximately of the participating companies have an employee with this job title who initiates the test request.

Question 4.2 - Prototypes Manufacturing:

The study showed that in prototype manufacturing; only 6% of participating companies' prototypes needs to be manufactured with exactly the same process as the finished product. 29% state that only key components always need to be manufactured using the exact same process as the finished product.

12% always have another alternative cost efficient process that could be used to manufacture the prototype. The sometimes category shows 76% for prototypes that need to manufactured with exactly the same process as the finished product, 59% for only key components and 59% for any other alternative cost efficient process. This could mean that with prototype manufacturing, if materials have been tested before being used in the manufacture of prototypes, there is no need incurring added costs to manufacture prototypes that might end up being destroyed anyway.

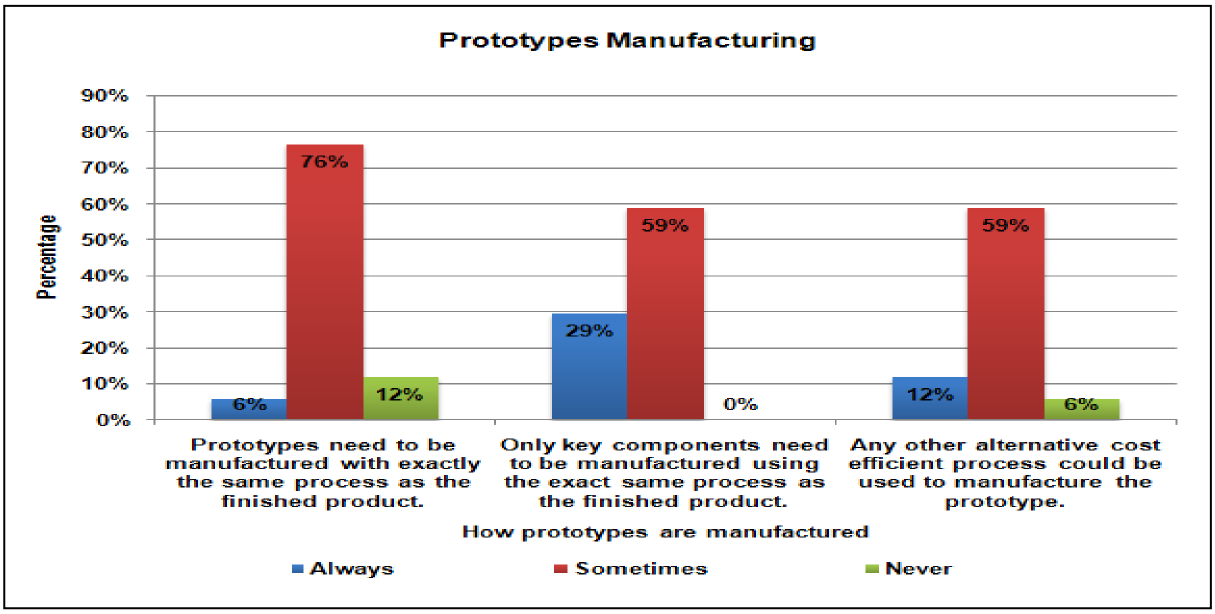


Figure 5.14 – chart showing how prototypes are manufactured in the participating companies

5.6 Section 5 – Test Planning

Question 5.1 - What are the typical data inputs for defining test plans?

The study showed that 88% of the participating companies *always* define system requirements in their test plan, while only 6% *sometimes* define system requirements in their test plan. 76% *always* define mechanical requirements, while 24% *sometimes* define mechanical requirements. 71% *always* define electrical requirements, while 24% *sometimes* define electrical requirements and only 6% of the participating companies *never* define electrical requirements. 65% of the participating companies *always* make project folders available, while only 24% of the participating companies *sometimes* make project folders available for defining test plans.

A single participating company which accounts for 6% stated that results from simulation models are typical data inputs for defining test plans. This leaves room for investigation in this case as simulation models are known to aid efficiency and resource optimisation.

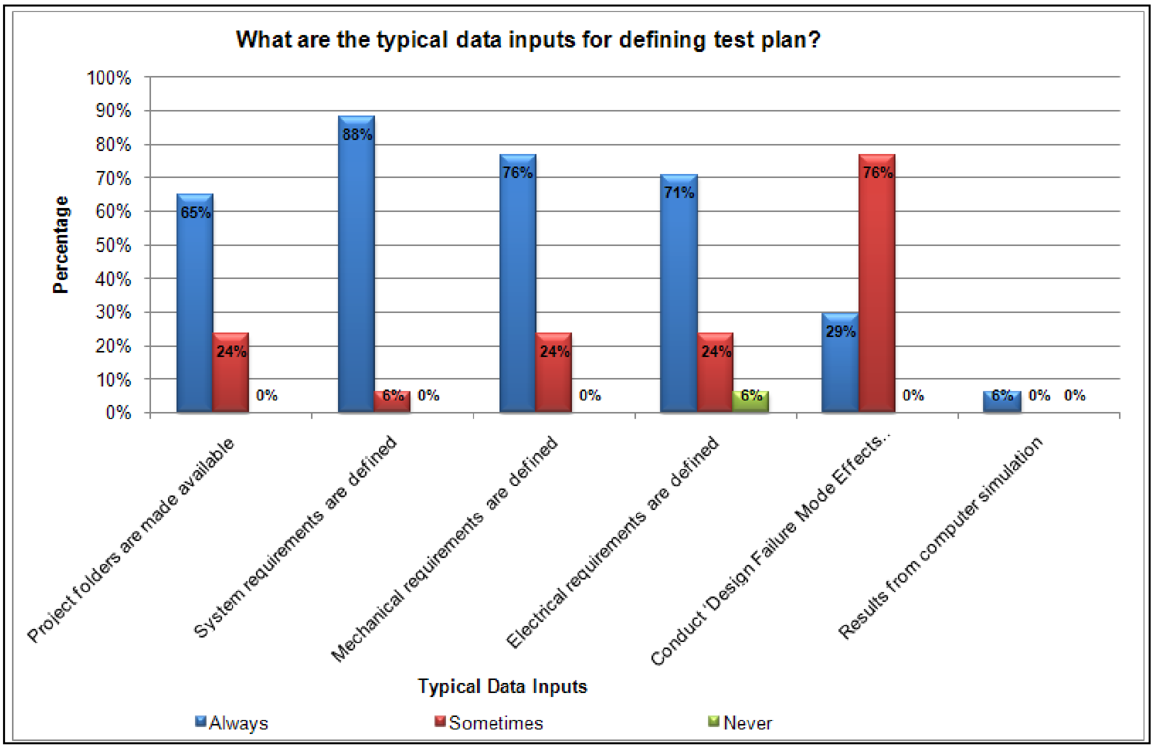
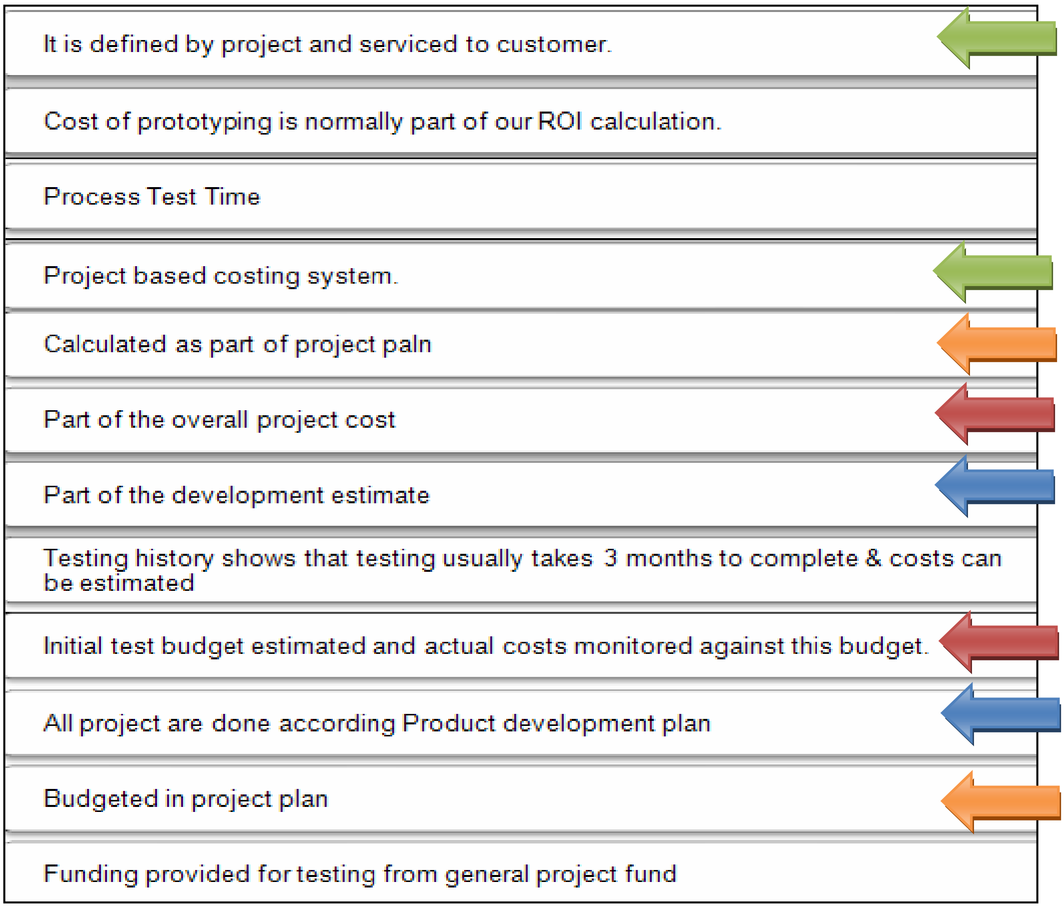


Figure 5.15: Chart showing the typical data inputs in the definition of a test plan

The sponsor company always defines all the five data inputs and when compared to the results from the study, this is seen as good practice. In the case of DFMEA on the other hand, only 29% of the participating companies *always* conduct this type of analysis in their test plan, while 76% sometimes conduct this type of analysis. This shows that it might not be a necessity in all cases but might be more product and industry specific.

Question 5.3 - Please state how costing is integrated into your test plan?

This was an open-ended question that allowed all participants to freely specify how costing is integrated into the test planning aspect of *independent quality validation model* at their companies.



It is defined by project and serviced to customer.

Cost of prototyping is normally part of our ROI calculation.

Process Test Time

Project based costing system.

Calculated as part of project paln

Part of the overall project cost

Part of the development estimate

Testing history shows that testing usually takes 3 months to complete & costs can be estimated

Initial test budget estimated and actual costs monitored against this budget.

All project are done according Product development plan

Budgeted in project plan

Funding provided for testing from general project fund

Figure 5.16: Chart showing the different ways by which costing can be integrated into test plans for hardware components

From the responses in figure, it is acceptable to say that costing is generally defined by project type, but integrated into test plans as part of the project plan, part of the product development plan, calculated as part of the overall project cost, or as a part of the initial test budget and actual costs monitored against this budget.

Question 5.4 - How do you make decisions about tests that need to go on and those that do not?

The study showed that 25% of the participating companies always carry out technical review with test facility and 75% of the participating companies *sometimes* carry out technical reviews with test facility in order to make decisions about tests that need to go o and those that do not. 47% *always* receive test samples, while 53% *sometimes* receive test samples in order to make decisions about what tests need to proceed and those that do not. 40% of the participating companies *always* conduct pre-test inspection and set-up, while 60% *sometimes* conduct pre-test inspections and set-up. 25% *always* decide if to proceed with test or not under advisory notice, while 67% *sometimes* decide if to proceed with test or not under advisory notice and only 8% of the participating companies *never* decide if to proceed with test or not under advisory notice.

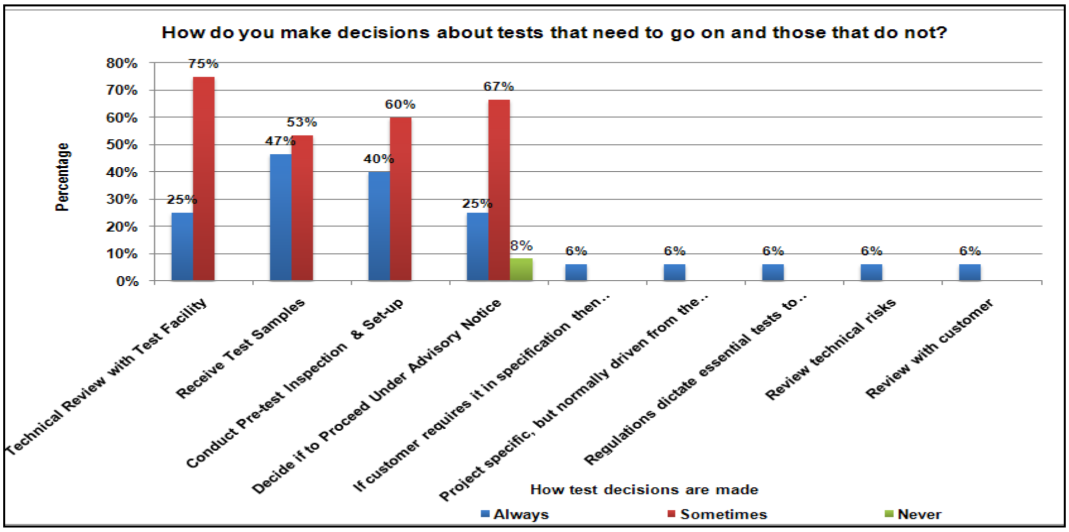


Figure 5.17: Chart showing how decisions are made about tests that need to go on and those that do not

The first four options on the chart are similar to what the sponsor company do, but the benchmark study revealed that some of the participating companies go about making decisions for tests that need to go on and those that do not. These include; if requested for in customer specification (6%), if regulations dictate essential tests to conduct, then confidence tests may or may not be carried out (6%), review of technical risks (6%) and review with customer (6%)

5.7 Section 6 - Requirements Document

Question 6.1 - What documents are required before testing can commence?

The study showed that 94% of the participating companies have to have a test specification document before testing on a hardware component can commence. 76% of the participants have to have a test request document, 65% have to have a test costs estimate document, 59% have to have a test house schedule document and 35% have to have peer review documentation before testing can commence.

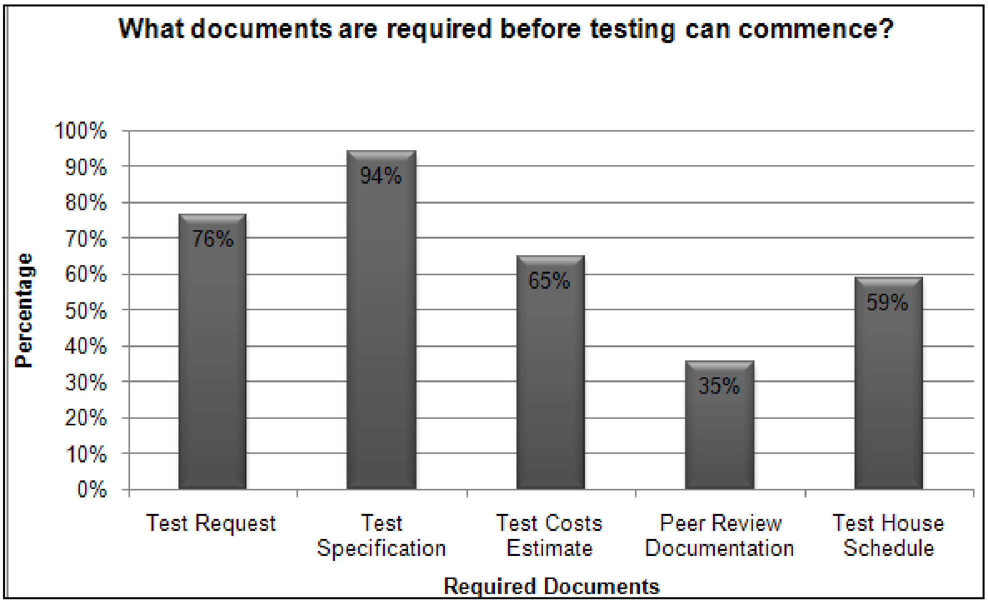


Figure 5.18: Chart showing the different documents required before testing can commence

These results are a good comparison with the sponsor company as all or some of these documents usually have to be made available before testing of a hardware component can commence.

5.8 Recommendations

Based on the results achieved from the benchmark study, recommendations were made and a roadmap with a recommended process phase map was proposed to the sponsor company, which was within the scope of the project.

The principles are as follows:

Principle 1: Ultrasonic Testing

- Involves the use of high frequency sound waves coupled to the components to be inspected and studying the reflection pattern of these waves.
- Finds increased applications in various industries. Several wave modes such as longitudinal, shear and surface waves can be used depending on the orientation and location of the discontinuities.

Advantages:

- Can reveal internal defects.
- High sensitivity to most cracks and flaws.
- High speed test with immediate results.
- Can be automated and recorded.
- Portable.
- High penetration in most important materials (up to 60ft in steel).
- Indicates flaw size and location.
- Access to only one side is required.
- Can also be used to measure thickness, Poisson’s ratio, or elastic modulus.
- Presents no radiation or safety hazard.

Limitations:

- Difficult to use with complex shapes.
- External surfaces and defect orientation can affect the test (may need dual transducer or multiple inspections).
- A couplant is required.
- The area coverage is small (inspection of large areas requires scanning).
- Trained, experienced, and motivated technicians may be required.

System Requirements and Implementation:

- An ultrasonic system begins with a pulsed oscillator and transducer, a device that transforms electrical energy into mechanical vibrations.
- The pulsed oscillator generates a burst of alternating voltage, with a characteristic principal frequency, duration, profile, and repetition rate.
- This burst is then applied to a sending transducer, which uses a piezoelectric crystal to convert the electrical oscillations into mechanical vibrations.
- Due to the fact that air is a poor transmitter of ultrasonic waves, an acoustic *coupling medium* – generally a liquid such as oil or water is required to link the transducer to the piece to be inspected and transmit the vibrations into the part.
- The pulsed vibrations then propagate through the part with a velocity that depends on the density and elasticity of the test material.
- A receiving transducer is then used to convert the transmitted or reflected vibrations back into electrical signals.
- The receiving transducer is often identical to the sending unit, and the same transducer can actually perform both functions.
- A receiving unit then amplifies, filters, and processes the signal for display, possible recording, and final interpretation.
- An electronic clock is generally integrated into the system to time the responses and provide reference signals for comparison purposes.
- Depending on the test objectives and part geometry, several different inspection methods can be employed:
    i. Pulse-echo technique – an ultrasonic pulse is introduced into the piece to be inspected, and the echoes from opposing surfaces and any intervening flaws are detected by the receiver.
    ii. Through-transmission technique – requires separate sending and receiving transducers. A pulse is emitted by the sending transducer and detected by a receiver on the opposite surface.
    iii. Resonance testing – can be used to determine the thickness of a plate or sheet from one side of the material. Input pulses of

varying frequency are fed into the material. When resonance is detected by an increase in energy at the transducer, the thickness can be calculated from the speed of sound in the material and the time of traverse.

Principle 2: Eddy-Current Testing

- Can be used to detect surface and near-surface flaws, such as cracks, voids, inclusions, and seams. Stress concentrations, differences in metal chemistry, or variations in heat treatment (i.e. microstructure and hardness) will all affect the magnetic permeability and conductivity of a metal and therefore alter the eddy-current characteristics
- When an electrically conductive material is brought near an alternating-current coil that produces an alternating magnetic field, surface currents (eddy currents) are generated in the material. These surface currents generate their own magnetic field, which interacts with the original, modifying the impedance of the originating coil.
- Various material properties and/or defects can affect the magnitude and direction of the induced eddy currents and can be detected by the electronics.

Advantages:

- Can detect both surface and near-surface irregularities.
- Applicable to both ferrous and nonferrous metals.
- Versatile – can detect flaws, variations in alloy or heat treatment , variations in alloy or heat treatment, variations in plating or coating thickness, wall thickness and crack depth.
- Intimate contact with the specimen is not required.
- Can be automated.

- Electrical circuitry can be adjusted to select sensitivity and function.
- Pass/fail inspection is easily conducted.
- High Speed.
- Low cost.
- No final cleanup is required.

Limitations:

- Response is sensitive to a number of variables, so interpretation may be difficult.
- Sensitivity varies with depth, and depth of inspection depends on the test frequency.
- Reference standards are needed for comparison.
- Trained operators are generally required.
- Only applicable to conductive materials, such as metals.
- Some difficulties may be encountered with ferromagnetic materials.
- Depth of penetration is limited
- Must have accessibility of coil or probe.
- Constant separation distance between coils and specimen is required for good results.

System Requirements and Implementation:

- Eddy-current test equipment can range from simple, portable units with handheld probes to fully automated systems with computer control and analysis.
- Each system includes;

i. A source of changing magnetic field capable of inducing eddy currents in the part being tested. This source generally takes the form of a coil (or coil-containing probe) carrying alternating current of a specific frequency and amplitude. (*Note:* High frequency gives shallow penetration and a higher eddy current density on the surface. Low frequency gives deeper penetration.) Various coil geometries are used for different-shaped specimens.

ii. A means of sensing the field changes caused by the interaction of the eddy currents with the original magnetic field. Either the exciting coil itself or a secondary sensing coil can be used to detect the impedance changes. Differential testing can be performed using two oppositely wound coils wired in series. In this method, only differences in the signals between the two coils are detected bas one or both coils are scanned over the specimen.

iii. A means of measuring and interpreting the resulting impedance changes. The simplest method is to measure the induced voltage of the sensing coil, a reading that evaluates the cumulative effect of all variables affecting the eddy-current field. Familiarity with characteristic impedance responses or comparison with signals from other parts or other locations can be used to identify or interpret the desired features in the specimen.

Principle 3: Monochromatic Laser Testing

- Monochromatic laser light is an advanced optical method that can be used to detect differences in the backscattered pattern from a part and a master. It is essentially electromagnetic radiation derived from photo emissions from atoms.

Advantages:

- The presence or absence of geometrical features such as holes or gear teeth is readily detected.

- Holograms can provide three-dimensional images of an object, and holographic inter-ferometry can detect minute changes in the shape of an object under stress.
- Emissions occur in the inverse manner resulting in the release of absorbed quanta as well as another atomic property known as ground state energy and monochromatic light and laser technologies take advantage of these atomic transitions.
- When a monochromatic light is directed to a substance or material, it induces transitions which are characteristic to the chemical properties of the constituent elements of such material.

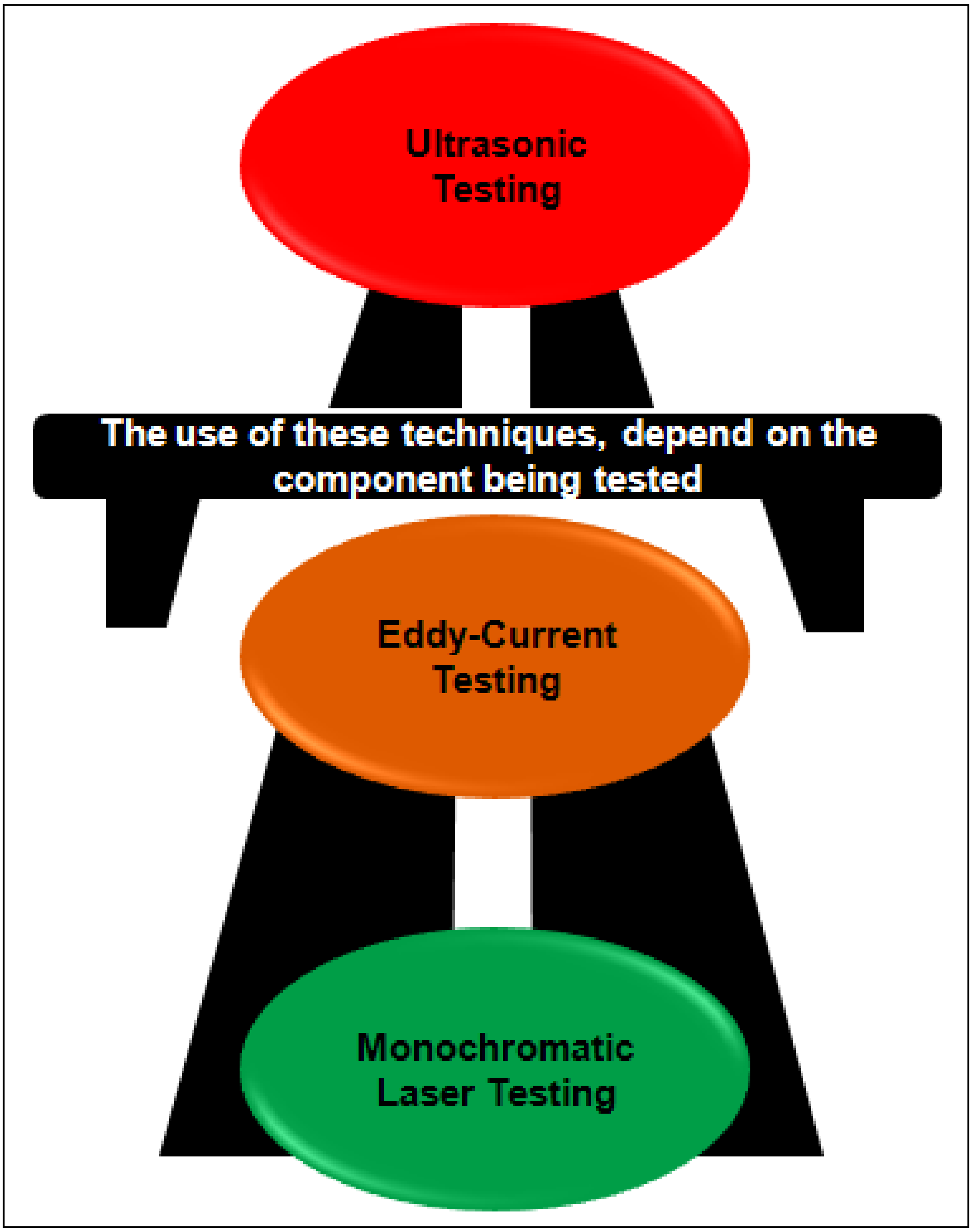


Figure 5.19: Proposed best practices to be considered for implementation at the sponsor company

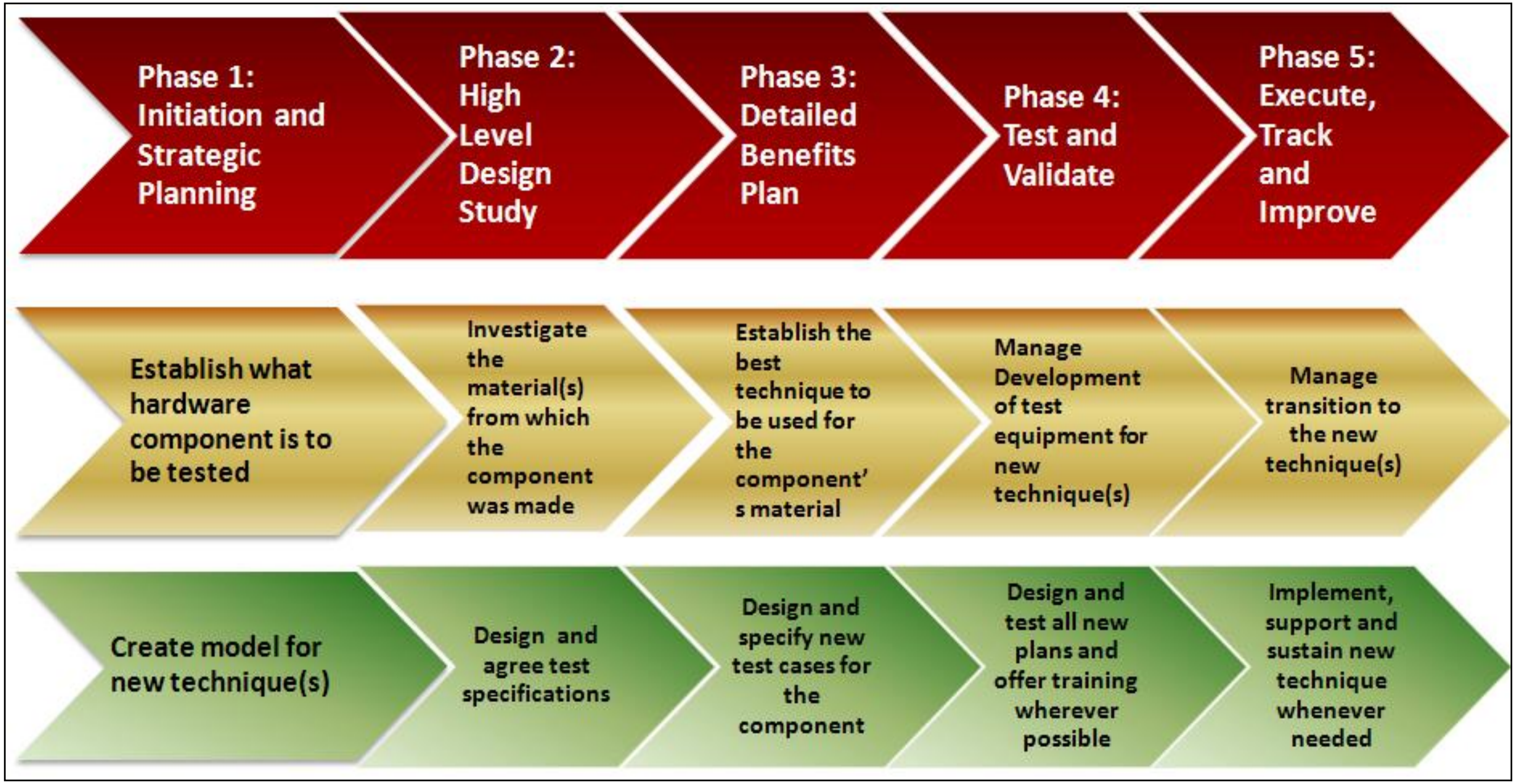


Figure 5.20: Roadmap showing the proposed recommendations for implementing the identified best practices

5.9 Closing Remarks

The number of questions to include in the questionnaire and what their relevance to the study would be was a task the author found daunting as it contained a lot of technical terminology she was not familiar with. With this in mind, the author consulted the academic supervisor for the project and was able to consolidate some of the questions together and the closed questionnaire was able to reach its final design stage. Once the questionnaire was finalised and accepted by the academic supervisor, the industrial supervisor inspected it, suggested changes which the author accepted without compromising the scope and outline originally presented and the questionnaire was launched online through 'survey monkey'.

The collection of data proved tedious at the start due to the fact that a lot of organisations required for the study had their key engineers off on summer holidays. The results show a varied amount of opinions on hardware testing, how they should be designed and carried out. However, the key findings from the study showed that the sponsor company is operating within industrial standards, which can be seen throughout the benchmark and key findings section of this report. Although the sponsor company is operating within industry standards, the study still highlighted that the sponsor company has room to implement some improvements which unfortunately is out of the scope of this project, but could be pursued as future work. The following chapter details recommendations and aspects that could be proposed as future work to this study.

6 CONCLUSION AND RECOMMENDATIONS

This chapter will cover the author's view on the topic area, the research methods, the research work done and the results that were achieved. The limitations of the study and what further work can be carried out in the future to further enhance the results of this research project.

6.1 Conclusions

The author's opinion of the project was one that could not easily be described at the start of the project based on past knowledge and experiences. In order to capture and analyse the industrial best practices of independent quality techniques to evaluate and validate product design and development, the author had to come to terms with the technicality of the subject area which posed an initial threat to the progress of the project as she had no previous engineering knowledge or manufacturing background.

The research methodology that was adopted by the author was executed through five technical objectives initially stated at the commencement of this project. It included collecting qualitative and quantitative data from the sponsor company and other manufacturing enterprises, through site visits, telephone calls, face-to-face interviews and an online questionnaire that was hosted on the survey monkey website. The results were analysed quantitatively through graphs and charts and the overall findings presented in a PowerPoint presentation through WebEx to the sponsor company.

A limitation of the research methodology that was adopted for this project was the fact that although testing and validation techniques can be generic in nature i.e. suited to any product, in most cases testing is usually product specific and industry specific. Tests carried out on the functionality of a pen for example will not be the same sort of tests carried out on a mobile phone's functionality. The author believes had there been more resources available time wise, the identified best practice (testing and validation) techniques could have been split into groups by industry sector and product type which would have helped provided more meaningful and focused analysis.

Another concern with the work done was the number of responses received in total from the various industry sectors. On the one hand, the questionnaire was directed at organisations that dealt with hardware components but on the other hand it had an underlying tone that made the questions more suited only to vehicle manufacturers or vehicle component manufacturers, which yet again backs up the previously stated thought about the research methodology that was adopted.

However, even with the identified limitations, the benchmark study still identified that the sponsor company was operating within the industry's best practices, but also highlighted the fact that there was room for improvement and implementing testing techniques identified from the review of academic literature. These techniques proposed for implementation are; Ultrasonic testing, Eddy-current testing and Monochromatic laser testing which is to be recommended to the Illumination and optics department at the sponsor company as it is not one of the new techniques to be considered by the *'Product Assurance'* team.

To conclude in the long run, there was good participation in the benchmark study but the author believes the findings which highlighted that all manufacturers carry out testing on hardware components either in-house or through external bodies. The benchmark study can also only be thought of as representing mainly UK manufacturers and not necessarily a true representation of the industry at large. This is suggested because the responses collated from the online survey were predominantly from UK manufacturers, but a wide representation across various areas of the UK manufacturing industry. For more in-depth analysis on the results please refer to **section 5 - Benchmark study and analysis of key findings**.

6.2 Benefits and limitations of the study

Benefits

- The major benefit and strength of this project to the sponsor company was the opportunity to investigate and review the latest academic research, industry applications and best practices in *independent quality validation and testing techniques.*
- An opportunity to receive external and unbiased points of view from possible competitors within the automotive industry on *independent quality validation techniques.*
- An opportunity to receive a proposal based on the analysis of current processes and extensive academic literature research about how benchmarked best practices within the automotive hardware product design and development validation techniques could be beneficial to if implemented effectively.

Limitations

While the research managed to present meaningful results in terms of the objectives, at the beginning of the project, a number of constraints were identified that affected the *“A Benchmark of the Independent Quality Validation Techniques of Product Design and Development”* project. Some of these were;

- The scope of the project being limited to three months.
- The data required for collection was not readily available because the survey went live online during the summer holidays in July when a lot of companies were either all on holiday or the key engineers required to participate were away on holiday.
- Due to the economic crisis, a number of the companies that were contacted were not willing to participate and share their knowledge, which meant a limited number of responses (seventeen to be specific).
- Due to the scope of the project and the time constraint, it was not possible to design the questionnaire for the survey with open-ended questions which could have been administered through face-to-face interviews, such that there was free flow of information to shed more light

on the research questions. The fact that the questionnaire was semi-structured allowed for some flexibility and easier data analysis, but in hind sight now, the project would have benefitted more from more open-ended questions, if there was more time to carry out detailed qualitative analysis, which could be achieved from future work either through another individual thesis project or a group project where more students will be involved in the collection and analysis of data.

6.3 Recommended future work

- Results of the study showed a good base for any company to benchmark its processes against, which could be put on a bigger scale by the sponsor company or any of the other participating companies through Cranfield University.
- Further work could be carried out on the recommendations highlighted in the roadmap regarding the effects of ultrasonic testing and eddy-current testing on vehicle hardware components.
- Monochromatic laser testing could also be further investigated to ascertain the usefulness to other manufacturing industry sectors as the author came across quite a few laser techniques but found it particularly difficult to identify the real monochromatic light / laser testing technique.
- Further investigation can be carried out on whether all the best practices recommended in this project are really the best industrial practices and how suitable they are when considering a broader range of product hardware and not just automotive components.

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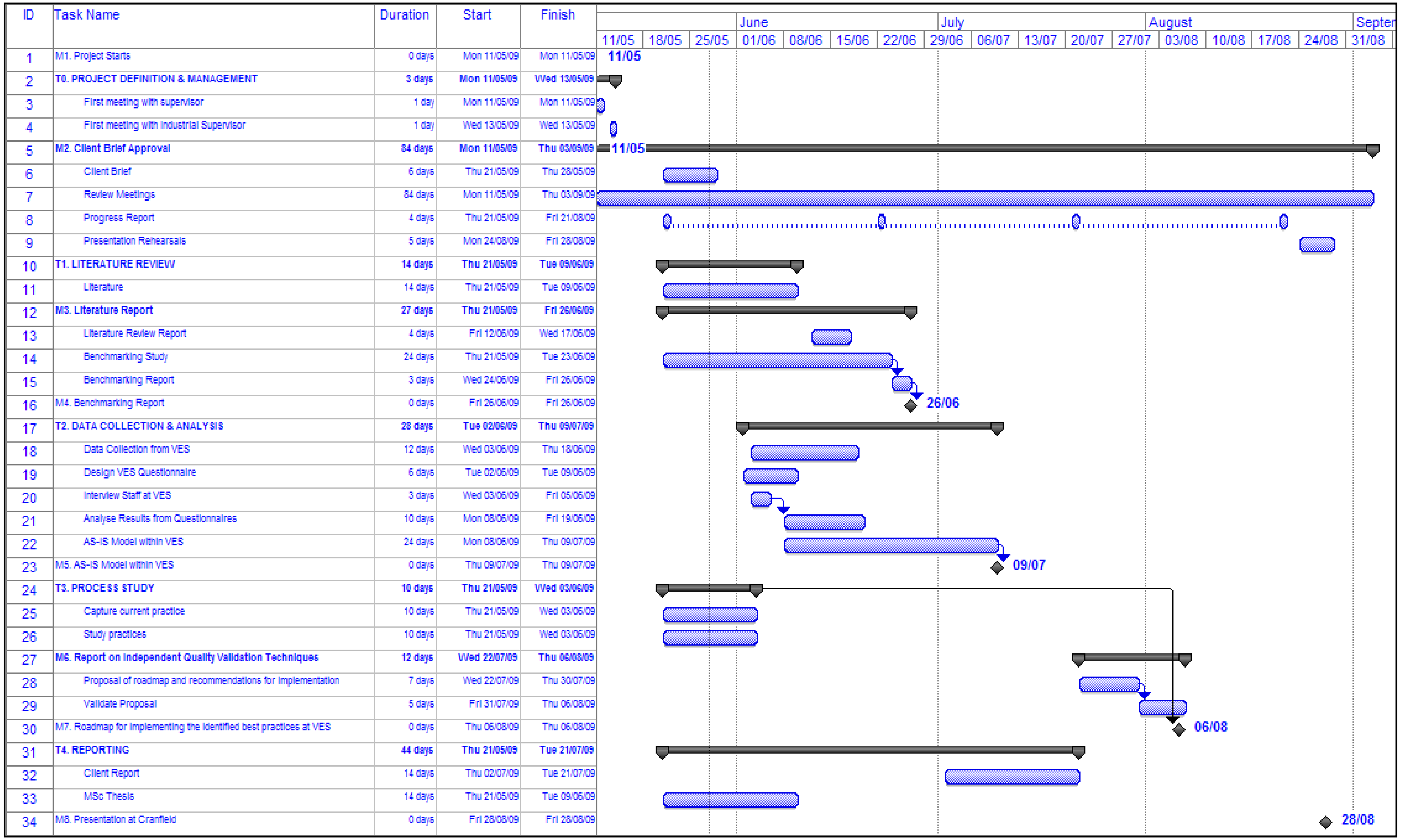
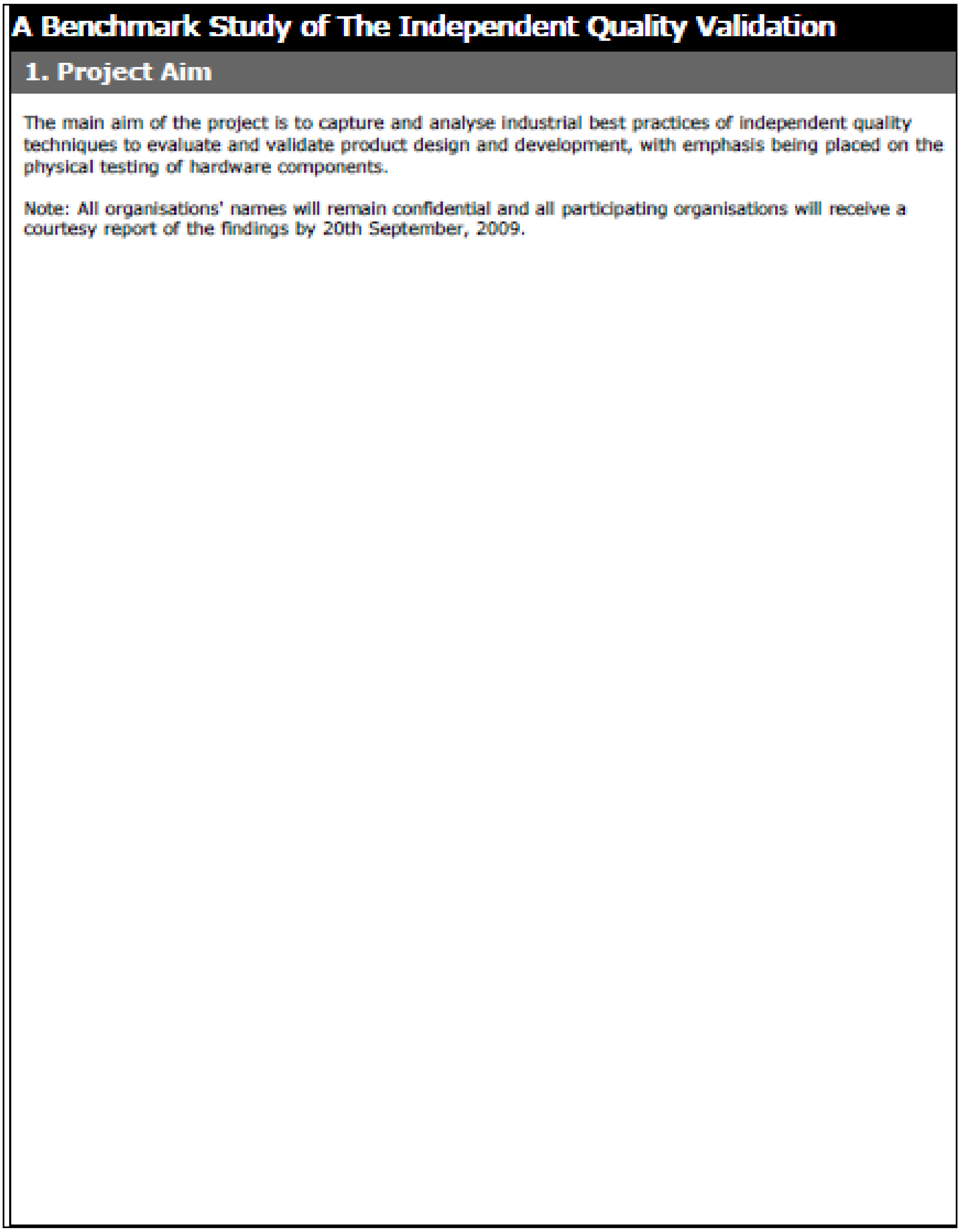
APPENDIX A: PROJECT GANTT CHART



ID	Task Name	Duration	Start	Finish
1	M1. Project Starts	0 days	Mon 11/05/09	Mon 11/05/09
2	**T0. PROJECT DEFINITION & MANAGEMENT**	**3 days**	**Mon 11/05/09**	**Wed 13/05/09**
3	First meeting with supervisor	1 day	Mon 11/05/09	Mon 11/05/09
4	First meeting with Industrial Supervisor	1 day	Wed 13/05/09	Wed 13/05/09
5	**M2. Client Brief Approval**	**84 days**	**Mon 11/05/09**	**Thu 03/09/09**
6	Client Brief	6 days	Thu 21/05/09	Thu 28/05/09
7	Review Meetings	84 days	Mon 11/05/09	Thu 03/09/09
8	Progress Report	4 days	Thu 21/05/09	Fri 21/08/09
9	Presentation Rehearsals	5 days	Mon 24/08/09	Fri 28/08/09
10	**T1. LITERATURE REVIEW**	**14 days**	**Thu 21/05/09**	**Tue 09/06/09**
11	Literature	14 days	Thu 21/05/09	Tue 09/06/09
12	**M3. Literature Report**	**27 days**	**Thu 21/05/09**	**Fri 26/06/09**
13	Literature Review Report	4 days	Fri 12/06/09	Wed 17/06/09
14	Benchmarking Study	24 days	Thu 21/05/09	Tue 23/06/09
15	Benchmarking Report	3 days	Wed 24/06/09	Fri 26/06/09
16	M4. Benchmarking Report	0 days	Fri 26/06/09	Fri 26/06/09
17	**T2. DATA COLLECTION & ANALYSIS**	**28 days**	**Tue 02/06/09**	**Thu 09/07/09**
18	Data Collection from VES	12 days	Wed 03/06/09	Thu 18/06/09
19	Design VES Questionnaire	6 days	Tue 02/06/09	Tue 09/06/09
20	Interview Staff at VES	3 days	Wed 03/06/09	Fri 05/06/09
21	Analyse Results from Questionnaires	10 days	Mon 08/06/09	Fri 19/06/09
22	AS-IS Model within VES	24 days	Mon 08/06/09	Thu 09/07/09
23	M5. AS-IS Model within VES	0 days	Thu 09/07/09	Thu 09/07/09
24	**T3. PROCESS STUDY**	**10 days**	**Thu 21/05/09**	**Wed 03/06/09**
25	Capture current practice	10 days	Thu 21/05/09	Wed 03/06/09
26	Study practices	10 days	Thu 21/05/09	Wed 03/06/09
27	**M6. Report on Independent Quality Validation Techniques**	**12 days**	**Wed 22/07/09**	**Thu 06/08/09**
28	Proposal of roadmap and recommendations for implementation	7 days	Wed 22/07/09	Thu 30/07/09
29	Validate Proposal	5 days	Fri 31/07/09	Thu 06/08/09
30	M7. Roadmap for implementing the identified best practices at VES	0 days	Thu 06/08/09	Thu 06/08/09
31	**T4. REPORTING**	**44 days**	**Thu 21/05/09**	**Tue 21/07/09**
32	Client Report	14 days	Thu 02/07/09	Tue 21/07/09
33	MSc Thesis	14 days	Thu 21/05/09	Tue 09/06/09
34	M8. Presentation at Cranfield	0 days	Fri 28/08/09	Fri 28/08/09

APPENDIX B: A BENCHMARK STUDY OF INDEPENDENT QUALITY QUESTIONNAIRE

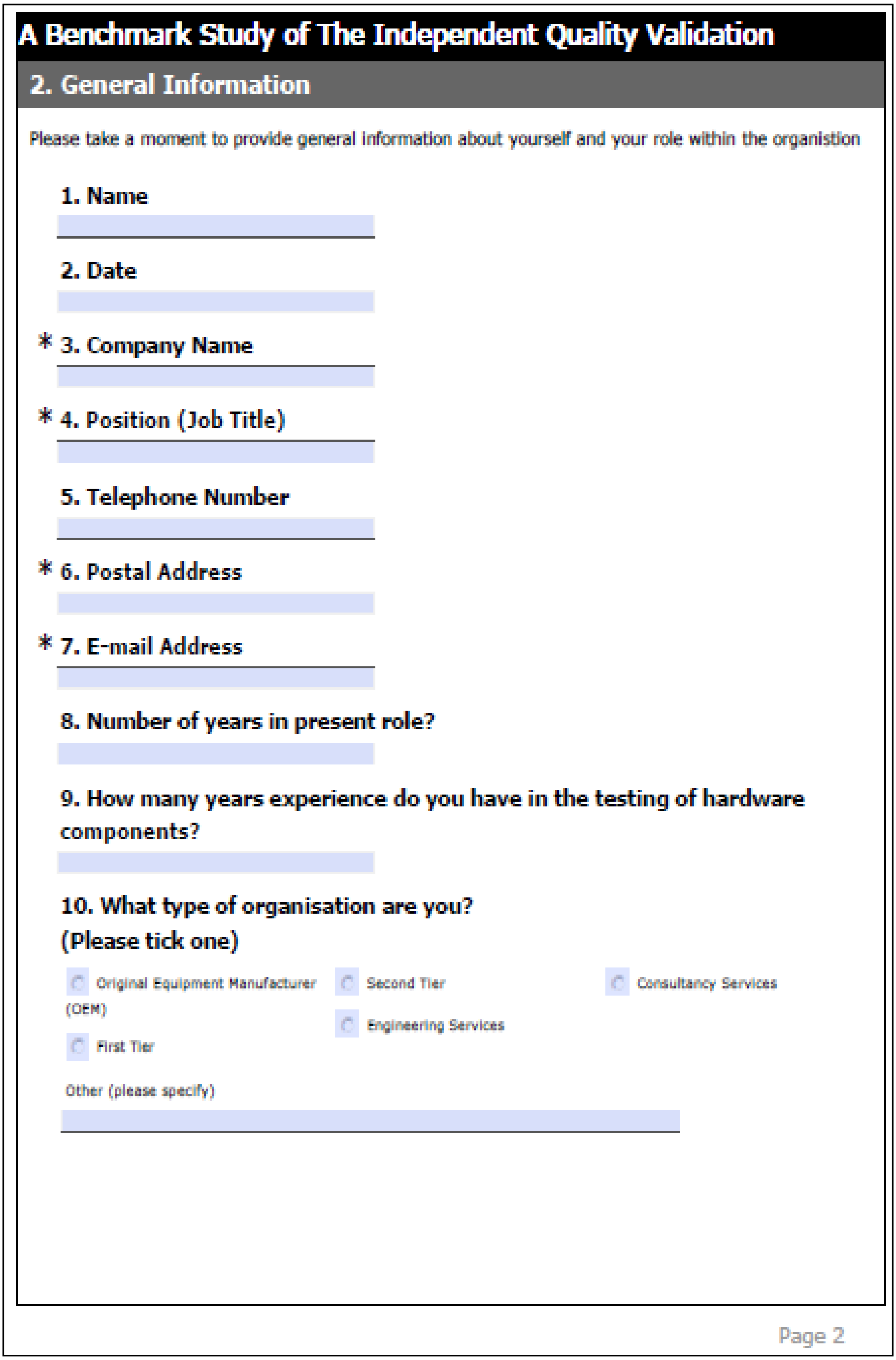


A Benchmark Study of The Independent Quality Validation

1. Project Aim

The main aim of the project is to capture and analyse industrial best practices of independent quality techniques to evaluate and validate product design and development, with emphasis being placed on the physical testing of hardware components.

Note: All organisations' names will remain confidential and all participating organisations will receive a courtesy report of the findings by 20th September, 2009.



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2. General Information

Please take a moment to provide general information about yourself and your role within the organistion

1. Name

2. Date

* 3. Company Name

* 4. Position (Job Title)

5. Telephone Number

* 6. Postal Address

* 7. E-mail Address

8. Number of years in present role?

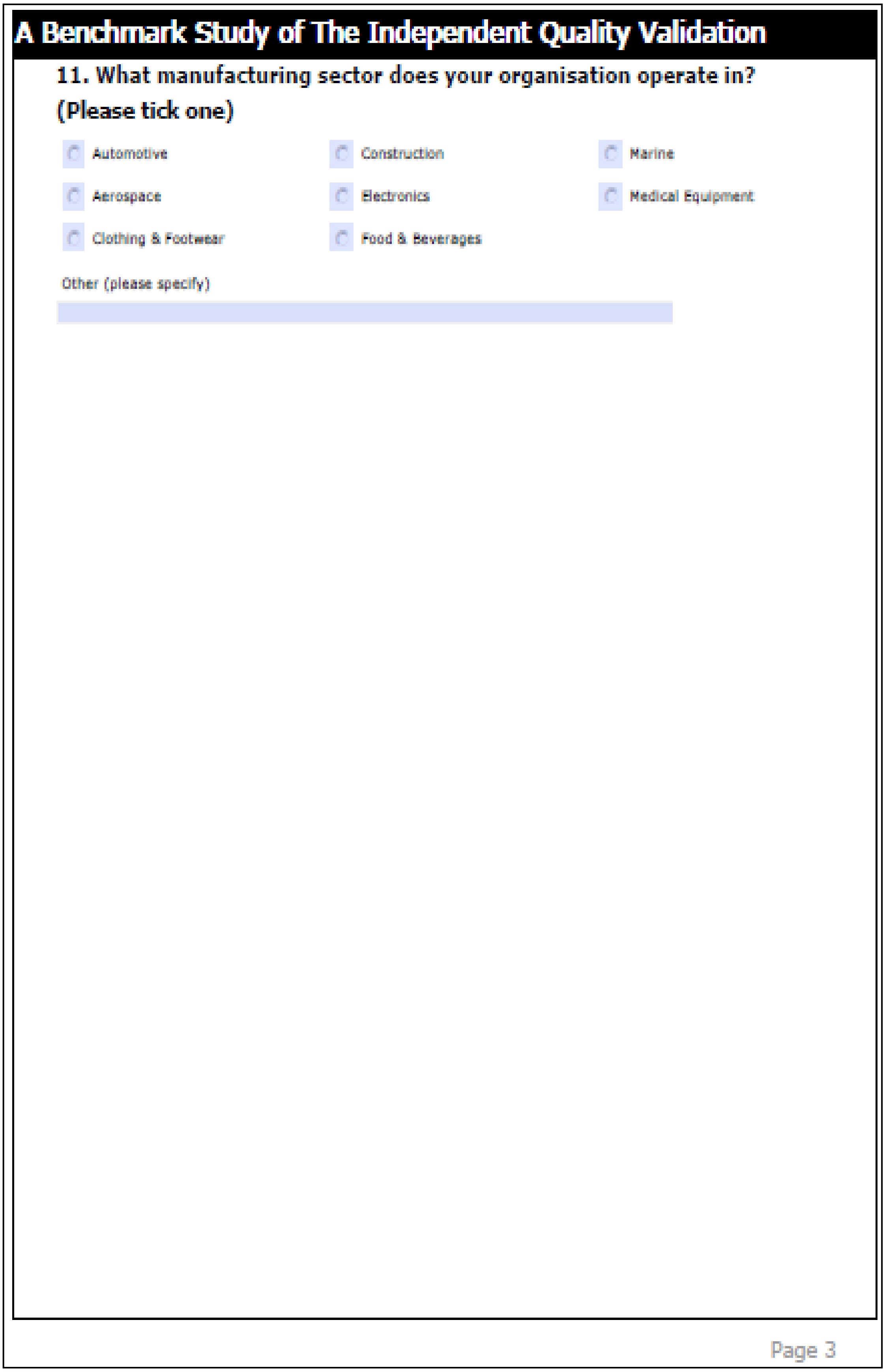
9. How many years experience do you have in the testing of hardware components?

10. What type of organisation are you?
(Please tick one)

○ Original Equipment Manufacturer (OEM)
○ First Tier
○ Second Tier
○ Engineering Services
○ Consultancy Services

Other (please specify)

Page 2



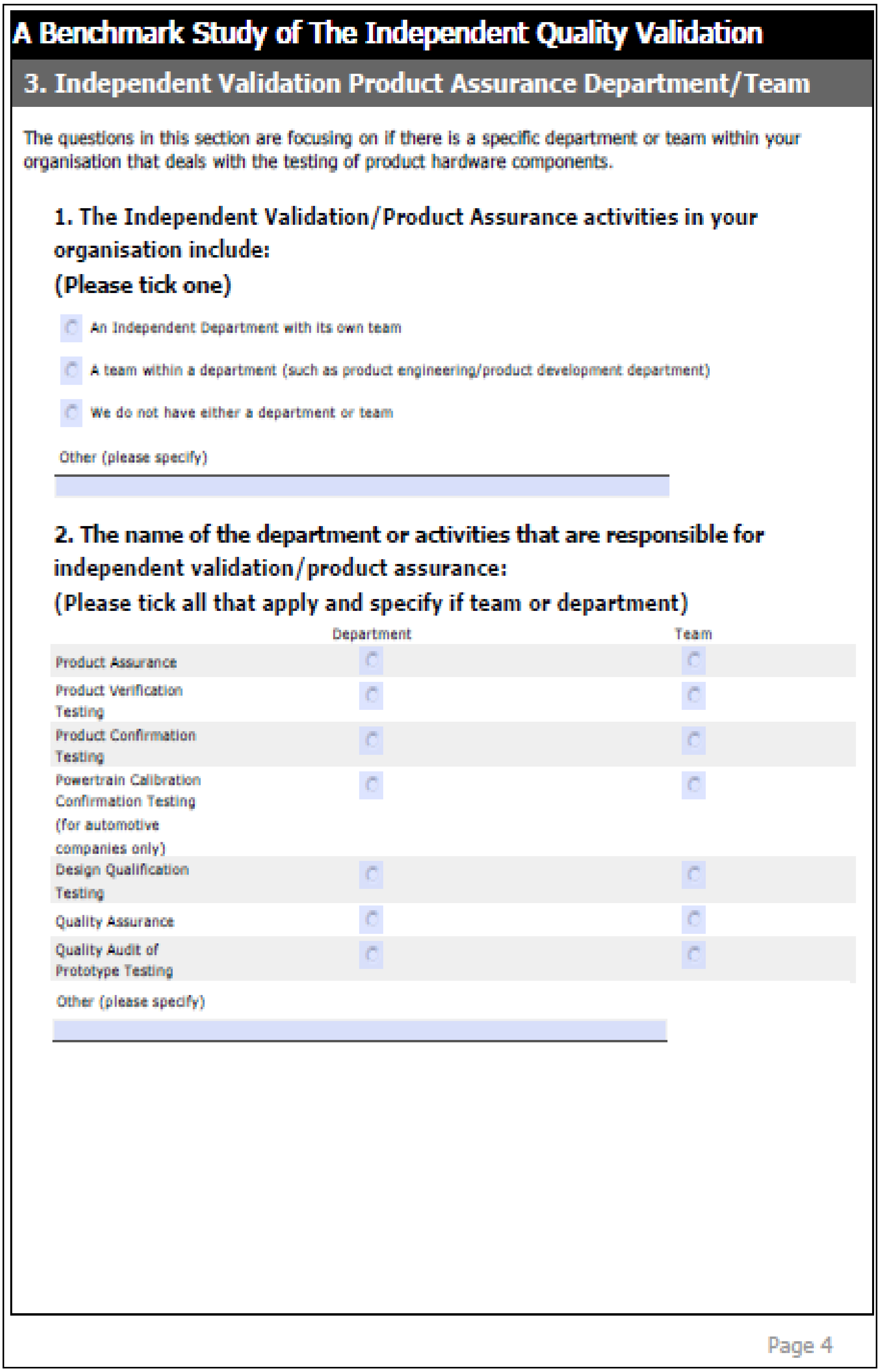
A Benchmark Study of The Independent Quality Validation

11. What manufacturing sector does your organisation operate in? (Please tick one)

○ Automotive
○ Aerospace
○ Clothing & Footwear
○ Construction
○ Electronics
○ Food & Beverages
○ Marine
○ Medical Equipment

Other (please specify)

Page 3



A Benchmark Study of The Independent Quality Validation

3. Independent Validation Product Assurance Department/Team

The questions in this section are focusing on if there is a specific department or team within your organisation that deals with the testing of product hardware components.

1. The Independent Validation/Product Assurance activities in your organisation include: (Please tick one)

○ An Independent Department with its own team

○ A team within a department (such as product engineering/product development department)

○ We do not have either a department or team

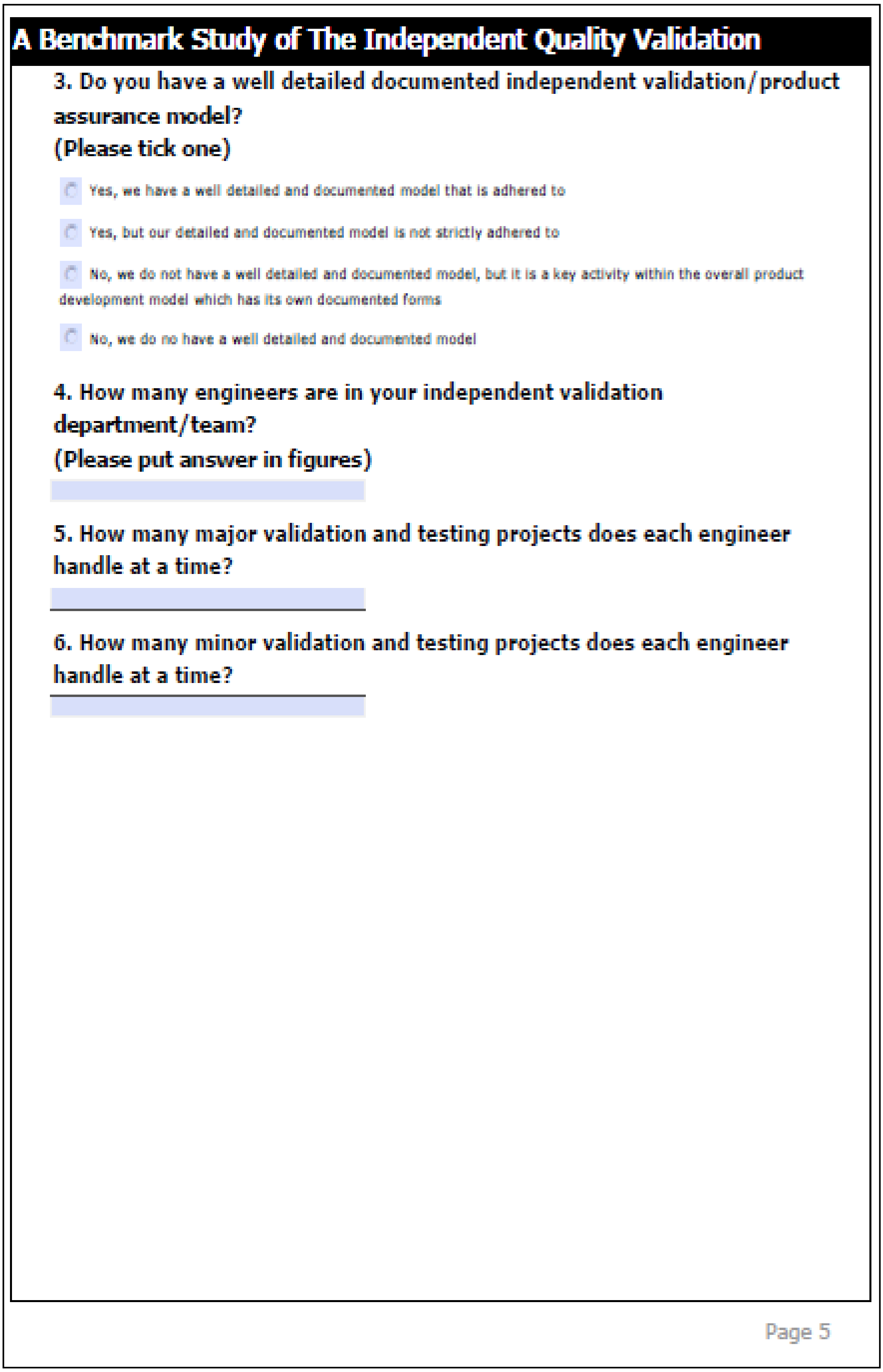
Other (please specify)

2. The name of the department or activities that are responsible for independent validation/product assurance: (Please tick all that apply and specify if team or department)

	Department	Team
Product Assurance	○	○
Product Verification Testing	○	○
Product Confirmation Testing	○	○
Powertrain Calibration Confirmation Testing (for automotive companies only)	○	○
Design Qualification Testing	○	○
Quality Assurance	○	○
Quality Audit of Prototype Testing	○	○

Other (please specify)

Page 4



A Benchmark Study of The Independent Quality Validation

3. Do you have a well detailed documented independent validation/product assurance model?
(Please tick one)

○ Yes, we have a well detailed and documented model that is adhered to

○ Yes, but our detailed and documented model is not strictly adhered to

○ No, we do not have a well detailed and documented model, but it is a key activity within the overall product development model which has its own documented forms

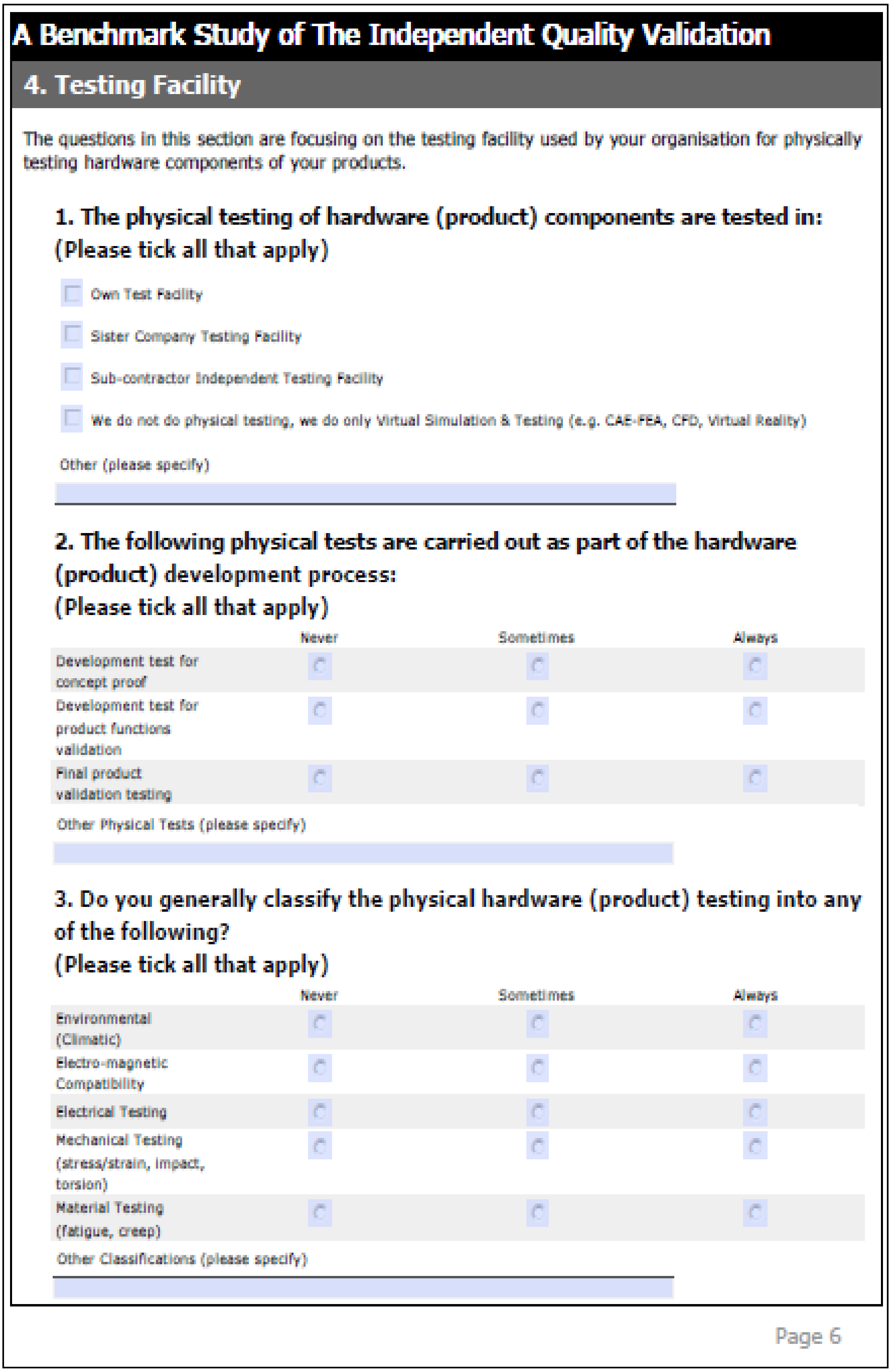
○ No, we do no have a well detailed and documented model

4. How many engineers are in your independent validation department/team?
(Please put answer in figures)

5. How many major validation and testing projects does each engineer handle at a time?

6. How many minor validation and testing projects does each engineer handle at a time?

Page 5



A Benchmark Study of The Independent Quality Validation

4. Testing Facility

The questions in this section are focusing on the testing facility used by your organisation for physically testing hardware components of your products.

1. The physical testing of hardware (product) components are tested in: (Please tick all that apply)

- ☐ Own Test Facility
- ☐ Sister Company Testing Facility
- ☐ Sub-contractor Independent Testing Facility
- ☐ We do not do physical testing, we do only Virtual Simulation & Testing (e.g. CAE-FEA, CFD, Virtual Reality)

Other (please specify)

2. The following physical tests are carried out as part of the hardware (product) development process:
(Please tick all that apply)

	Never	Sometimes	Always
Development test for concept proof	○	○	○
Development test for product functions validation	○	○	○
Final product validation testing	○	○	○

Other Physical Tests (please specify)

3. Do you generally classify the physical hardware (product) testing into any of the following?
(Please tick all that apply)

	Never	Sometimes	Always
Environmental (Climatic)	○	○	○
Electro-magnetic Compatibility	○	○	○
Electrical Testing	○	○	○
Mechanical Testing (stress/strain, impact, torsion)	○	○	○
Material Testing (fatigue, creep)	○	○	○

Other Classifications (please specify)

Page 6

A Benchmark Study of The Independent Quality Validation

4. Are any of these specific types of tests carried out on hardware (product) components? (Please tick all that apply)

	Never	Sometimes	Always
Visual Non-Destructive Testing	○	○	○
Liquid Penetration Testing	○	○	○
Magnetic Participle Testing	○	○	○
Ultrasonic Testing	○	○	○
Radiography	○	○	○
Eddy-Current Testing	○	○	○
Acoustic Emission Monitoring	○	○	○
Leak Testing	○	○	○
Thermography	○	○	○
Strain Sensing	○	○	○
Monochromatic Laser Testing	○	○	○
Electrical Resistivity	○	○	○
Computed Tomography	○	○	○
Chemical Analysis & Surface Topography	○	○	○
Aerodynamics Testing	○	○	○
Durability, Fatigue & Functional Performance	○	○	○
Noise, Vibration & Harshness (NVH) Testing	○	○	○
Powertrain & Emissions Testing	○	○	○
Proving Ground Testing	○	○	○
Ride & Handling Testing	○	○	○
Safety & Structural Testing	○	○	○

Other (please specify)

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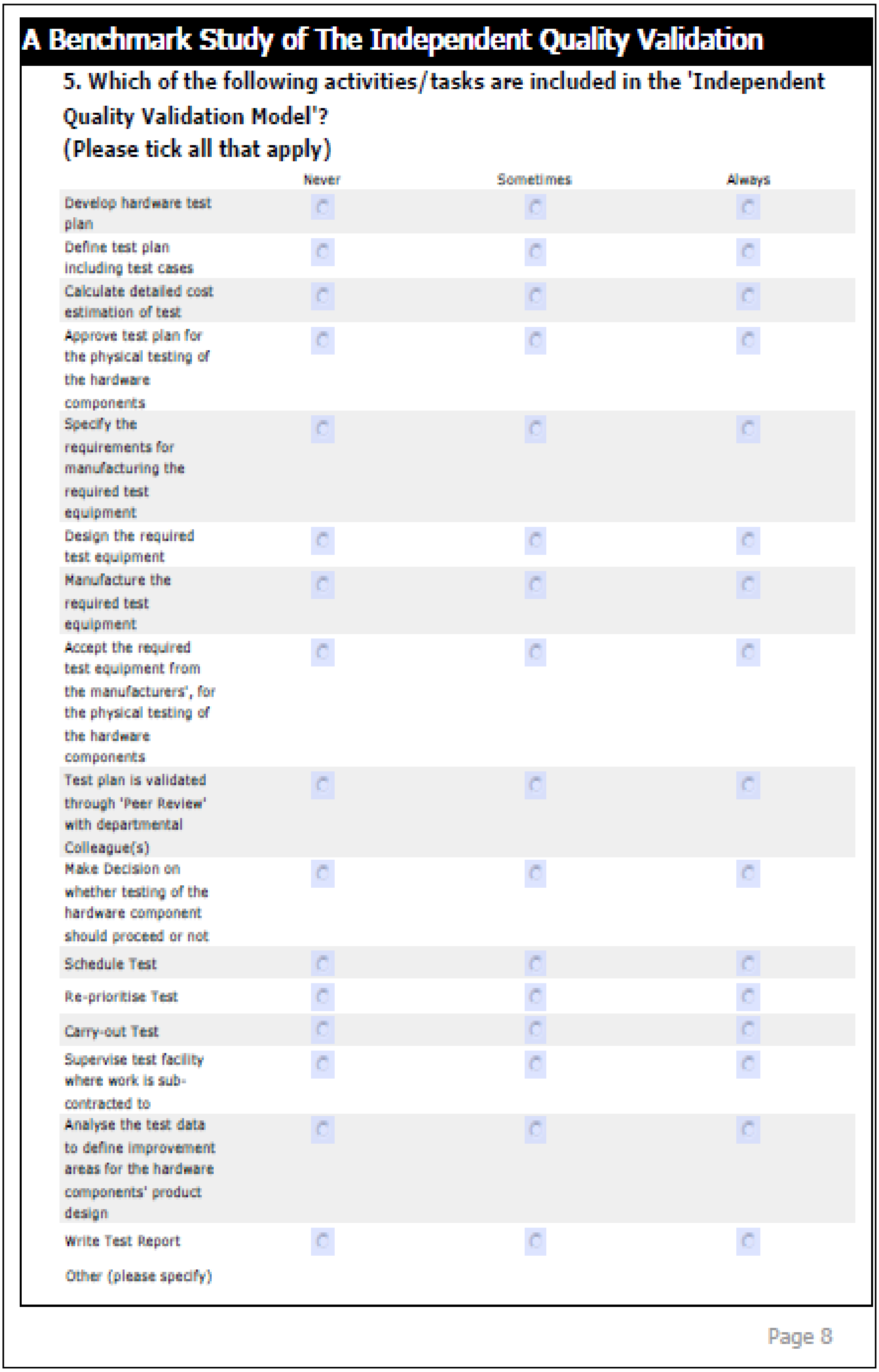

A Benchmark Study of The Independent Quality Validation

5. Which of the following activities/tasks are included in the 'Independent Quality Validation Model'?
(Please tick all that apply)

	Never	Sometimes	Always
Develop hardware test plan	○	○	○
Define test plan including test cases	○	○	○
Calculate detailed cost estimation of test	○	○	○
Approve test plan for the physical testing of the hardware components	○	○	○
Specify the requirements for manufacturing the required test equipment	○	○	○
Design the required test equipment	○	○	○
Manufacture the required test equipment	○	○	○
Accept the required test equipment from the manufacturers', for the physical testing of the hardware components	○	○	○
Test plan is validated through 'Peer Review' with departmental Colleague(s)	○	○	○
Make Decision on whether testing of the hardware component should proceed or not	○	○	○
Schedule Test	○	○	○
Re-prioritise Test	○	○	○
Carry-out Test	○	○	○
Supervise test facility where work is sub-contracted to	○	○	○
Analyse the test data to define improvement areas for the hardware components' product design	○	○	○
Write Test Report	○	○	○

Other (please specify)

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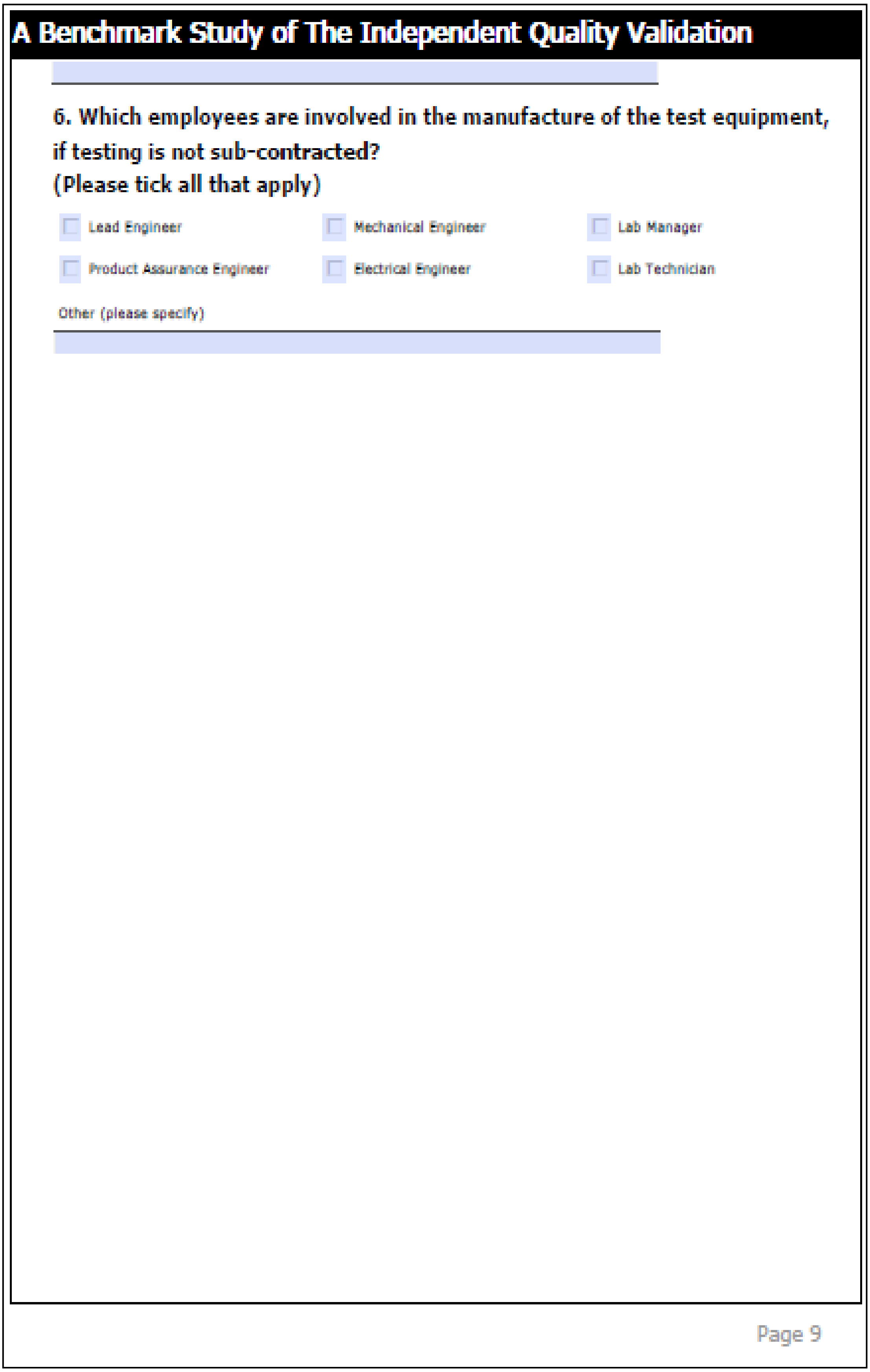

A Benchmark Study of The Independent Quality Validation

6. Which employees are involved in the manufacture of the test equipment, if testing is not sub-contracted?
(Please tick all that apply)

☐ Lead Engineer
☐ Product Assurance Engineer
☐ Mechanical Engineer
☐ Electrical Engineer
☐ Lab Manager
☐ Lab Technician

Other (please specify)

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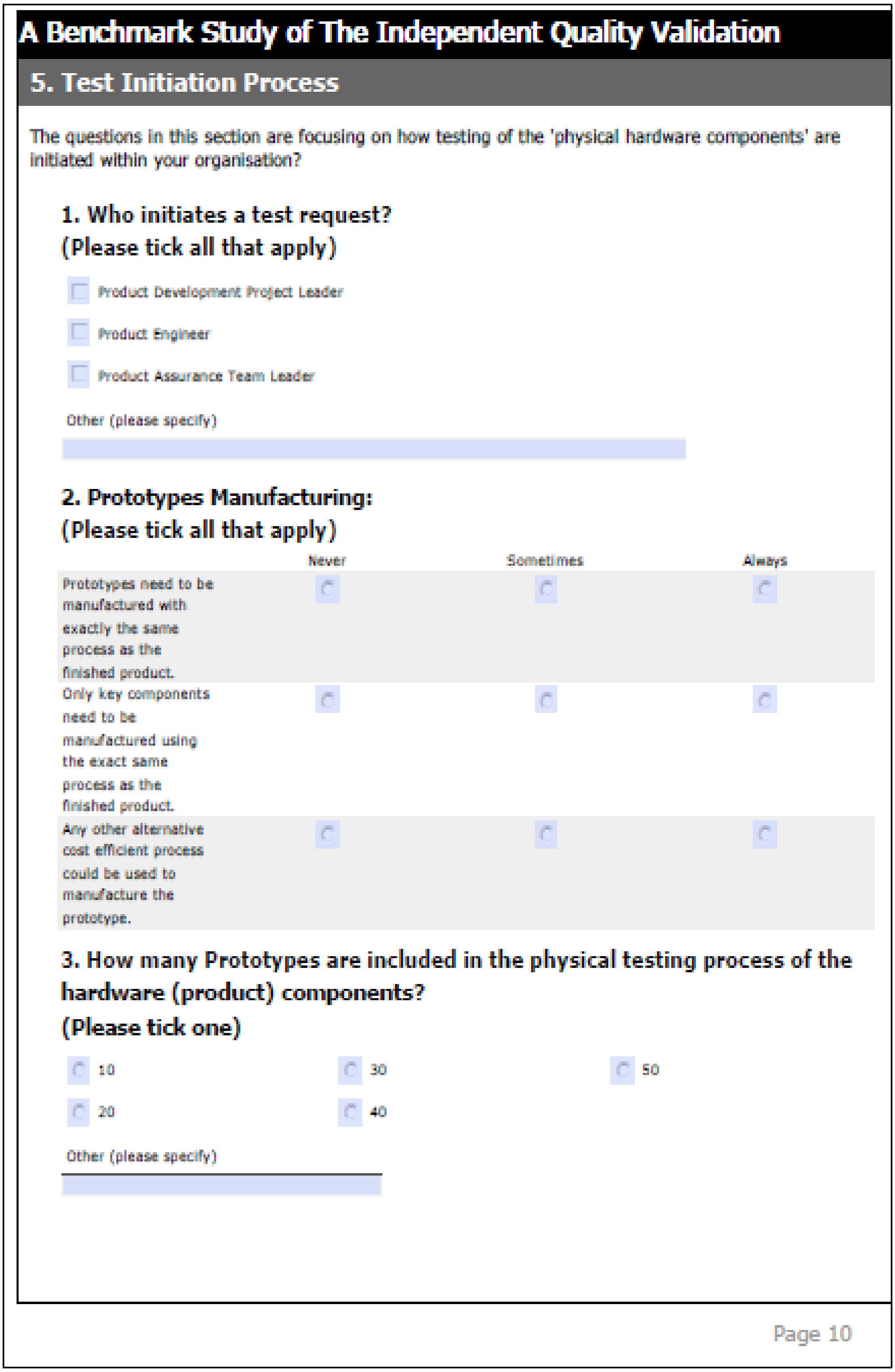

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5. Test Initiation Process

The questions in this section are focusing on how testing of the 'physical hardware components' are initiated within your organisation?

1. Who initiates a test request? (Please tick all that apply)

☐ Product Development Project Leader

☐ Product Engineer

☐ Product Assurance Team Leader

Other (please specify)

2. Prototypes Manufacturing: (Please tick all that apply)

	Never	Sometimes	Always
Prototypes need to be manufactured with exactly the same process as the finished product.	○	○	○
Only key components need to be manufactured using the exact same process as the finished product.	○	○	○
Any other alternative cost efficient process could be used to manufacture the prototype.	○	○	○

3. How many Prototypes are included in the physical testing process of the hardware (product) components? (Please tick one)

○ 10

○ 20

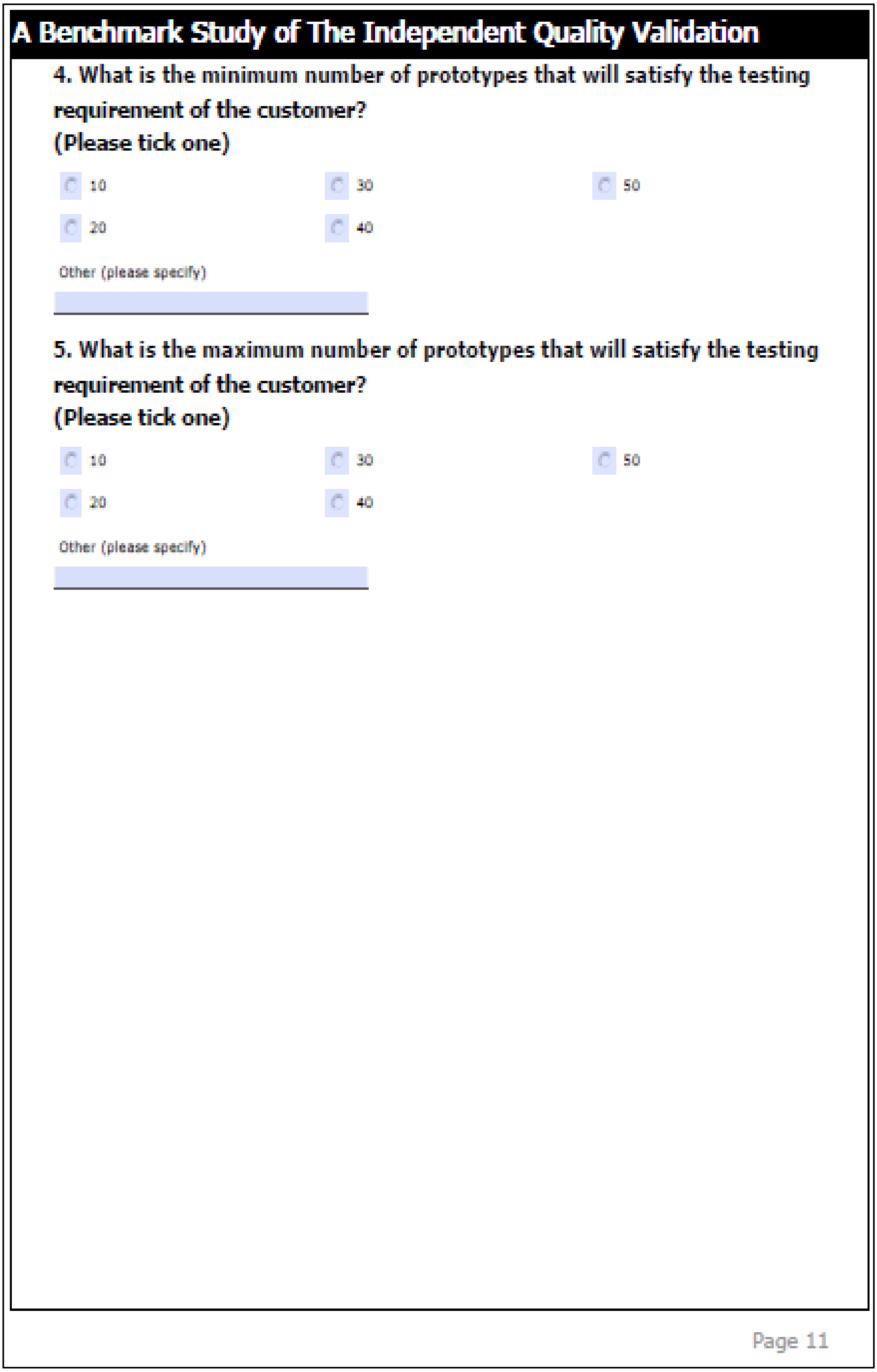
○ 30

○ 40

○ 50

Other (please specify)

Page 10



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4. What is the minimum number of prototypes that will satisfy the testing requirement of the customer?
(Please tick one)

○ 10
○ 20
○ 30
○ 40
○ 50

Other (please specify)

5. What is the maximum number of prototypes that will satisfy the testing requirement of the customer?
(Please tick one)

○ 10
○ 20
○ 30
○ 40
○ 50

Other (please specify)

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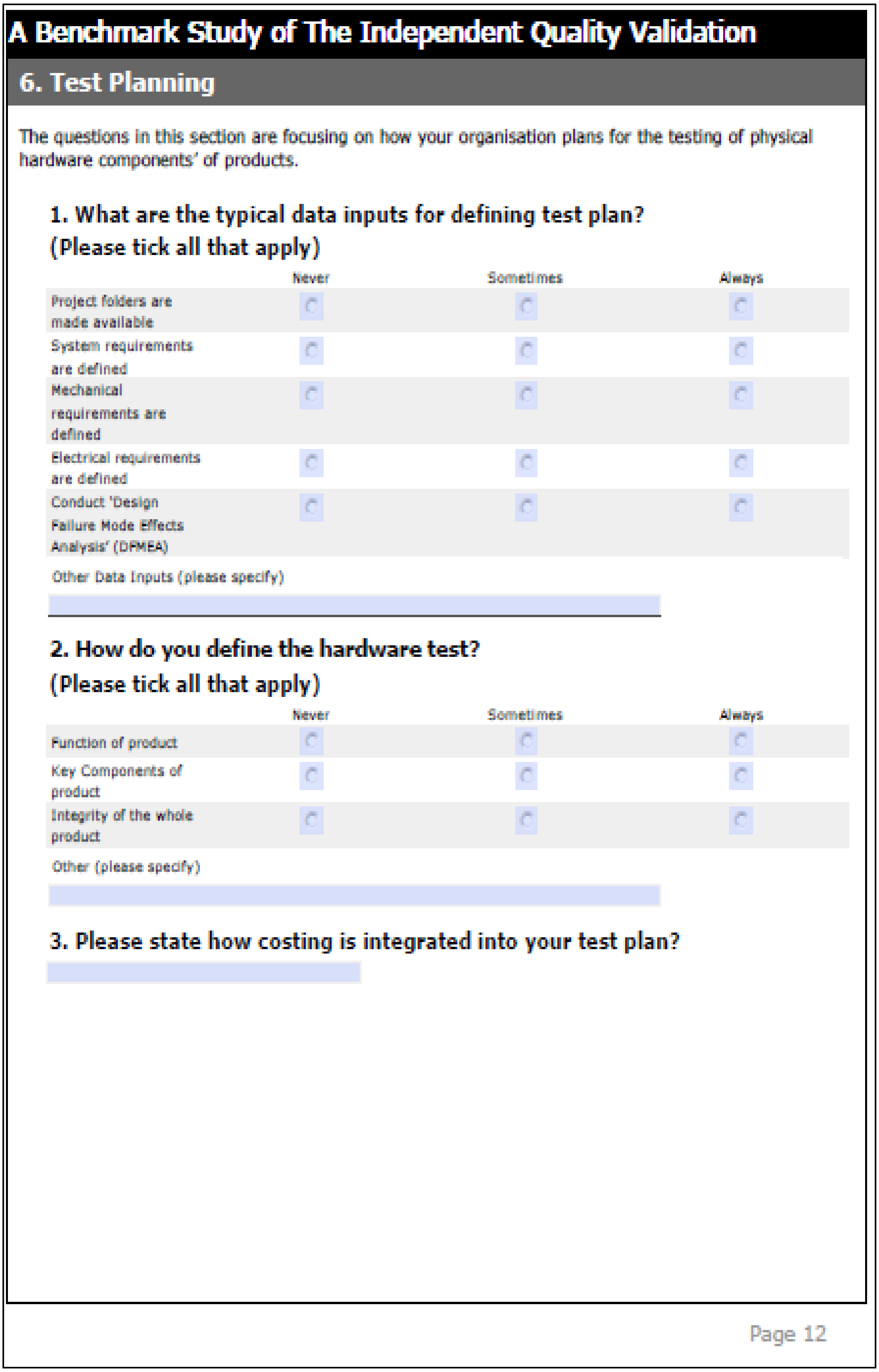

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6. Test Planning

The questions in this section are focusing on how your organisation plans for the testing of physical hardware components' of products.

1. What are the typical data inputs for defining test plan? (Please tick all that apply)

	Never	Sometimes	Always
Project folders are made available	○	○	○
System requirements are defined	○	○	○
Mechanical requirements are defined	○	○	○
Electrical requirements are defined	○	○	○
Conduct 'Design Failure Mode Effects Analysis' (DFMEA)	○	○	○

Other Data Inputs (please specify)

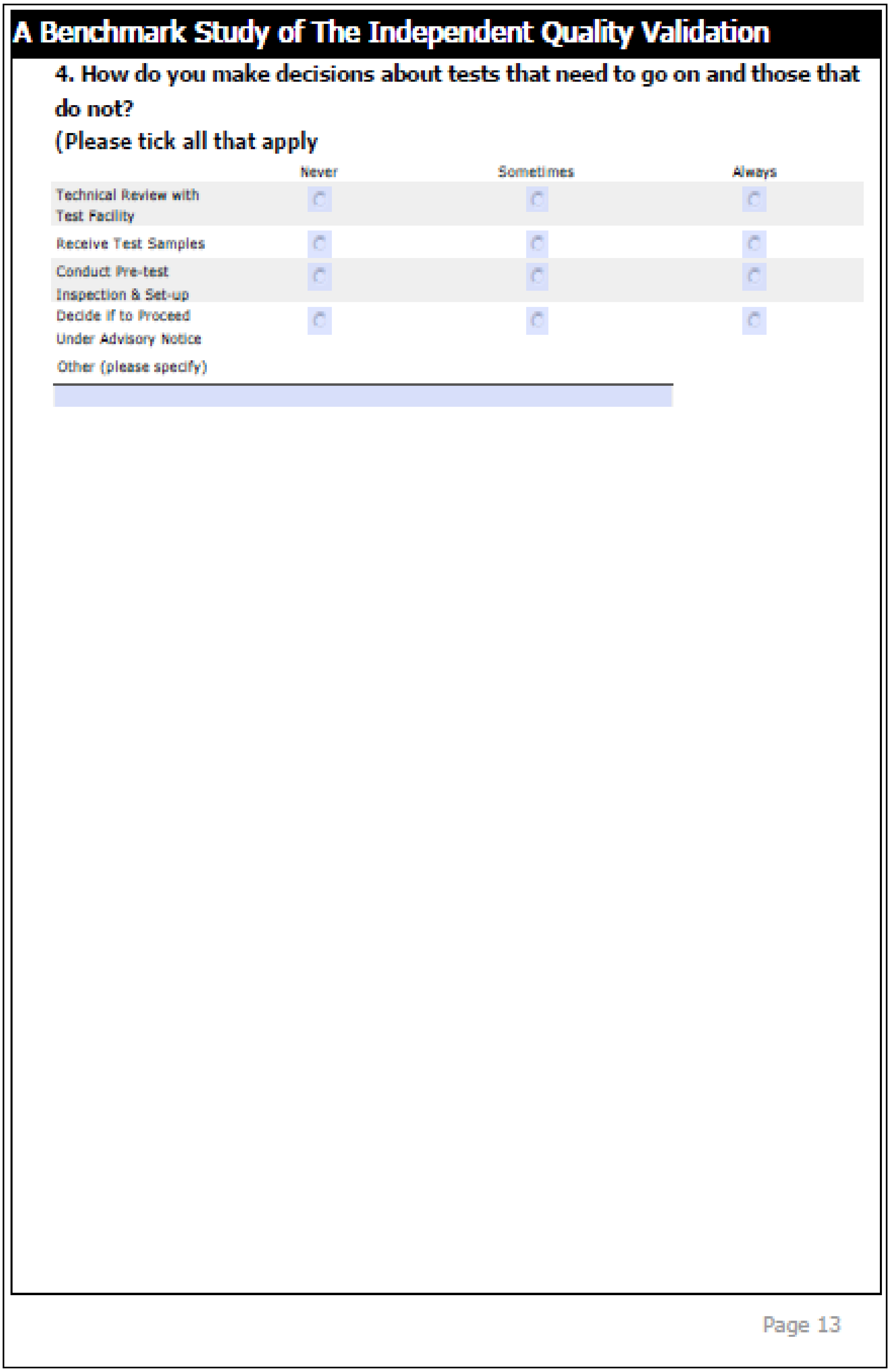
2. How do you define the hardware test? (Please tick all that apply)

	Never	Sometimes	Always
Function of product	○	○	○
Key Components of product	○	○	○
Integrity of the whole product	○	○	○

Other (please specify)

3. Please state how costing is integrated into your test plan?

Page 12



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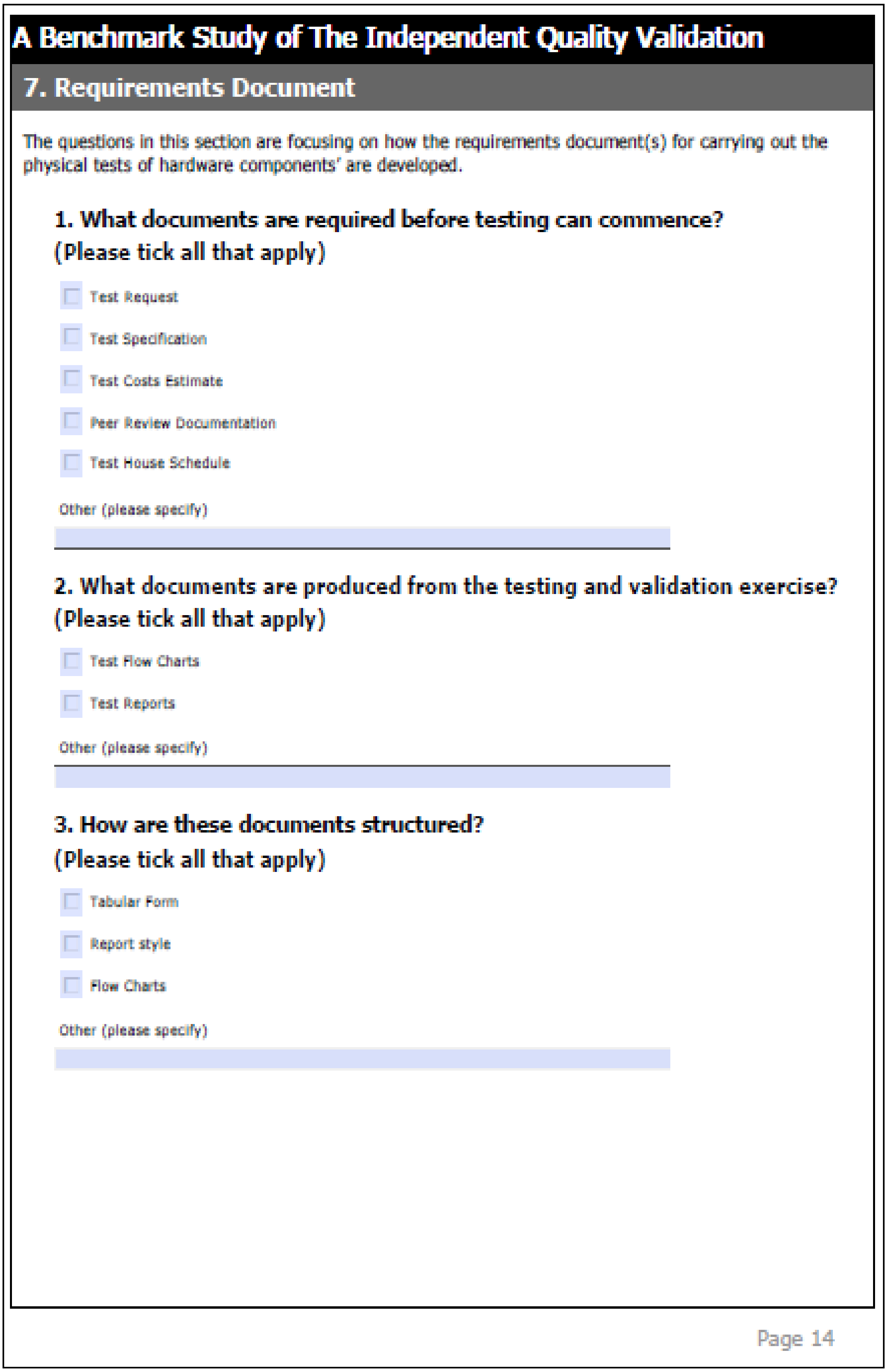
4. How do you make decisions about tests that need to go on and those that do not?

(Please tick all that apply

	Never	Sometimes	Always
Technical Review with Test Facility	○	○	○
Receive Test Samples	○	○	○
Conduct Pre-test Inspection & Set-up	○	○	○
Decide if to Proceed Under Advisory Notice	○	○	○

Other (please specify)

Page 13



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7. Requirements Document

The questions in this section are focusing on how the requirements document(s) for carrying out the physical tests of hardware components' are developed.

1. What documents are required before testing can commence?
(Please tick all that apply)

☐ Test Request
☐ Test Specification
☐ Test Costs Estimate
☐ Peer Review Documentation
☐ Test House Schedule

Other (please specify)

2. What documents are produced from the testing and validation exercise?
(Please tick all that apply)

☐ Test Flow Charts
☐ Test Reports

Other (please specify)

3. How are these documents structured?
(Please tick all that apply)

☐ Tabular Form
☐ Report style
☐ Flow Charts

Other (please specify)

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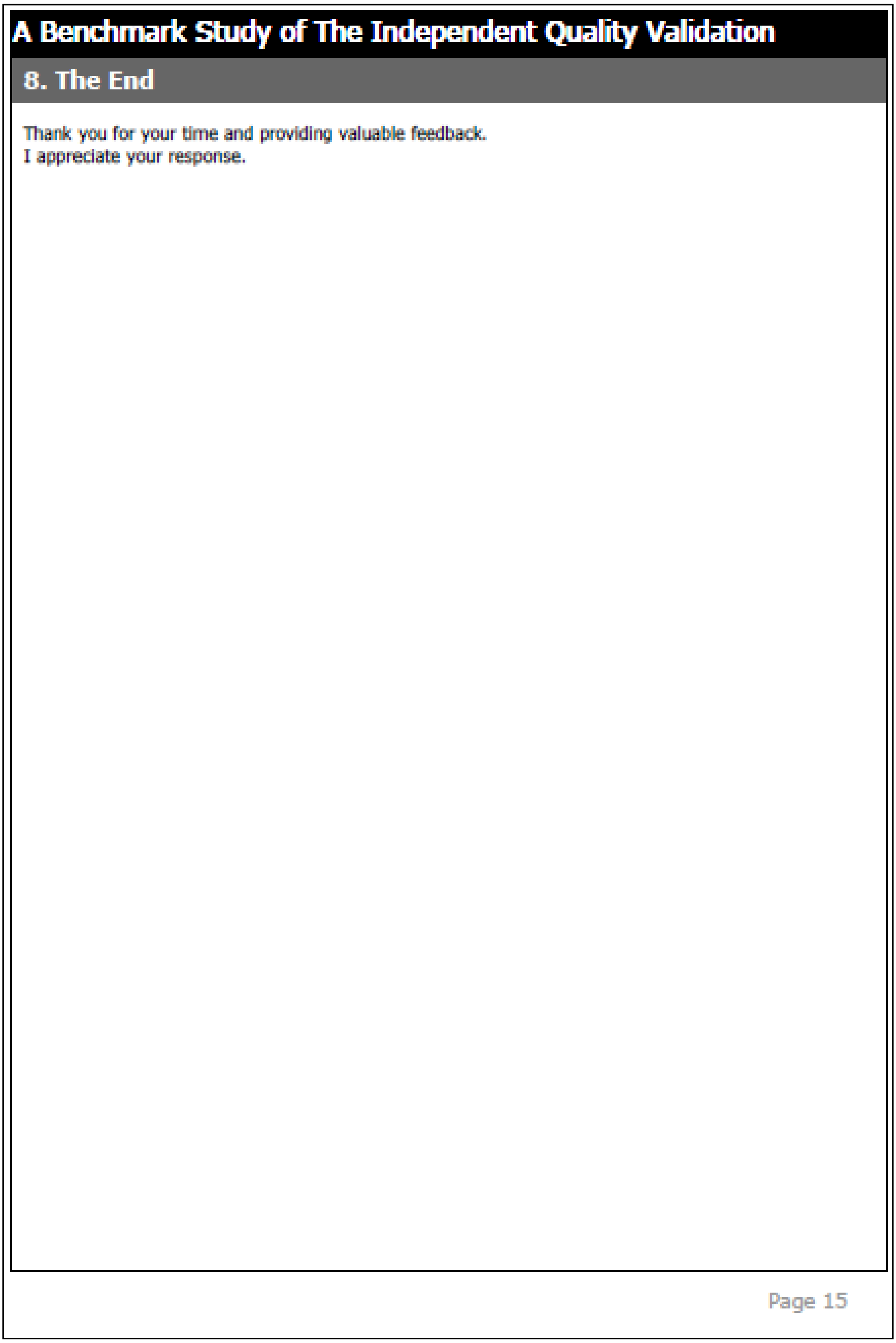

A Benchmark Study of The Independent Quality Validation

8. The End

Thank you for your time and providing valuable feedback.
I appreciate your response.

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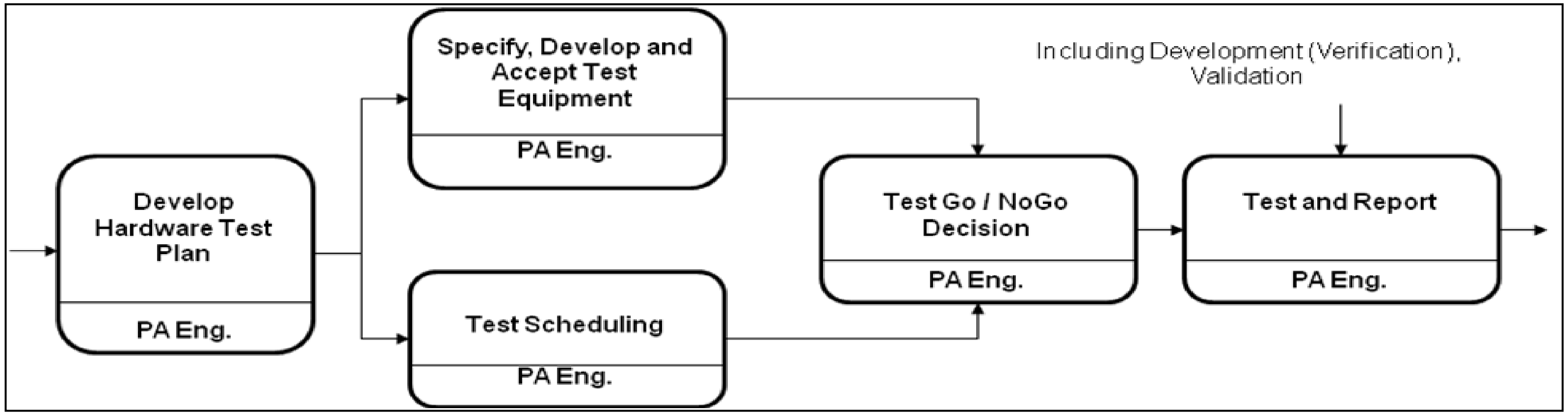
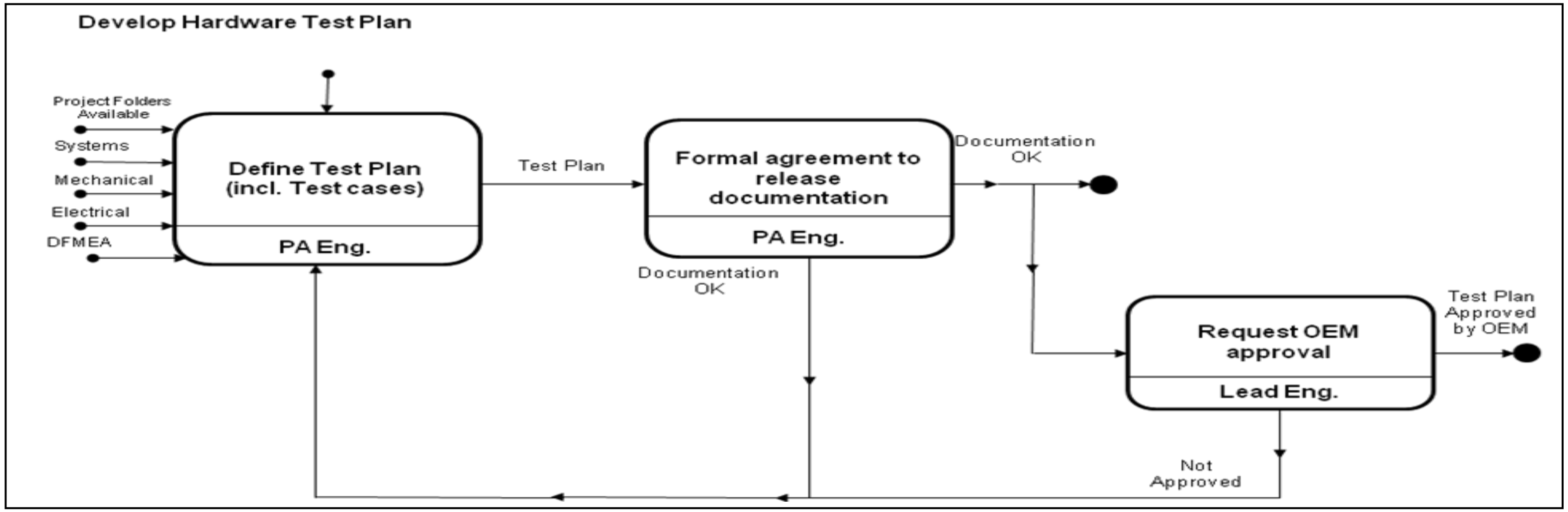
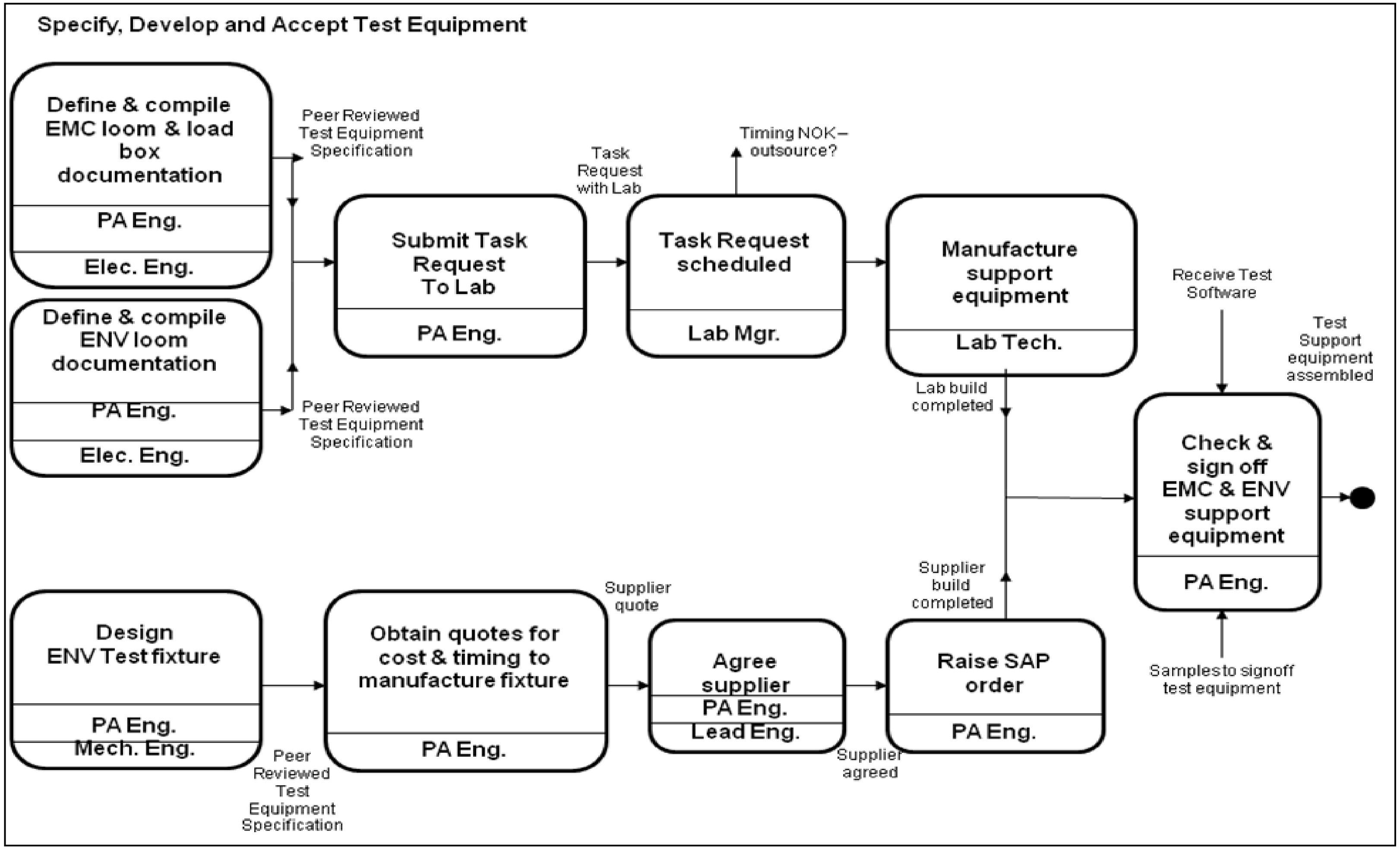
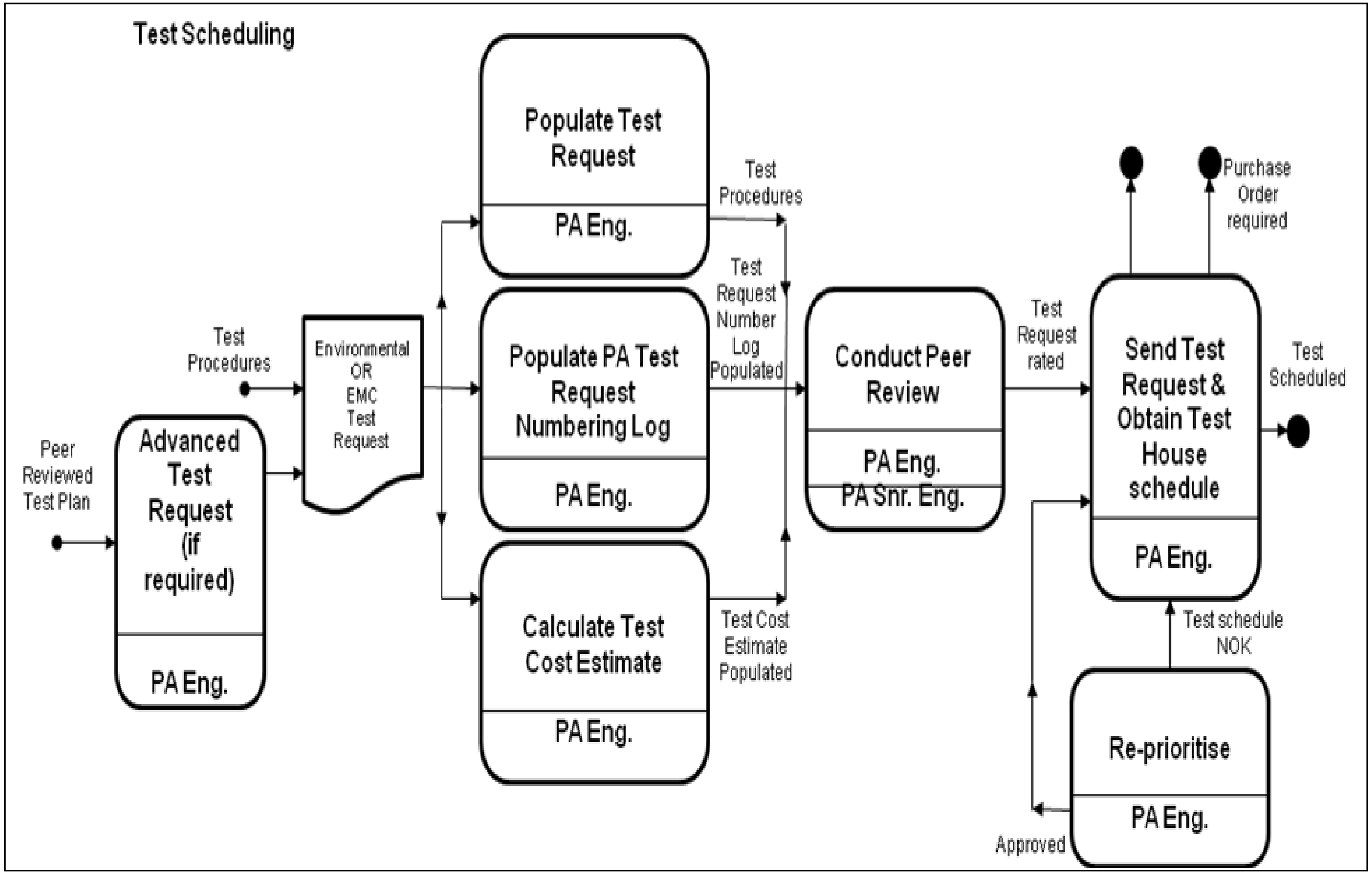
APPENDIX C: EXCERPTS FROM SPONSOR COMPANY'S INDEPENDENT VALIDATION MODEL

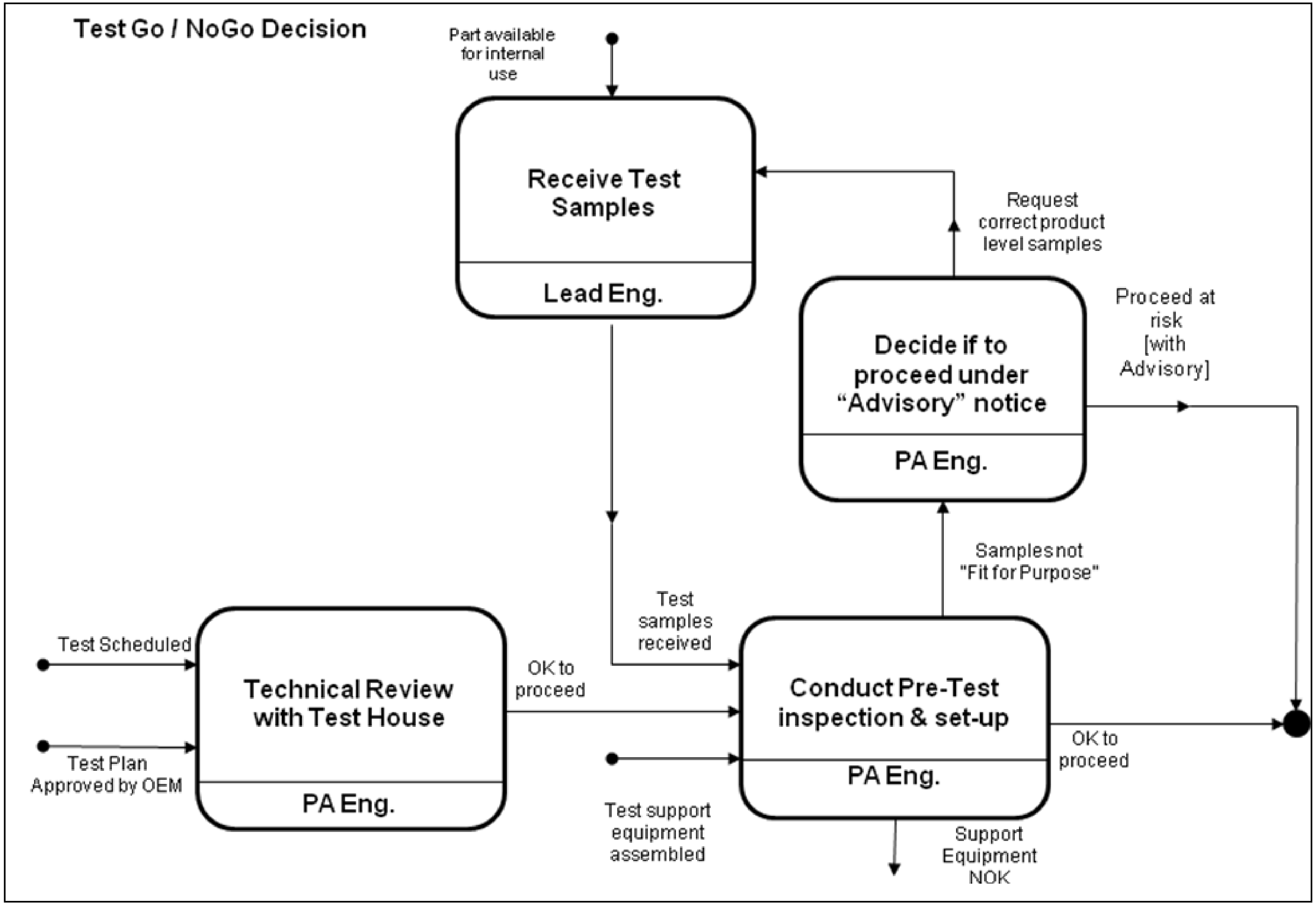
Product Assurance Hardware Validation Test Cycle (Includes Environmental and EMC)

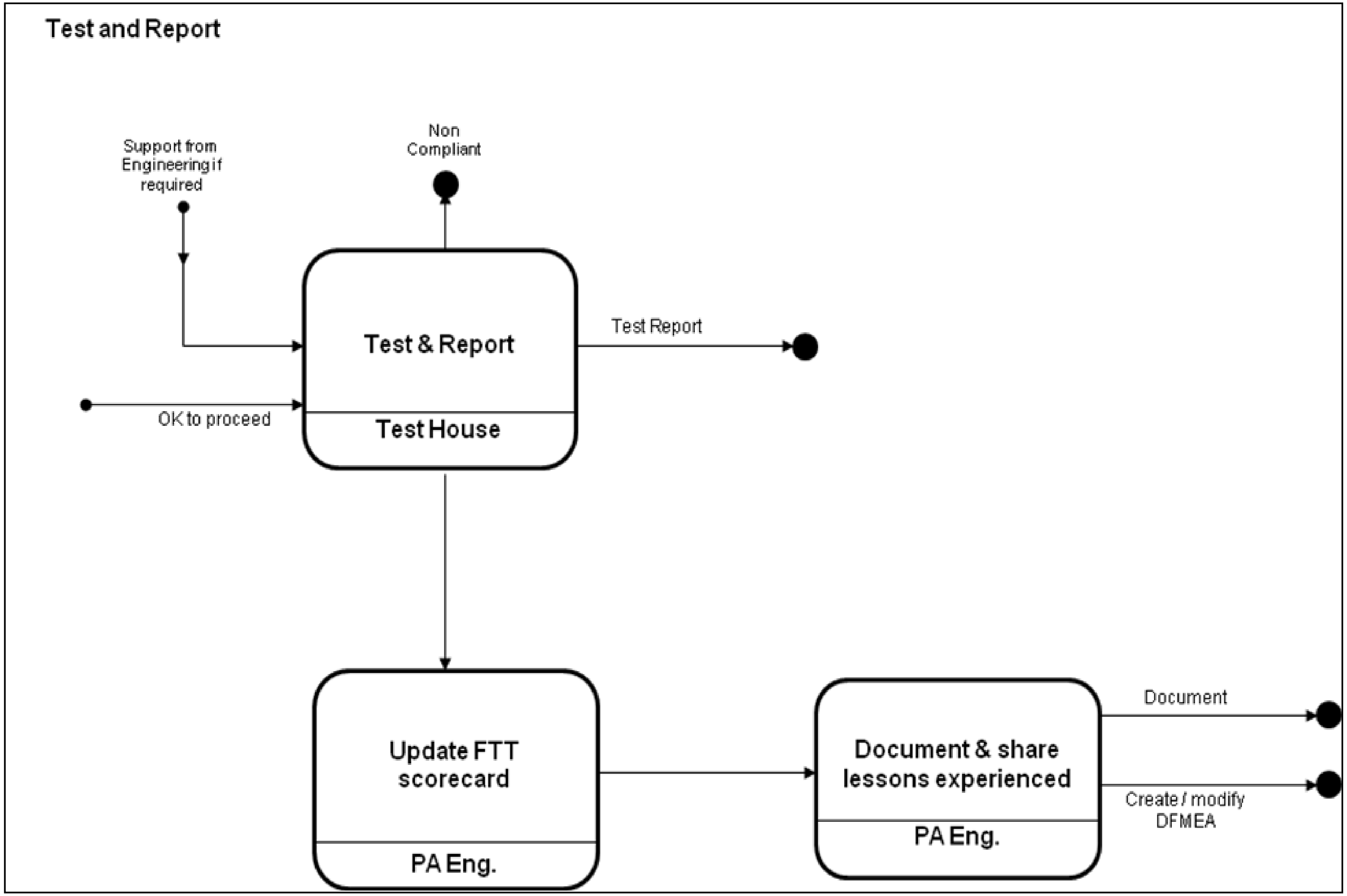





Specify, Develop and Accept Test Equipment
Define & compile EMC loom & load box documentation
PA Eng.
Elec. Eng.
Peer Reviewed Test Equipment Specification
Define & compile ENV loom documentation
PA Eng.
Elec. Eng.
Peer Reviewed Test Equipment Specification
Submit Task Request To Lab
PA Eng.
Task Request with Lab
Task Request scheduled
Lab Mgr.
Timing NOK – outsource?
Manufacture support equipment
Lab Tech.
Lab build completed
Receive Test Software
Test Support equipment assembled
Check & sign off EMC & ENV support equipment
PA Eng.
Samples to signoff test equipment
Design ENV Test fixture
PA Eng.
Mech. Eng.
Peer Reviewed Test Equipment Specification
Obtain quotes for cost & timing to manufacture fixture
PA Eng.
Supplier quote
Agree supplier
PA Eng.
Lead Eng.
Supplier agreed
Raise SAP order
PA Eng.
Supplier build completed


Test Scheduling
Peer Reviewed Test Plan
Advanced Test Request (if required)
PA Eng.
Test Procedures
Environmental OR EMC Test Request
Populate Test Request
PA Eng.
Populate PA Test Request Numbering Log
PA Eng.
Calculate Test Cost Estimate
PA Eng.
Test Procedures
Test Request Number Log Populated
Test Cost Estimate Populated
Conduct Peer Review
PA Eng.
PA Snr. Eng.
Test Request rated
Send Test Request & Obtain Test House schedule
PA Eng.
Purchase Order required
Test Scheduled
Test schedule NOK
Re-prioritise
PA Eng.
Approved


Test Go / NoGo Decision
Part available for internal use
Receive Test Samples
Lead Eng.
Request correct product level samples
Proceed at risk [with Advisory]
Decide if to proceed under "Advisory" notice
PA Eng.
Samples not "Fit for Purpose"
Test samples received
Test Scheduled
Technical Review with Test House
PA Eng.
OK to proceed
Conduct Pre-Test inspection & set-up
PA Eng.
OK to proceed
Test Plan Approved by OEM
Test support equipment assembled
Support Equipment NOK


Test and Report
Support from Engineering if required
Non Compliant
Test & Report
Test House
Test Report
OK to proceed
Update FTT scorecard
PA Eng.
Document & share lessons experienced
PA Eng.
Document
Create / modify DFMEA

APPENDIX D: ADDITIONAL FINDINGS FROM BENCHMARK STUDY QUESTIONNAIRE SURVEY

Test Planning

Question 5.2 - How do you define the hardware test?

The study showed that 87% of the participating companies *always* define hardware tests as the function of their products, while the other 13% *sometimes* define hardware test as the function of the product. 81% *always* define hardware test as the integrity of the whole product, while only 19% *sometimes* define hardware test the integrity of the whole product. This shows the importance of functionality of products in product design and development and the integrity of the product as a whole. However this does not mean that the key components of a product are not equally as important. 67% of participating companies *always* define hardware testing as the testing of key components and 33% *sometimes* define it as the testing of key components.

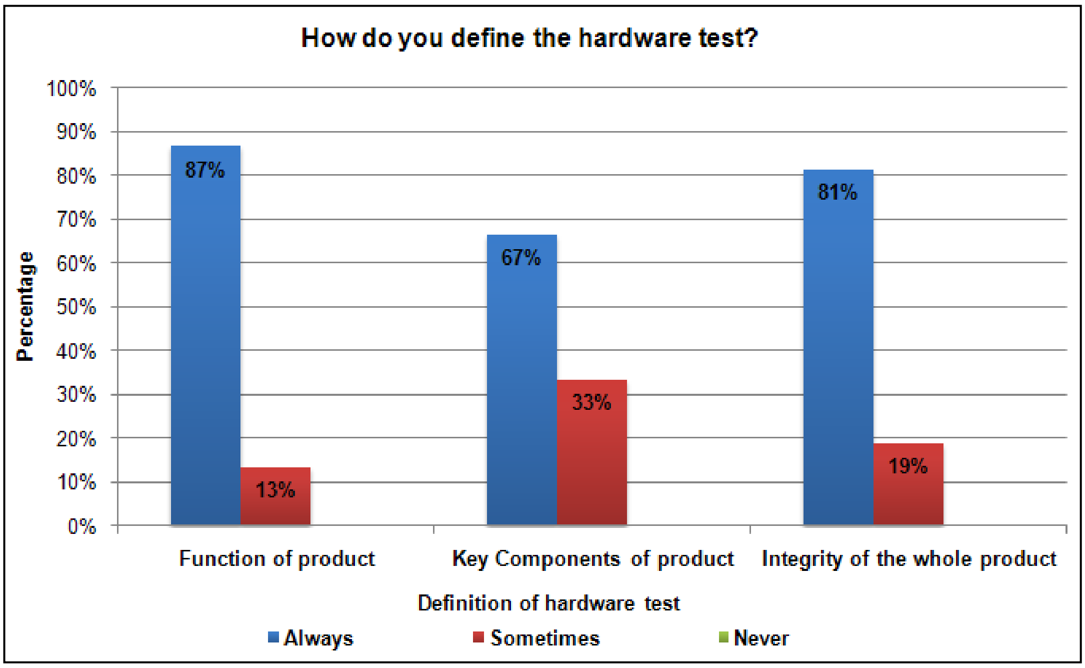


Figure 6.1: Chart showing the different definitions of hardware test

Requirements Document

Question 6.2 - What documents are produced from the testing and validation exercise?

The study showed that 100% of the participating companies produce test reports and 18% produce test flow charts.

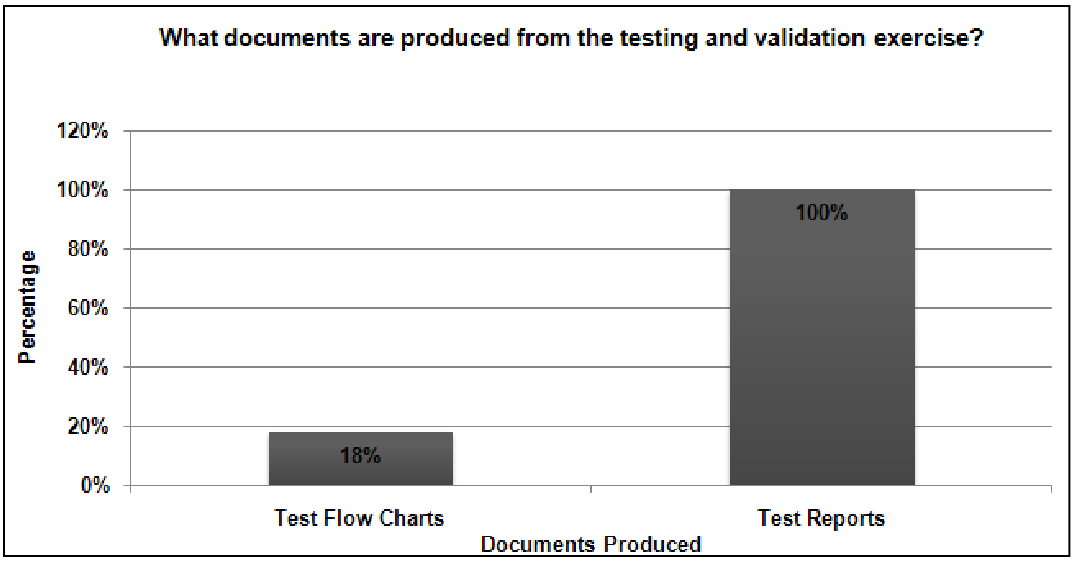


Figure 6.2: Chart showing the documents produced from the testing and validation exercise at the participating companies

The sponsor company always produces both test flow charts and test reports. This could be as a result of the type of tests usually carried out or as a result of the types of product components being tested by the sponsor company.

Question 6.3 - How are these documents structured?

The study showed that 100% of the participating companies structure the documents from their testing and validation exercise as report styled documents, 41% as tables and 18% as flow charts.

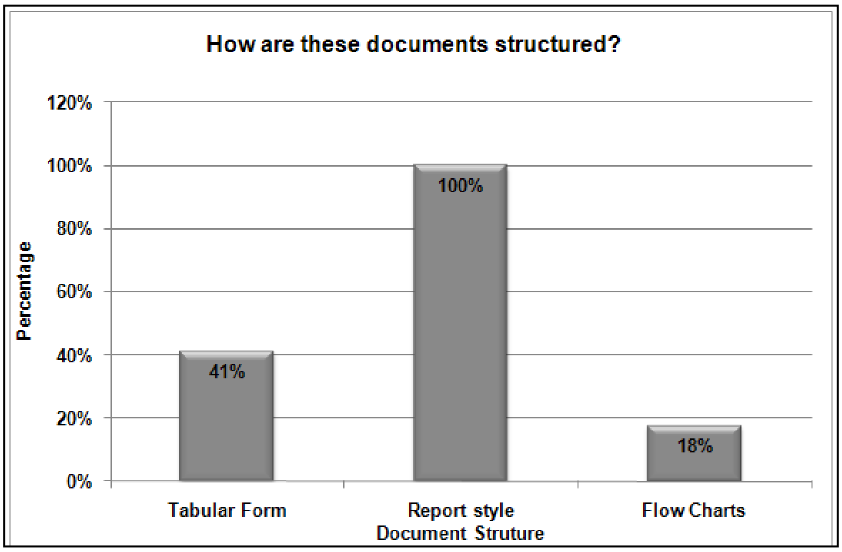


Figure 6.3: Chart showing how documents from testing and validation exercise at the participating companies is structured

The sponsor company falls within all three categories with more emphasis being placed on tabular and report style structures.