Title: The Role of Directors in Corporate Governance: Product Design Risk Management

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I hereby certify that the work embodied in this Dissertation Project is the result of original research and has not been submitted for a higher degree to any other University or Institution.

(Signed) ___________________________
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Synopsis

Company directors are obliged to ensure effective operational risk management governance to protect shareholder wealth. Product recalls are a risk to profitability (Davidson and Worrell 1992). This study adopts a broad conceptualisation of product recall, involving the return of products due to fault/defects. “Product recall” may include formal recalls enforced and recorded by regulatory bodies, informal recalls that may be initiated by a company but not recorded as such and/or return of products by customers due to defects.

Not all risk can be foreseen, which is aptly referred to as unknown-unknown risks (Dombret 2012). Design methods impact product reliability and safety. Some methods, such as tolerance analysis (Singh, Jain and Jain 2003), may comply with company standards as defined by management, but still create unreliable product.

Thus, the research problem pertains to the ubiquitous presence of unknown-unknown risks of product recall due to unknowingly inadequate product design processes, reporting structures and potentially incompatible organisational climate that creates an impediment to directors in the fulfilment of their legal obligations to ensure effective operational risk governance.

By evaluating a typical case, this study will adopt a holistic approach starting with directors and their evaluation of their company’s risk management structures, methods, internal controls and risk management climate. Agency theory, whistle blowing, bounded rationality, and other theories will underpin the investigation. This facilitates an exploration of directors’ understanding of product recall risks and how they ensure their company employs suitable operational risk governance and product design methods in mitigating unknown-unknown risks.
1.0 Chapter One: Introduction

1.1 Overview

This introduction reviews the phenomenon and justification for this study. Supporting theories are explored, with the research problem discussed and outlined to impart on the reader why this study is important to both practice and literature. Research questions follow, with a brief outline of methodology and an outline of each chapter. While the focus of this dissertation is NOT engineering in itself, to understand the organisational climate and social phenomena being explored, a surface understanding of the terms employed is required. To this end, and to aid the reader, a glossary of terms is provided.

1.2 Research Catalyst

Directors have a responsibility to shareholders to ensure that the correct governance structures, reporting and controls, are established to reduce the probability of operational risk such as product recalls. The introduction of Sarbanes-Oxley Act, 2002 legislation in the USA and the Turnbull guidelines in the UK have increased the focus on operational risk to reduce the probability of corporate collapses, and the resulting damage to shareholder interests (Liebesman 2005; Rikhardsson et al. 2006; Drennan 2004). Product recalls cause significant damage to companies and are by definition an operational risk. However, product recalls continue to occur. As challenged by their analysis of the GM ignition switch recall that killed 13 people, Eifler, Lerche Olesen and Howard (2014), point out there are many reliability based design methods that are well established. So why are these not being used to avoid recall? Similarly, Wetmore III, Summers and Greenstein (2010) and Pritchard and Kotow (2010) discuss the Deepwater horizon and the challenger space shuttle disasters and the engineering failures that cause them. However, within their studies Eifler et al. (2014), Pritchard and Kotow (2010) and Wetmore III et al. (2010) recognise that these engineering failures occurred within a social environment that worsened or hid the true extent of the risk. Thus undermining operational risk governance structures and created the potential for unknown-unknown risk to stakeholders at the highest levels within their organisations. This research is catalysed by the real world industrial examples provided
by the GM ignition switch recall, the Deepwater Horizon and the Challenger Space Shuttle disasters, and in direct response to the questions raised by the studies into these events as described above. Similarly, this research is catalysed by the legal and governance changes to operational risk occurring throughout industries. As such, this study seeks to understand the interaction between engineering design processes, the organisational climate, and how these interact to create unknown-unknown risk limiting the effectiveness of governance structures. Thereby limiting Directors ability to discharge their governance obligations.

1.3 Justification of Research

Theoretical Justification

In response to studies of high profile product recalls by Eifler et al. (2014), Pritchard and Kotow (2010) and Wetmore III et al. (2010) this study will give greater focus to social factors, organisational climate (Patterson, Warr & West 2004) and governance structures than to product design process. A review of literature demonstrates that there are gaps within literature when considering the combined effect and the interaction of these theories and phenomena. The social factors will include agency theory to explore the challenges between management and governance (Eisenhardt 1989a). Whistle blowing and the mum effect will also be used to demonstrate how social phenomena can combine with organisational climate to dissuade employees and engineers from reporting and/or escalating risk (Keenan 2002; Smith, Keil & Depledge 2001). As a result, this study will expand on knowledge by creating a model that describes the interaction within engineering processes, organisational climate and governance structures and how they can combine to create product recall risk that cannot be detected by company directors. This model will then contribute to theory by closing the gaps indentified within the literature review. Further, studies suggest there is a dearth of research into design processes in the UK (Antony, Kumar & Labib 2008; Kondic 2009). This study will increase current knowledge in this area.

This study has been grounded using numerous supporting theories and concepts which are used to understand phenomena as it emerges in an attempt to respond to the research questions. Agency theory states that agents should act in the interest of the principle,
and that this needs to be verified. The conflict occurs when the agent does not act, or is perceived not to act, in the principles interest (Eisenhardt 1989a). In the context of this study, agent refers to the company management and principle refers to company directors. Further limiting the effectiveness of governance structures, and as described by Keenan (2002), is the inhibition of whistle-blowing. This is the act of reporting to authorities on immoral or illegal activities within a company. As this often goes against existing power structures, there is typically pressure for individuals and/or groups to keep quite to avoid penalty for speaking out. The mum effect has similar mechanisms and impact to transparency as whistle-blowing, in that existing power structures inhibit individuals and groups from speaking out against a pending negative event that could probably be avoided where they to do so (Smith et al. 2001). Whereas supporting whistle-blowing, and by extension whistle blowers, are identified as an important component of an effective governance structure and have protection under UK law (Bowers et al. 2007), the mum effect refers to individual interactions within and between teams. In the context of this study this may be where an individual engineer does not speak-up and report what he believes are inadequate review of product designs, through team pressure to ‘keep mum’. No laws have been broken, no fundamentally immoral act undertaken and therefore the concept of the mum effect is separated from whistle blowing. In this way, the inhibition of whistle blowing requires individuals to keep mum. However, keeping mum is not always the inhibition of whistle blowing.

Additionally, Jones (2002) discusses the concept of *bounded rationality*, which refers to an individual’s inability to understand their world and that it is limited by their access to information over a given amount of time, their cognitive skills and their education. This clearly limits their ability to understand all risk.

Within this study the term "social factors" is employed to collectively and separately describe the above concepts or phenomena, rather than list each repetitively. This has been done to reduce repetition, with other less important concepts being added to the list of social factors, as the study progresses. These social factors occur to a greater or lesser extent based on the company’s focus and influences within their organisational climate. Organisational climate is described by Langford (2009) as "... tangible and observable practices, systems and outcomes." thus climate is the manifestation of organisational culture.
A summary of the gaps within theory and literature and how this study resolves these is produced in table 1.

<table>
<thead>
<tr>
<th>What theories tell us</th>
<th>Where and why theories are limited</th>
<th>How this study address these limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Process</strong></td>
<td>Few gaps exist within literature, with the existence of risks as an output of design well established.</td>
<td>Established theories. No contribution.</td>
</tr>
<tr>
<td>All forms of risk emerge out of design process. (known, known-unknown and unknown-unknown). Known risks being corrected during design.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Design Review and Risk Analysis</strong></td>
<td>Literature does not adequately define these social root causes.</td>
<td>Identification of, and the mechanisms behind, social factors that can individually and/or collectively transition known risk to unknown unknown risk within a high technology companies PDP.</td>
</tr>
<tr>
<td>Through the design review process risks are identified and managed but unknown- unknown risks remain and these can cause product recalls. Literature suggests that there is a social root cause to recalls and engineering disasters influencing the creation of these unknown unknown risks</td>
<td>Some theories suggest that social factors could distort the risk discovery process, such as agency theory and the mum effect, thus creating unknown-unknown risk. However, many either insufficiently, or not explicitly, describe the impact on governance reporting as it relates to unknown-unknown risks and product recalls. Similarly, when or if multiple social factors occur simultaneously. Does organisational climate interact with these social factors to influence risk discovery or reporting? In what way? How?</td>
<td>The discovery of an eclectic confluence of social factors interacting with organisational climate and inadequate design methods to reduce risk discovery and the effectiveness of governance structures thus increasing the occurrence of unknown-unknown risk.</td>
</tr>
<tr>
<td><strong>Governance and Recall Risk</strong></td>
<td>Literature does not fully specify the actions directors take within UK high technology SME OEM companies to understand unknown-unknown risk as this specifically relates to product recall.</td>
<td>This study identified that within the respondent company, directors did not take specific actions to reduce unknown-unknown risks, and thus recalls had occurred.</td>
</tr>
<tr>
<td>Agency theory supports the concept that management act in their own interest by limiting influence of directors. An example is to alter reports</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>What theories tell us</strong></td>
<td><strong>Where and why theories are limited</strong></td>
<td><strong>How this study address these limitations</strong></td>
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<td>--------------------------</td>
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<tr>
<td>to their own benefit, and thus under report the likelihood and/or severity of unknown-unknown risk. Literature does discuss Black Swan theory within the context of engineering disasters and governance.</td>
<td>When there is a product recall, directors are not expecting this severe event to occur. Literature does not adequately explain if or how recalls can be described as a Black Swan event rather than simply a serious unexpected event.</td>
<td>In part, because directors did not know to take specific action to reduce unknown-unknown risks, the mechanisms by which a product recalls resembled a Black Swan event were evident. Similarly, the theoretical requirements for the applicability of Black Swan theory were demonstrated.</td>
</tr>
</tbody>
</table>

Table 1: summary of the gaps within theory and literature and how this study resolves these
Practical Justification

Through the use of the model described above, directors will be more informed about some of the underlying causes of product recall risks within their company. As a consequence of this study they will be more capable of modifying their internal governance structures, organisational climate and/or design methods to ensure they more effectively discharge their risk management obligations, and reduce their own personal liabilities. In light of recent high profile product recalls, in some cases causing death, empowering directors to manage product reliability is not only in the interest of shareholders and Directors, but also the public.

1.5 Research Problem

Literature supports the link between product reliability, recalls and the design process. Literature also discusses individual social factors and organisational climate and how these influence business operations, including product development projects. Product recalls continue despite the recognition of the above, with scholars questioning why, and exploring one of these facets of the problem separately but not both in tandem. This study explores these facets in an integrated manner to understand this problem, to make both a contribution to knowledge as well as propose improvements to practice in an attempt to reduce the impact of product recalls on Directors, companies and society.

1.6 Research Questions and Objectives

The aim of this study is to understand directors' awareness of unforeseeable risks in their company's product design process and to understand the methods directors use to ensure there is sufficient governance and management oversight to mitigate, control or eliminate these risks.

Research question one: What product design methods are used within the case study company and how informed are the directors of these methods?

Research question two: Why and how have hidden risks emerged, and do directors understand such risks within product design processes?
**Research question three:** How has their knowledge from research question one and research question two helped them to influence design process and risk management structures and how do they ensure their influence achieved its intended outcome?

**Research question four:** How have these directors considered and cultivated an organisational climate and social factors that contribute to the attainment of the directors expectations of governance structures and product design processes discussed in research question three?

**Research objective one:**
To understand directors ability to comprehend the product design methods that their governance structures are attempting to control. To achieve this, the gap between the companies actual methods and directors perception of these needs to be established.

**Research objective two:**
To understand directors ability to comprehend the product recall events, and the possible causes of them, that their governance structures are attempting to control. To achieve this, the gap between the actual events and directors perception of these needs to be established.

**Research objective three:**
To understand how directors have modified management and governance structures to control product recall risks. This requires answers from the first to questions to provide context.

**Research objective four:**
To understand the extent to which directors have considered the impact of social factors and organisational climate on their governance structures, and what action they may have taken to encourage an organisational climate that supports transparency and active management of product recall risk.
1.7 Contribution to Knowledge

This study contributes to knowledge by expanding on the interaction between Product Development Processes (PDP's), organisation climate and governance structures and how these can combine in a dysfunctional manner to create product recalls. Specifically, the inhibition of whistle blowing and employees/managers keeping mum ensured governance reporting did not reach directors, ensuring they could not modify the design processes, address social factors nor the governance structures themselves.

Conflict between agents and principals was also observed with managers adjusting reports to avoid accountability. Product design review methods, themselves forming an aspect of risk control governance, were found to be influenced by social factors with dominant personalities and conflict also influencing project decision processes. This again denied directors the ability to act, by leaving them with a false sense of security that risks were well managed. It was evident then, and as demonstrated within this study, that inadequate design process coupled with a supportive organisational climate reduced directors ability to create an adequate governance structure.

Without an adequate governance structure directors were incapable of understanding the mutually dependant relationship between inadequate design process and organisational climate and thus severe this relationship. Despite numerous product recalls this vicious circle was self supporting such that it continued to ensure there was insufficient transparency into the company for directors to know of the need to act.

The study contributes to theory by responding to recent studies into recalls and engineering disasters where their authors have challenged that the cause must lay beyond engineering alone and that there must be a social cause to these events. The study demonstrates that this is indeed the case through the use of organisational climate to qualify and explore these social phenomena. The study concludes that poor engineering coupled with phenomena such as agency theory, whistle blowing, bounded rationality work in sympathy with organisational climate a self supporting system that undermines effective governance.
Through the mechanism above, this study demonstrated that risks emerging from the design and review processes changed in nature from being known risks or known unknown risks to far more dangerous unknown unknown risks. The Black Swan Theory was explored to determine its potential to explain the emergence of these risks and the resultant product recalls experienced by the participant company. As such, this study demonstrated the applicability of the Black Swan Theory to SME OEM’s within a high technology industry.

Further, contributions to practice are provided by a comparison of recent high profile product recalls to the case study organisation. This results in a model that may be used to understand these interactions. This then presents the possibility of using this model as a tool within industry to determine if an organisation has the underlying pre-conditions to make it vulnerable to product recall.

1.7 Research Methodology

Through exploration via inductive methodology (Bowen 2008) the use of a typical and within case case-study qualitative methodology will be employed (Ayres, Kavanaugh & Knafl 2003). It will employ methods such as semi structured interview, surveys and the collection of organisational artefacts. Conjectures will be iteratively created, questioned, modified and re-questioned until a point of saturation is reached typical of an inductive method (Bowen 2008). Quantitative methods such as surveys and organisation artefacts are be used to aid validity via triangulation (Scandura & Williams 2000).

For the purpose of this study, the participating company is divided into three groups. Those not involved in the product development process in any form, company directors, and managers/employees that are either directly involved or indirectly involved in product development. Using a purposive sampling method, (Tongco 2007) the last two groups were invited to participate. Directors were requested to contribute to semi-structured interviews, while employees and managers were invited to participate in semi-structured interviews and surveys. Through the use of thematic coding, via Nvivo, and descriptive statistics using SPSS, data was explored to in an attempt to uncover phenomena and answer the research questions.
1.8 Chapter Summary

This dissertation is divided into five chapters, including this first chapter. The literature review in Chapter Two contains a discussion on the change in directors’ obligations, moving them from financial responsibility alone to operation risk. The review demonstrates product development and design process interaction and hierarchy. Further, it discusses how design methods influence product reliability. Exploring quality control, the literature review brings out the way in which many authors and indeed industry, struggle to understand how quality control has been shown as ineffective at improving product reliability. Rather, that quality and reliability is designed into product as has been shown in literature and practice for almost twenty years. Social phenomena is discussed, as is literature indicating that design can be influenced by discrete phenomena such as whistle blowing and keeping mum. Methods for managing risks within companies is discussed, and compared to design methods, quality control and the social phenomena previously explored. This is then linked to organisational climate, to understand how literature links climate to product design and thus product reliability and recall risk.

Chapter Three outlines the research methods in particular the research paradigm and strategy as summarised above. It goes onto discuss the research design, including purpose, unit and level of analysis and the data collection method. Lastly the sampling design is also presented.

The findings chapter presents the data from the semi-structured interviews, survey and artefacts. These are summarised, tabulated and compared. Where appropriate, important themes are identified, pertinent artefacts discussed and statistically relevant survey data coupled with descriptive statistics employed to form triangulation. This data is then applied to the research questions, and these are answered in turn.

In the last chapter, this study's contribution to knowledge and implications for practice are explored and discussed. Similarities with Black Swan theory, and its potential use within product design, risk management and governance is discussed. A model is
identified and named as the Whirlpool Model that describes the phenomena explored within this study. Specifically the interaction between governance, product development processes, design methods, social factors and organisational climate. This study proposes that this interaction should be called Recall Risk Governance Opacity.

1.9 Delimitations and Assumptions

This study is limited to the influences surrounding the design and design review aspects of the PDP. Due to the reduced potential for discovery, this study has excluded companies whereby their directors know they have high product recall risk due to design process and are thus addressing this. Similarly, companies that are known to employ design methods created to increase product reliability. As discussed by Antony et al. (2008) and Kondic (2009), citing the example of six-sigma, small to medium enterprises (SME’s) have not typically taken up design methods that were created to increase product reliability. As such, large companies have also been excluded. To ensure there is sufficiently rich phenomena to explore, companies that do not conduct their own product design and manufacture have been excluded. Similarly, companies that produce product with a combination of electronic and mechanical assemblies are included, rather than software design, to ensure sufficient complexity in the design process. However, the participating company should not be operating within a high risk safety environment to avoid this study unnecessarily entering the High Reliability Organisation (HRO) versus normal accident theory debate described by Rijpma (2003). Consistent with Yin (1981), to fully explore the depth and complexity of the phenomena being explored, a case study consisting of a single company has been chosen. Similarly, the choice of a typical case method was influenced by the desire to see why and how the phenomena being studied influenced an organisation with the characteristics described above. To observe an atypical case would not have provided opportunity for discovery as it is likely that the phenomena would not exist in sufficient depth.
2.0 Chapter Two: Literature Review

This chapter reviews and considers literature relating to company directors operational risk governance obligations, product development and design processes, the nature of product recall risk and organisational climate. With particular attention to how these interact, this literature review not only describes current theory, it also demonstrates where studies disagree and reveals potential gaps within literature. From these gaps, the research questions emerge.

2.1 Directors Legal Obligations

The collapse of Enron stimulated an increased awareness of the need to expand managerial oversight by boards of directors and that this expansion was captured by legislative changes such as the Sarbanes-Oxley Act 2002 (Rockness & Rockness 2005; Drennan 2004). This stimulated an increased awareness of the role operational risk plays in the successful long term viability of companies, rather than the traditional but narrower focus on the financial success of the company as the dominating influence (Ingley & Van Der Walt 2008). Indeed the UK board of directors obligations to manage risk within their company is outlined within the Financial Reporting Council (2012, p. 7) "The board is responsible for determining the nature and extent of the significant risks it is willing to take in achieving its strategic objectives. The board should maintain sound risk management and internal control systems."
The study completed by Elliott et al. (2000), further demonstrates the change in legislative requirements in their analysis of the Turnbull Guidelines. These guidelines detail the requirement for directors of UK publically listed companies to consider operational risk as equally important as financial risks and within the bounds of their governance obligations. The growing operational risk management obligation via the Turnbull Guidelines in the UK is also supported by Dickinson (2001, p. 362). He clarifies this operational risk to include "...human error, fraud, systems failure and disruption of production" (p. 362). There is clearly growing operational risk based governance obligations via numerous recent additions to legislation in many countries as described by the work done by a number of other authors: (McCrae & Balthazor 2000; Supatgiat, Kenyon & Heusler 2006; Brown, Steen & Foreman 2009). In a globalised world, significant legislative changes such as the Sarbanes-Oxley Act, 2002 has an impact on countries not directly specified by the legislation's immediate jurisdiction. Shaffer (2006) discusses the conflict that surrounds the extraterritorial legal obligations within the Sarbanes-Oxley Act 2002 and incompatibility with other countries legal framework such as the EU and UK. These extraterritorial legal obligations force UK listed companies to comply with Sarbanes-Oxley Act 2002 legislation even if they are not listed within the USA, further entrenching the requirement to ensure sufficient oversight of operational risk.

Such changes are not without their detractors. Indeed, Romano (2005) in his criticisms of the manner in which governance policy was adopted without sufficient rigour in rapid response to the Enron collapse, describes the Sarbanes-Oxley act (2002) as “...Quack Corporate Governance”. However, regardless of the debate surrounding its merits, the Sarbanes-Oxley act (2002) is enacted in law, and the discussion on its credibility is outside the scope of this study. Rather this study accepts the current legal frameworks and seeks to understand one aspect of the fulfilment of governance obligations within it.

Numerous scholars (Sullivan 2012; Lai, Azizan & Samad 2010), are quick to assert that risk and reward is inherent within business. From an unsystematic risk perspective, Sullivan (2012) accepts the need to create operational risk management structures within companies. Further, he describes the attempt to remove all risk as unhealthy, and
thus highlights the importance of understanding and managing a company's risk rather than attempting to eliminate risk completely.

As discussed above there have been numerous legislative changes over the last 15 years in the area of risk management and corporate governance both within the UK and internationally. In the most part, these legislative changes were stimulated by a desire to protect shareholder wealth. Atkinson and Florio (2009) link greater shareholder returns with non-financial (that is, operational) risk management processes. In support of this point, the study by Davidson and Worrell (1992) substantiates the damage to shareholder wealth created by product recalls.

Daughety and Reinganum (1995) discuss the impact of product defect, as this relates to product safety, that is created by the product manufacture or design process. Further, they discuss the difficulty when assigning a provision for such liability. They cite the companies Ford and Jonson and Johnson as experiencing significant and unexpected commercial damage when faced with liability costs that were far greater than provisioned. Indeed Scott (2008) argues that it is impossible to provision against such "unknowable" risk as it is by definition "unknowable". By extension taking preventative action is also unachievable.

Vaid (2008, p. 331) states that effective management of operational risk via business continuity planning is required to meet Sarbanes-Oxley Act, 2002 obligations. He goes on to describe operational risk as "... damage to assets,...,execution/delivery failures." Clearly the financial damage caused by product recall can be described as execution/delivery failure. It could be argued that the market damage to branding and/or intellectual property caused by product recalls is damage to company assets. This is consistent with the study by Brown et al. (2009) that points out that in 2006 the Australian Stock Exchange issued an exposure draft updating its governance principles. This update explicitly identified brand, reputational damage, product and service quality as material business risks. Material business risks requiring governance oversight by directors. As such, this study seeks to understand the link between governance obligations, and the management of operational risks surrounding product design.
2.2 Managing risk: Technical and Behavioural Factors

When considering the literature surrounding the management of risk, it can be divided into two groups, technical factors and behavioural factors. Within this study, the technical factors are described as the risk management methods and processes themselves as well as the processes and methods that are present within the working environment from which the risks emerge. However, methods and processes are executed by people. Therefore, behavioural factors also need to be considered and how these may influence the successful execution of the risk management methods and processes, or technical factors.

2.2.1. Technical Factors

Literature attempts to provide insight into managing operational risk and/or unknown-unknown risk. Stoelsnes (2007) defines unknown risk in two ways. Known-unknown risk and unknown-unknown risk. Known-unknown risks are defined as risks whereby information and/or knowledge has not been accessed to resolve the risk, but the content of the risk is knowable with correct linkage between the situation and the participants. Unknown-unknown risks exist when the information or knowledge does not exist and therefore the linkage between situation and participant cannot be formed (Stoelsnes 2007). Consequently, Stoelsnes (2007, p. 272) describes the influence of unknown unknowns on the successful delivery of projects as "impossible to evaluate in advance " Stoelsnes (2007) also discusses methods to increase system robustness to compensate for unknown-unknown risks and thus deliver projects to expectations. While Stoelsnes (2007) discusses project management methods generally, he cites engineering examples where high reliability outcomes are required. In the context of this study, the generic concept of making systems robust to compensate for risk is applied to the specific concept of making product design process robust against risk of poor product reliability and thus recall. For example, using modern design methods, to reduce exposure to risks within the design process, as discussed above. Further, the use of absolute tolerance methods rather than intuition to ensure the design will produce a reliable product (Recchia et al. 2005). While absolute tolerance calculations are more complex, and require greater resource, the design is more robust against poor product reliability.
Scenario Planning has been proposed by Stulz (2008), Hinrichs (2009) and Peterson, Cumming and Carpenter (2003) as a means of managing the business impact of risks should they come to fruition. Indeed, this appears to be a viable method on which to begin to manage unknown-unknown risk. However, given the infrequent, severe and unexpected nature of product recalls, it is likely that such planning would be extensive and risk appearing as an unrealistic doomsday scenario. To overcome this view, and thus substantiate the need for such a plan the proposer of such a scenario may well have to 'blow the whistle' on practices that some managers may not like discussed openly (Smith et al. 2001). Consequently, the acceptance of such a scenario would be predicated on directors’ acceptance of the need to plan for such an extreme event. If this level of awareness of the risks were achieved, it is more likely that the root cause of the risk, insufficiently robust design methods and governance structures as discussed below, would be addressed. Perhaps because these root causes are seen as trivial, with seemingly well understood theory and practice, their collective impact on the system is underestimated.

Reasoned risk taking is proposed by Carpenter, Pollock and Leary (2003). This method suggests that business is not without risk, and thus it is more important to understand the rationale behind risks so they can either be managed or accepted. This again assumes that the existence, nature and impact of risks are understood and quantified. If this is the case, then it is likely the risks would have already been resolved, thus removing the benefits of employing reasoned risk taking at executive level. Indeed, it seems incongruous that a reasoned risk position could be justified against unknown-unknown risk. The barriers to understanding and quantifying unknown-unknown design risk leading to product recall being central to this study.

Vaid (2008) discusses the idea of business continuity planning. However, he accepts the idea that this process is more suited to external risks. In their study of the risk governance at a large Australian listed biotech company Brown et al. (2009) found that current risk management structures are clearly inadequate in light of emerging operational risk management legislation as discussed in section 2.1. Brown et al. (2009) cite the application of technology as the cause, and propose the creation of an audit
committee that functions between the senior management and the board of directors with the intention of assisting the board with understanding the technical and operational risks faced by their organisation. As with reasoned risk taking and scenario planning, this does not take into consideration the barriers to quantifying some forms of risk.

Daughety and Reinganum (1995, p. 1189) take a similar perspective of risk and product design. They state that "R&D is a stochastic process, partially controlled by investment, which ultimately yields an equilibrium set of acceptable product risk levels." They go on to discuss risk within R&D in simple economic terms based on product design risk being "stochastic" or statistically predictable. They give an example of a product with a desired level of safety risk. They uphold that the amount of R&D investment will influence the products safety. The high cost of production being economically offset by the reduced risk contingency. Once the product design has reached the desired level safety, through increased R&D expenditure, the R&D effort is discontinued. The extra expenditure leads to an increase in price which is adjusted in response to market demand based on market acceptance of the achieved level of safety.

Thus, Daughety and Reinganum (1995, p. 1189) present product design as mathematically predictable and absent of unknown risk. For example, they expect an increase in R&D spending to have a proportional decrease in the probability of product recall. Efatmaneshnik and Reidsema (2007) however, acknowledge the existence of unknown risk. This unknown risk removes the mathematical predictably described by Daughety and Reinganum (1995, p. 1189).

However, in the context of an SME, where resources are limited, the risk management methods proposed by a number of authors (Stoelsnes 2007; Carpenter et al. 2003; Stulz 2008; Brown et al. 2009; Hinrichs 2009) appear to require a greater investment to mitigate the risks than to address the root cause, that is, implementing rigorous design process and governance structures. Certainly Chermack and Lynham (2002) identify the high cost of scenario planning. Further, typical risk management methods become ineffective when faced with unknown-unknown risk. To repeat Stoelsnes (2007, p. 272), the effects of unknown-unknown risks on projects become "impossible to evaluate in
advance”. Most importantly, these risk management methods require that directors have understood and embraced their role in operational risk management oversight, and have the technical skills to discharge their responsibilities. In the context of this study, that is the ability to create suitable controls and reporting structures within a high technology organisation to ensure that the management team are identifying and managing operational risk (Brown et al. 2009). However, this requires directors to have sufficient core skills to understand and influence the content of the governance control and reporting structures, with some studies suggesting this is not always the case leading to ineffective governance (Ingley & Van Der Walt 2008). Further, it is probable that directors include within these cores skills and ability to understand the possible interaction between behavioural factors and technical factors.

2.2.2. Behavioural Factors and Organisational Climate

As introduced above, people execute processes and methods within and organisation and therefore behavioural factors must be considered. This section reviews the debate surrounding, and the applicability of, the use of the organisational climate model to describe the aggregate behavioural factors within a company.

As described by Langford (2009), organisational climate is distinct from organisational culture. Langford (2009) describes climate as a sub-set of culture. Climate being described by Langford (2009) as "... tangible and observable practices, systems and outcomes." thus climate is the manifestation of culture, which is based on values and assumptions. Wallace, Hunt and Richards (1999) are less definitive in their opinion that climate is a subset of culture, however, they do agree with Langford (2009) that the two have often been used interchangeably in error. They do suggest however, that climate is internally focused on tangible influences of managerial policy, with culture being more focused on internal and external influences with many of these influences being beyond managerial control. In their quantitative study, Wallace, Hunt and Richards (1999) demonstrate linkages between culture, climate and managerial values, and in this way they are, at least in part, consistent with Langford's (2009) view of organisational culture versus organisational climate.
Organisational climate is widely considered to be generalisable across many industries, national identities and cultures. Langford (2009) supports the general application of organisational climate, likening it to general measures of personality. Indeed, he supports its general application for three main reasons. Firstly, being a general measure of climate allows for its use and comparison across studies. Secondly, if a general measure were not employed, researchers would risk narrowing studies dimensions without understanding the whole picture, and lastly, a general application of organisational climate measures is required to determine which phenomena or outcome they which to improve. The success of organisational climate as a general tool is supported by a diverse range of studies in areas such as education in the United Kingdom (Barker 2001), child service is the United States of America (Glisson & Hemmelgarn 1998), informational technology development in South Africa (Castro & Martins 2008), the Nursing profession in the United States (Hemingway & Smith 1999) and professional sales in the United States of America (Churchill Jr, Ford & Walker Jr 1976).

Importantly there are many studies that employ organisation climate to evaluate complex social factors within the workplace. Examples in literature include studies by Muchinsky (1977) and Churchill Jr et al. (1976) that explore the link between job satisfaction and organisational climate. Hemingway and Smith (1999) outline the links between stressors, employee behaviours such as absenteeism through the lens of organisational climate. Studies by Silva, Lima and Baptista (2004) and also Neal and Griffin (2002), link safety climate, as a facet of organisational climate, and employees behaviour regarding risk taking as it relates to safety. Being employed in a setting that relates to risk, the use of organisational climate in this literature further demonstrates the ability of organisational climate to facilitate understanding of appropriate and applicable complex social factors and phenomena.

In a similar fashion to that described by Langford (2009), this study is interested in how complex behaviours or social factors are influenced (or described) by organisational climate and thus how these behaviours impact on product reliability via the product development and review processes and structures discussed and explored in detail below. Further, utilising the general nature of organisational climate (Langford 2009)
allows the scope of the study to remain sufficiently broad to avoid incorrectly narrowing influencing dimensions.

In agreement with Langford (2009) and Wallace et al. (1999), Patterson et al. (2005) also identify on-going confusion over organisational culture and climate. Consequently, it appears that some scholars either dismiss one theory in favour of the other, or utilise one theory when the other may be more beneficial. Further, they agree that there is a conceptual overlap, with climate being more indicative of surface operational systems and outcomes which are themselves influenced by culture. In an attempt to provide a quantitative measure for organisational climate Patterson et al. (2005) propose and validate a framework which can assist in understanding the organisations social environment or climate. Their model employs a number of dimensions that describe attributes of organisational climate, and these are in turn aggregated into quadrants. It is this framework that will be used to form the case study survey in this research project.

2.3 Product Development Process

As previously stated, technical factors include not only the risk management methods and processes, but also the methods and processes relating to the organisation under study that influence the existence and consequence of risks. For example, it is probable that risk emerging from dairy farming methods would be different in nature from risks emerging from space exploration methods. Therefore, to provide context to the study, section 2.3 explores literature that describes the methods and processes employed by companies within the sampling frame and how these companies manage risk.

The product Development Process (PDP) is the over-all series of methods that take a product from conception, through to production (Veryzer 1998). Within the PDP lay many different processes. These include product specification, design, production, test, quality control and the like. This study is limited to the influences surrounding the design and design review aspects of the PDP, how these are coherent with organisational climate, and their consequential impact of product reliability and recall risk. Numerous methods can be employed within each of these processes. The most common will be considered in this study and literature review (Table 2).
### Process | Description | Examples of methods
--- | --- | ---
Product Development Process | The overall process employed by the company to develop product, from initial conception through to product release. | Waterfall, Concurrent Engineering, Agile
Design Process | A subset of the Product Development Process that takes requirement specifications and creates a product that can be manufactured. | Absolute Tolerance stack-up, Statistically based tolerance, Experience/intuition based tolerance, Taguchi, Six-Sigma
Design Review Process | A subset of the Product Development Process that takes design and reviews them against company goals (e.g. cost, reliability etc...) | Peer review, FMEA, Testing

**Table 2:** Description of high level processes used in a product development environment and their constituent methods.

The generic structure of the PDP described by Veryzer (1998) and Cooper and Kleinschmidt (1991), and thus table 2: Description of high level processes used in a product development environment and their constituent methods, can be diagrammatically presented by Figure 1. This diagram demonstrates the linkages between the methods shown in Table 2. Starting at box 1, new product projects proceed through the design process, producing complex design outputs labelled generically as "reports" including design risks to be assessed and prioritised as shown in box 2. Management then evaluate the risks and decide, based on their view of the companies acceptance of risk, that risks either need to be managed by advising the project team to redesign the product (box 5) or whether they can be accepted (box 3). This is typical of most stage and gate PDP management structures. (Cooper, Edgett & Kleinschmidt 1999)
As discussed by Cooper, Edgett and Kleinschmidt (2001) and Cooper et al. (1999), and shown in box 3 Figure 1, senior management produce summaries of project progress, key risks and mitigation strategies for review by directors. Also discussed by Cooper et al. (2001), director and senior management understanding of the status of product development, and risks, is principal to managing a successful portfolio of strategic new products by directors. New product development projects within a portfolio of projects, are not required to be without risk. However, the aggregate risk to the company needs to be understood by directors in order to assess initial reward versus risk profiles, and to continue to assess reward versus risk profiles (Cooper et al. 2001). Directors need to be sufficiently experienced and educated within the strategic issues faced by the company to maximise their ability to moderate managerial decisions, provide governance and direction (McDonald, Westphal & Graebner 2008). In the context of this study, the complexities of risks as they emerge from the new product development process. As shown in box 4, Figure 1, directors assess the risks emerging from each design project within the new product portfolio (Cooper et al. 2001). As shown in box 4, directors then provide influence in the form of guidance, challenge or moderation, to senior managers advising them on acceptable risk profiles, reporting structures while contextualising these using their own expertise in new product development processes.
Figure 1: Graphic representation of a generic Product Development Process showing typical and simplistic view of risk management.

Known risks are created within design process. These are reduced as they progress up the company hierarchy.

1. Product design

2. Design risks are assessed.

3. Management either accept risks or allocates resource for resolution of risks.

4. Directors consider risks and influence change accordingly

5. Product re-design

Decision

Influence

Report

Report

Report

Report
2.3.1 Product Development in the UK

Arguably the most well known of the product design processes used to improve product reliability and manufacturability is Six Sigma (Harry & Crawford 2004; Chung & Hsu 2010). As such it may serve as a basis to determine the degree of uptake of modern design methods by UK OEM SME’s, given this study is based on UK companies.

Despite its relative popularity, research by Antony et al. (2008) and Kondic (2009), suggest that there are few studies relating to SMEs and the application of Six Sigma. Both of these studies also suggest that Six Sigma appears not to have been widely taken up by SME’s. The work undertaken by Antony et al. (2008) is of particular relevance as it is a study of UK manufacturing SME’s and demonstrates the benefits SME’s have received by the application of Six-Sigma.

Wessel and Burcher (2004), and Kondic (2009) state that the biggest barrier to SME’s employing six sigma is the belief that it is a system for large companies and that SME's have insufficient resources to employ such a system. Harry and Crawford (2004) agree, and claim that Six Sigma was never meant for SME’s, only large companies. Consequently they propose a simplified version for SME’s.

In their research study of SME’s in Turkey, Erginel (2010), discuss the disparity between SME’s and large companies in their uptake of Total Quality Management (TQM) principles. Specifically he mentions the low uptake of the principle of basing decisions on facts. It seems unlikely then, that these SME’s would have a significant uptake of complex fact based design processes such as Six-Sigma. Similarly, they are likely to depend on subjective design review processes, rather than ensuring that decisions are underpinned with fact based inputs as discussed in section 2.5. Thus the study by Erginel (2010) may suggest that the experience of SME OEM's in Turkey is likely to be comparable to that of the UK. Thus suggesting in both cases that there is an avoidance of complex fact based design and design review processes.
2.3.2 Waterfall versus Concurrent Engineering

There are numerous product development methodologies. However, the debate surrounding methodologies is typically centred on whether to use a Waterfall method or a concurrent engineering method (Cusumano 2001). The waterfall method, draws upon the concept that each department from product specification, design and manufacturing have definable inputs and outputs that are passed between departments in a sequential manner until the product is released to manufacturing (Cernuzzi, Cossentino & Zambonelli 2005). For example, marketing create a product specification, which is passed to the design team, who pass a design to manufacturing to build. This flow takes a one way path, with teams acting in isolation, and because of this it is sometimes compared to a waterfall, with product development activities occurring sequentially rather than in parallel or concurrently.

Concurrent Engineering however, facilitates the ability for product development tasks to occur simultaneously (Lindkvist, Soderlund & Tell 1998). For example, design teams may commence designing the plastics housing of a product, even if the details of what is required for product labelling has not been finalised. They only need to have been advised on the size of the label. Indeed, this allows marketing teams to decide at the last minute what is required on the label. This increased flexibility is typically described as one on the benefits of concurrent engineering when compared to waterfall methodology as confirmed by Cusumano and Smith (1995, p. 1), "...sequential "waterfall" type of development process, which has both advantages (it can be relatively structured) and disadvantages (it is not very flexible to accommodate specification and design changes during a project)." Typically, concurrent engineering's flexibility is achieved through multi-departmental teams in a collaborative environment: "In fact, the major rationale for concurrent engineering (CE) is to shift away from a serial “throw it over the wall” approach to parallel processing of activities. As usually practiced, CE attempts to bring more feedback upstream earlier, generally through face-to-face meetings" (Sobek, Ward & Liker 1999, p. 71).
However, despite the large body of support for concurrent engineering (D'Ambrosio, Darr & Birmingham 1996), because of its ability to reduce time to market by engaging multiple teams simultaneously, waterfall methodology remains strong, with the demise of waterfall methods being over stated (Laplante & Neill 2004). Indeed, many researchers argue that actually, serial or parallel paths and disciplines depend on the project. There is no one size fits all solution (Smith & Eppinger 1998). Other authors strongly criticise waterfall methods due to the sequential nature of the process and manner in which teams become separated (Carroll 1997).

Another feature of current engineering is the acceptance that an output from one department, acting simultaneously as the input to another, may not be perfect. Consequently, the method introduces the idea that product development does not flow as a river over a waterfall. Rather, that outputs are close to complete when passed to downstream departments. These departments then use the information provided collaboratively and intelligently to complete what they can. They then request further information from upstream departments once they reach the limits of their knowledge. This process of going back upstream for clarification or further iteration, commonly referred to as iteration (Terwiesch, Loch & Meyer 2002), forces co-operation and social interaction between departments, and disciplines. Yassine and Braha (2003) argue that this multidisciplinary iterative approach reduces the impact of bounded rationality as no designer in isolation can identify all possible solutions required to produce the perfect product. Jones (2002) discusses the concept of bounded rationality, which refers to an individual’s inability to understand their world and that it is limited by their access to information over a given amount of time, their cognitive skills and their education. This clearly limits their ability to understand all risk. As such, and in the context of this study, if product development processes support design engineers functioning separately to other functions, as in a waterfall method, then their ability to perceive risk is limited. They are limited by the collective bounded rationality of project participants from a similar educational and employment background. That is, engineering design. The involvement of other departments during design such as production, quality and sales, increases the collective knowledge and awareness of sources and consequences of design based risks. Therefore, within a waterfall method based project, many design based risks are left unresolved.
2.3.3 Agile

This concept of utilising process iterations was expanded on and formalised even further to create the concept of the agile methodology. Initially implemented in the software development environment, this product development method embraced the ideal of collaborative multidepartment projects, and expanded on this by encouraging looser more flexible process with rapid iterations (Matthews et al. 2006). This has the benefit of facilitating a form of evolutionary rapid trial and error to ensure they are governed (ultimately) by customer expectations. Supporters of agile process hold firmly to the flexible nature of agile methods and generally reject the benefits of rigid process that typically accompanies the waterfall method (Sy 2007).

2.3.4 Design methods

Design methods are the calculations, drawings, evaluation methods, and risk assessment tools used by design teams within product development projects to create product (Brown & Eisenhardt 1995). It is this group of activities, processes, participants and governance reporting/structures that is the focus of this study. In support of this focus, Ahire and Dreyfus (2000) separate "Design management" and "Process management." The former describing the management effort in improving designs and the later manufacturing methods. In their empirical study Ahire and Dreyfus (2000) discuss the relative importance of both of these efforts in achieving internal and external quality. Ahire and Dreyfus (2000) state that external quality is indicated by "...customer complaints, warranty and litigation." and concluded that both design management and process management have a critical influence on external quality. In other words, a products design impacts it's field reliability. This position is further supported by Hussain and Murthy (2003) whereby they quantify the link between product design and warranty cost due to field failure.
2.3.4.1 Tolerance design: Simple example

Consider the simplistic problem of a rod or shaft entering a hole. The diameter of the hole (B) must be larger than the diameter of the shaft (A) so that the rod or shaft can turn within the hole or perhaps move in and out of the hole. See Figure 2 below:

**Figure 2**: Side view of a rod or shaft able to enter a hole in a piece of metal due to sufficient gaps. The diameter of A has a tolerance of x, the diameter of the hole (B) has a tolerance of y.

If the rod becomes too large (i.e. x increases), and/or the hole becomes too small (i.e. y reduces) the rod will not be able to enter the hole as these two parts will collide. See Figure 3 below:

**Figure 3**: Situation 1: Collision between parts caused by a large rod and/or a small hole. (i.e. x being too large and/or y being too small.)
Similarly, as materials become hot or cold they expand or contract. If, as a result, the rod is too small and the hole too large, then the gaps become excessive and this may cause a different problem. (i.e. tolerance x is too small, and tolerance y too large) See Figure 4 below:

![Figure 4](image)

**Figure 4:** Situation 2: Excessive gap between parts caused by a large hole and/or a small rod diameter. (i.e. tolerance y being too large and/or tolerance x being too small.)

Lastly, if the rod is already in the hole, and the rod diameter expands and/or the hole shrinks. (i.e. x increases and/or y reduces). In this situation, the rod cannot either rotate or move in and out as the two parts have become bound together. See Figure 5:

![Figure 5](image)

**Figure 5:** Situation 3: Collision between parts caused by rod diameter enlargement and/or a shrinking hole after rod instalment. (i.e. tolerance x being too large and/or tolerance y being too small.)
Situations 1 to 2, demonstrate that to function correctly (rod being able to turn and/or move in and out of hole), the variation in their individual sizes, known as tolerances, and their interaction relative to each other, known as tolerance stack-up, must be calculated (Recchia et al. 2005). That is, they must be designed so that at one extreme the combination of tolerances does not become too tight, and at the other extreme the combination of tolerances does not become too loose.

Situation 3 demonstrates what could happen if dimensions change during product life. Tolerances, and thus tolerance stack-up, change throughout a product's life as the product is exposed to external factors such as heat, humidity, dust, moisture and the like. The effect of external factors on tolerances needs to be considered during tolerance stack-up calculations or the product may become defective (Recchia et al. 2005).

2.3.4.2 Literature and tolerance design

The impact of design on reliability is supported by Singh, Jain and Jain (2003). Within their study they illustrate how incorrect tolerance methods can lead to malfunctioning product. They also point out that despite this, traditional tolerance design decisions are made by intuition rather than by formal design methods as discussed in this literature review. Further, they suggest that traditionally, these design decisions are made by the design team in isolation rather than in tandem with the manufacturing and/or quality engineering teams. That is, experience is used to decide whether tolerances need to be calculated on all parameters on all components or just the components and/or parameters the design engineer believes are likely to be important. As such, manufacturability and/or reliability (two significant aspects of product quality) are not necessarily designed into product. These competing needs can cause inter-departmental conflict with implications discussed later in this study. Similarly Chase and Parkinson (1991) discuss how the application of tolerances influences product performance. One extreme is to determine the tolerance stack-up of all parameters on all components, the other is to use intuition as described above. A middle ground is to use statistical methods to assess the probability and potential impact of tolerance stack-up issues, and address potential tolerance stack-up problems where identified (Gilbert, Bell & Johnson 2005).
Indeed, Wetmore III et al. (2010) cite an out of tolerance o-ring as the technical cause of the Challenger space shuttle failure. The social causes of how this design was approved, despite engineers identifying the faulty tolerance design pre-flight will be discussed later in this document. However, the design of the o-ring had remained the same since the design of the first space-shuttle and had produced a number of successful launches. Yet, with the right conditions (excessive cold) the previously benign out of tolerance condition (that is, being used below its designed temperature rating tolerance) caused a catastrophic failure, where previously it had not.

2.3.4.3 Quality Control versus Design for Quality

When considering product reliability, why focus on design process? Surely, manufacturing process and/or product inspection (Quality Control), if perfectly delivered, would eliminate situations 1 to 3 in the simple example? (section 2.4.1) Thus eliminating product that does not meet customer requirements, or does not function correctly, and thus deliver perfect field reliability? Perhaps quality control methods alone could ensure that product does not fail at some time in the future while being used by the customer. While this was the belief for many years, there is a body of literature that disagrees. For example, Jebb, Wynn and Rizvi (1989) discuss the manner in which Quality Control has moved from inspection, to process management to designing Quality into products over the last 50 years.

Using the simple example above (section 2.4.1) OEM design engineers would be concerned with ensuring the rod was designed and then manufactured to fit within the hole anywhere within the tolerance band of $A^{+/-}x$. Typical of manufacturing processes (Nassif 2000) the diameters of a batch of rods, perhaps many thousands, will have slightly differing lengths, but inspection has made sure the rod diameters are within $A^{+/-}x$. If graphed, the varying rod heights create a distribution. See Figure 6(a). OEM quality control inspection would re-check that the rod diameters are within $A^{+/-}x$.

However, if through the use of intuition, the design engineer judged rod diameter was not a critical tolerance, the engineer may chose not to accurately calculate the extremes of the rod diameter tolerances relative to the hole diameter. There are hundreds of parts
in the machine being designed, with each part have many dimensions. So instead of a detailed analysis, for the diameter of the rod the engineer applies an estimated tolerance. There is the possibility of a region within the rod diameter distribution where the rod diameters are too large, even though this region is within the designed tolerance. Put simply, rods could be manufactured to specification, but the specification is wrong, and most importantly, not known to be wrong. The influences around the engineers decision being a principle point to this study. See Figure 6(b) showing this region, or 'defect zone'.

\[ \text{Figure 6: Demonstrating the relative location of rod diameter distributions, the location of an unknown defect zone.} \]

In this simple example, it could be argued that when the rod is presented to the hole, if the rod is large enough to be within the defect zone, then the defect would be found during manufacturing and or inspection as it would not fit into the hole. However, as mentioned in the simple example situation 3 (section 2.4.1), dimensions can change throughout individual products life. For instance, as explained by Manson (1953), as materials become hot or cold they expand or contract. Similarly, different materials do so at different rates, and different shapes cause expansion and contraction of different dimensions. Continuing with the simple example, it is possible that the large diameter rods in the defect zone just fit the hole with little gap. As such the entire assembly passes through manufacturing and quality control as functional. Once in the field, however, a percentage of products used in a warm country start to fail as the rod expands more than the hole. When individual products are returned for repair, they are tested in a relatively cooler factory to find they work, and that the defect cannot be replicated, thus not found.
This example demonstrates that the distribution of rod diameters can change while in use, and that failure to consider this affect during tolerance calculations can lead to field failure. Indeed, the simple example is mirrored by the scenario discussed by (Eifler et al. 2014) in his review of the GM ignition switch recall. They claim that the full range of tolerances within the tolerance stack up was not considered, with the calculations considering only nominal dimensions. Nominal in this simple example being diameters A and B, devoid of tolerance figures. Consequently, ignition switches failed when the car happen to go over certain bumps, when used with key rings and hit by drivers knees. Exploring the simple example further, the shape and centring of the distribution of rod diameters should not be assumed during design. It may be that during the first half of the product range's life, (not individual products) the rod diameter's distribution appears as per Figure 6 (c) above, whereby the rod diameters are far from the defect zone. In which case defects are not seen in the field. After a period of time, weeks, months or even years, and following a process change by the rod manufacturer, the distribution moves to resemble Figure 6 (b), whereby the defect zone now comes back into play. Again here, Inspection and quality control would be unable to detect this issue, as the defect zone was unknown. This then triggers a string of unpredictable defects and product recalls, even though the manufacturing process is still to specification, and therefore within control. Further, it will not be known which individual unit in the field has a rod prone to this situation and which does not. Indeed this may be triggered by a cost down exercise by the OEM themselves as they ask the rod manufacturer to reduce variation in their product to design quality into their product (Jebb et al. 1989).

Similarly, where statistical tolerance methods are employed, design engineers assume that the distributions discussed above are going to be central to the nominal tolerance, and therefore not enter the defect zone (Gilbert et al. 2005). However, without undertaking full tolerance stack-up calculations, instead relying on nominal dimensions as with the GM ignition switch recall, the existence of the defect zone in the statistics based tolerance stack-up again goes unknown, and therefore uncontrolled.

The simple example is now changed slightly, in that the rod is now mass manufactured and the tolerance x, is not specified by the OEM's design engineer, but a published specification. Should the design engineer judge through intuition that the tolerance
stack-up between the rod and hole does not require full and complete calculation, then there is again the risk discussed above. However, the mass manufacturer produces millions of rods. As the OEM only uses batches of one-thousand, they may find that at some future point their entire delivered quantity for the year has rod diameters within the defect zone. A large number of field defects are now pending that is undetectable to the OEM’s inspection process. This may trigger a product recall, with the cause having its origins in the design process.

The study by Tapiero, Reisman and Ritchken (1987) supports the simple example above in that they draw a clear distinction between "manufacturing unreliability" as a consequence of poor quality control and other production processes and "product unreliability" designed into products through poor process. That is, defects become inherent within the product. Thus product unreliability causes early field failure, warranty returns, and if significant enough could create a product recall via customer rejection and/or a product that could present a safety hazard to users and/or the public.

It is not expected that product will last forever. However, when it does fail it is expected to fail in a way that does not render the product dangerous to users or the general public. Failure to design product in a way that ensures this, places the company at risk. Safety and compliance are features that are designed into the product, and as features are subject to the design process. Again taking the simple example, perhaps the rod and hole represent a solenoid driven locking shaft (rod) that engages into a hole to stop people using a faulty elevator. In this way, it has become a safety feature on the elevator. This approach is also consistent with Kloss-Grote and Moss (2008) in their assertion that the design process influences product quality and project risks. Further, the idea that safety, compliance and reliability are influenced by design is enshrined in legislation. For example, BS EN 61010-1:2001, Safety requirements for electrical equipment for measurement, control, and laboratory use, outlines the requirement to demonstrate that safety has been designed into the product and that the product can only fail in a safe manner (British Standards Institute 2001). This is expressly different to the use of quality control or manufacturing procedures such as inspection, which merely maintain the design intent, even if the design would lead to an unsafe product. This is exemplified by Kumar and Schmitz (2011, pp. 235-236) in their case study on product
recalls in the toy industry, "... the products had marginal designs from the start, and thus unaware of the design issues, the quality department made sure the toys were built consistently per specification which created a proliferation of consistently bad product. This lead to massive recalls." As such, it can be demonstrated that poor design can lead to risks of products becoming unreliable by either failing within the warranty period, earlier in its lifecycle than would be expected (premature failure) or in an un-safe/non compliant manner.

2.3.4.4 Tolerance versus Test

Hussain and Murthy (2003) argue that testing product designs to the point of failure and then rectifying the component(s) design can strengthen the product design. Thus sufficiently testing product can create certainty in the products design and increase product reliability. In contrast, Nadpara et al. (2012, p. 20) demonstrate the link between testing, design and product performance in their study of pharmaceutical products, "Quality cannot be tested into products but quality should be built in by design". They clearly separate the idea of inspection/quality control or testing quality (reliability) into products at the end of a production process. Rather they support the concept of "Quality by Design".

Every component within the product has multiple parameters. As such they have multiple tolerance distributions to consider in design as discussed in the simple example above. Where within these distributions have the products components been selected for this product proving test? How will this test reflect component use throughout the products lifecycle? To again use the simple example, if the components within the sample test products have come from a distribution similar to graph (c) in Figure 6, then it is likely that no temperature or humidity testing will identify the existence of the defect zone. Even a simple product with few components will have hundreds of interacting parameters with distributions. Producing a test for every combination seems unviable. If designing for every one of these combinations was considered inefficient, justifying the use of testing followed by redesign (trial and error) as an alternative, then testing for each combination is even more inefficient. Efatmaneshnik and Reidsema (2007, p. 760) refer to this situation as a "concurrent optimisations problem".
For the approach proposed by Hussain and Murthy (2003) to be viable, one presumes the contributing factors leading to a future failure are known in advance and can be tested for, thus limiting the scope of the test. Even if this were so, and it were practical to test for a single parameter within a single critical component (e.g. can the o-ring on the space shuttle function below its rated temperature tolerance?), as the number of critical components increase the operational limitations on the product increase in sympathy. This creates the need for more product function compromises and increases the potential for error, and social pressure (or conflict) to accept design compromises.

Efatmaneshnik and Reidsema (2007, p. 760) similarly identify this tolerance design issue "... In cases where the concurrent optimisation problem is complex, that is the number of variables is high (e.g. more than 10) the satisfaction of design requirements is unlikely...".

The impact of the resultant social pressure or conflict cannot be ignored. Engineers will decide on the test parameters above and will interpret the results. Coeckelbergh (2006) argues that engineering decisions are not always based on hard science. Engineers’ feelings, opinions and group social pressure may heavily influence design decisions and project risk identification and management. Lloyd and Busby (2003) support this view. They argue that intuition and social pressures distract engineers away from the ethical impact of design decisions. Socially acceptable design decisions and compromises may lead to engineering disaster and/or unreliable product.

Further, for this design by experiment methodology to be reliable it requires a number of pre-conditions. It is common for components to be designed and manufactured to function outside their published specification by some margin, to reduce risk to manufacturers of non-compliant parts (Aitken & Idgunji 2007). Using the space-shuttle example, if the o-ring used on the Challenger space shuttle was tested to see if it would work reliably below its published lowest temperature rating, how would the test engineers know that this tested sample is indicative of manufactured population? This O-ring may have functioned 10 degrees lower that the published specification. Will the next one? or the next one? What is the parameter(s) and associated tolerance(s) that need to be controlled? Chemical composition of the rubber? Dimensions? These
questions cannot be readily known. Secondly, When a component is manufactured in quantities of thousands or millions, testing in single digits becomes statistically non-representative and could lead to a false sense of security. Thirdly, consider when a component is unknowingly used in a manner outside the manufacturers specifications. Perhaps this was due to intuitive design tolerances and supported during design review due to test results on a few units. Should the manufacturer reduce the margin described at the beginning of the paragraph, then test results would become unforeseeably irrelevant. This creates potential unforeseeable, or latent, product defects, again, by design.

If the manufacturer does not know the component is being used in a manner inconsistent with their published specifications, they will not know to advise the user (OEM) of their component if there is a change to the manufacturing distribution described in the simple example. Further, component manufacturers typically reject liability for the use of product outside their published specifications. This makes foresee-ability of the need to repeat testing (putting aside its lack of statistical validity) an impossibility. Further, if a component is manufactured in the order of millions, it is unlikely that they would (or could) resolve to notify every customer that uses a component in a manner inconsistent to its published design intent. With diverse and distributed global supply chains, how would this be achieved? Adding to this complexity, what would constitute a change?

A viable solution would be to choose a more suitable component, or if this is impossible modify other aspects of the design so that other components can be used instead and within specification. Thus the viable solution to the problem moves back from test methods to design process. However, this presumes that there are few obstacles to doing so. Efatmaneshnik and Reidsema (2007) propose an alternative approach. They propose the better solution is to adopt a reductive methodology at the system level to create a robust system. In a methodology similar to Taguchi (1986), they propose that it is better to understand the sources (variables) of instability within a system and rather than attempt to control them, eliminate their impact and/or the need for them within the system level design. Thus creating a robust system, that is, a robust product by design. This has strong similarities to Taleb (2008) in his work suggesting system level anti-
fragility as a risk management method. The work by Taguchi (1986) was subsequently expanded upon by D'Errico and Zaino (1988) and by Sato (2007) who discusses the successful use of systems engineering and its interaction with macro-social values in the space industries.

2.3.4.5 Design Review Processes

There are numerous design review processes and this includes simply discussing the design reasoning in a group or with a peer. Indeed design review could include an engineer looking over their own work. However, as discussed by a number of scholars (Carbone & Tippett 2004; Bertsche & Lechner 2008; Xiao et al. 2011; Kloss-Grote & Moss 2008; Main & McMurphy 1998) Failure Mode Effect Analysis (FMEA) is one of the most commonly used review tools used to review both engineering design as well as product development project risk. Indeed Bertsche and Lechner (2008) describes FMEA as one of the most commonly used qualitative methods used to improve reliability.

Sutrisno, Kwon and Hyon (2013, p. 54) defines FMEA as a tool used to:

"... identify potential and or actual failure modes in a ... product; to rank the criticality of the failures by their risk priority; and finally to find improvement method to avoid re-occurrence of the failure mode in future. In estimating the risk due to a failure mode, an index called the RPN (Risk Priority Number) is used, which is obtained by multiplying the ratings of detect ability (D), occurrence (O), and severity (S) of the failure mode"

With the exception of Sutrisno et al. (2013), in their support of this commonly used tool these authors do not discuss the impact of social factors, rather, they describe FMEA as an absolute science whereby the reviewing team can tabulate and quantify all possible risks, mitigate their cause, their likelihood of occurrence, and/or their severity. They intimate that using this knowledge with absolute certainly the product is redesigned to remove all risks of failure. This approach is similar to that employed by the work completed by Ahmadi and Wang (1999). Sutrisno et al. (2013), does acknowledge the qualitative nature of the rankings as being limited by the experience and subjectivity of the analysing teams. Similarly Yeh, Liu and Lee (2011) propose the use of genetic algorithms to reduce subjectivity. Chin, Chan and Yang (2008) propose the use of fuzzy
logic and knowledge based systems to improve the FMEA inputs. Wetmore III et al. (2010) even suggests the integration of six-sigma methodology to add scientific and quantitative rigour to the FMEA based risk assessment process.

However, while Senders (2004) agrees that it is a common and helpful tool, in his study of FMEA in its uses in medicine, he points out its limitations by stating that it requires the analysts to be able to imagine and then tabulate the unthinkable as would be expected from the FMEA process. This point clearly aligns with bounded rationality theory which presents an additional challenge to the processes rigour. Hansson (2005) also disagrees with the effectiveness of risk management systems that take opinions, attaches a number or ranking to them based on an assumed probability of occurrence with an assumed severity and then presents this as a meaningful and quantitative analysis. While not referring to FMEA by name, his intent is clear. Hansson (2005) goes on to point out that when there is a lack of real numerical evidence behind rankings or scores, excessive uncertainty is injected into a system that does not then manage or represent this uncertainty to the analysers or the users of the analysis. Again, this creates excessive confidence in the rigour of the risk analysis. Indeed, Gilbert et al. (2005) go so far as to propose using FMEA as a tool to focus design compromises. They argue that design rigour can be relaxed on failure modes with little impact on customer expectations as identified by FMEA. Again, this assumes FMEA and the use of FMEA is without flaw. Proponents of system level design as discussed above Taguchi (1986) and Efatmaneshnik and Reidsema (2007) would likely argue that if a feature can fail with little detriment to the products performance as described by legal requirement or by the user, then perhaps the better question is why has it been included in the system at all.

While many authors do not mention the impact of subjectivity, groupthink or bounded rationality on the effectiveness of the FMEA process, there are sufficient authors that have identified this limitation and proposed alternative methodologies to lend greater rigour to the process. Group think referring to the phenomena whereby teams seek consensus leading to the exclusion of alternate possibilities (Janis 1971). Clearly, FMEA's is commonly used and holds great potential for influence by social factors and organisation climate, as would simple discussion with a group/peers (peer review) or
self review. As such, the term 'Design Review' as used in this study, will encompass one or all of these processes.

When considering directors legal obligations discussed above, and having considered the impact of design and design review methods on product as discussed by literature, the first research question emerges:

**Q1** What product design methods are used within the case study company and how informed are the directors of these methods?

### 2.4. Organisational Climate and Unknown-Unknown Risks in PDP

The term "social factors" has been used above to describe behaviours and interaction by groups and individuals within their company. Indeed, engineering is influenced by culture with outcomes heavily influenced by organisational and national cultural norms (Sato 2007). Similarly, there is a strong link between organisational culture, employee morale and performance within organisations. Specifically product quality and reliability from R&D improves with job satisfaction. i.e. employee morale (Zhou et al. 2008). Johnson and McIntyre (1998) demonstrated that job satisfaction can be measured by organisational climate models. Specifically, positive correlations between Communication, Goals, Creativity, Innovation and Decision Making measures and job satisfaction.

#### 2.4.1 Management and Leadership Style

There are numerous studies that support the concept of organisational climate, and it's relevance to the product development process. Griffin (2002) specifically reviews product development processes and identifies that participatory management styles shorten the New Product Development (NPD) cycle, whereas autocratic management styles increases it, in an acknowledgement that humans behaviour is contextual. Similarly, Sarros, Cooper and Santora (2008) discuss the impact of leadership on organisational climate. In their study they demonstrate the link between transformation leadership shown by management and the creation of innovative organisational climate. This is particularly important given the link to job satisfaction and the Innovation measure as demonstrated by Johnson and McIntyre (1998) above.
2.4.2 Supporting the Communication of Dissenting Views

Literature has numerous examples whereby organisational climate is and has been used to evaluate the social factors described above. These are discussed below.

Mesmer-Magnus and Viswesvaran (2005) discuss individuals preparedness to whistle-blow and organisational climate as an important contextual variable. Whistle Blowing refers to the act of speaking out to positions of authority when immoral and or illegal acts are supported by organisational leaders (Keenan 2002). As such, there is pressure to conform and not become a whistle blower. Specifically, individuals are more likely to blow the whistle within a company that sees such activities as productive, than within an antagonistic organisational climate. This is discussed further by Zapf (1999), his work discussing the link between organisational climate and bullying. Following his rationale it is likely that a potential whistleblower is more likely to be bullied into keeping quiet in certain organisational climates. This would further ensure that risks (and/or breaches of ethics) remain hidden if raising them challenges accepted group norms. Keenan (2002) discuss the importance of upper management creating an ethical climate within the organisation and its positive influence on whistle blowing. Similarly Keenan (2002) discusses interpersonal communication climate. He describes this as a supportive climate whereby people seek to understand and treat others with respect tends to encourage whistle blowing.

2.4.3 Ethics and Social Responsibility

Francis and Armstrong (2003) discuss the impact of ethics and social responsibility within a company and how this also impacts risk management and peoples preparedness to speak up. Drennan (2004) links individual ethics and the creation and reporting (or not) of risk. He discusses how the media spotlight on companies and individuals can ensure people stay 'mum'. The fear of retaliation from within the company, or lack of support by the company to external media claims is likely to be influenced by the degree to which the climate is supportive and/or ethical as discussed by Keenan (2002). Similar to the position by Sarros et al. (2008), Engelbrecht, Van Aswegen and Theron (2005) describe the positive contribution to an ethical organisational climate that can be
created by transformational leadership. Indeed, Brinsfield, Edwards and Greenberg (2009) closely links organisational climate to employees' behaviours after there is a wrongdoing by or within the company, and whether employees will stay mum or whistleblow. In an acknowledgment of the social complexities surrounding risk management, Sullivan (2012) also argues the need for directors to encourage a risk management friendly culture by encourage staff to not only do “...the right thing” (Sullivan 2012, p. 3), but also for directors to encourage accountability and transparency.

2.5 The Creation of Unknown-Unknown Risks Within Projects:

Jones (2002) discusses the concept of Bounded Rationality, which refers to an individual’s ability to understand their world and that it is limited by their access to information over a given amount of time, their cognitive skills and their education. Elliott et al. (2000) correctly points out that if risks are not understood then they cannot be addressed. When this rationale is coupled with bounded rationality, it brings into question the idea of rankings as used in FMEA as engineers will not be able to exceed their bounded rationality to produce the perfect risk assessment. Coupled with the inherent subjectivity of the FMEA process, it is likely that risks will go unidentified and/or impact and/or consequences underestimated. Hansson (2005) discusses the risks surrounding the use of experts to compensate for this lack of certainty. However, he claims that they are themselves a source of uncertainty and potentially create another layer of bounded rationality and/or encourage group think. Taleb (2005a) cites over confidence in one's own knowledge as a significant source of risk, and is thus in unison with Hansson (2005). Taleb's view clearly resonates with the Dunning-Kruger effect, whereby individuals lack of knowledge encourages them to be over confident of their decisions and conclusions. Paradoxically, their lack of knowledge restricts their ability to know the limit of their knowledge (Kruger & Dunning 1999). This then creates a risk that the analysis appears more uncertain that it actually may be. As explored above, experts and project members alike are still limited to bias introduced by personal values as well as bounded rationality. It is likely then, that project members thus becoming blind to unknown-unknown risks that they mistakenly believe are known-unknown risks.
Bounded rationality is not the only social factor influencing the effectiveness of design decisions and risk evaluation. Indeed, Wetmore III et al. (2010) discuss the consequences of social interactions and group think on decision making during design review. They cite the Challenger space shuttle disaster as an example whereby an out of tolerance o-ring was allowed to pass through design review due to social pressure. Managers sighted the previous launches as evidence the design is sound. This is akin to attempting to test quality into a product rather than design it in as discussed above. Indeed even after this risk was escalated, many within the project team experienced pressure to conform. Further, social pressure was applied by decision makers for the engineers to prove the design would fail, rather than prove it would succeed. Thus distorting the argument to suit desired outcomes. This is similar to the "narrative fallacy" term coined by Taleb (2008). Indeed Nafday (2009) discusses how engineers also use narrative, bias, tunnel vision and ignore uncertainty while justifying decisions.

It would seem that by reversing the logic within the debate, or indeed controlling the debate (narrative) unknown-unknown risks were made to appear through narrative, as known-unknown risk.

There was another effect of this pressure. Engineers no longer spoke out. This is similar to the "Mum effect". To explain this effect, Marler et al. (2012) use the back drop of a Korean Air flight that crashes even though the co-pilot and in flight engineer had noticed the pilot’s error. They discuss the “mum effect” and the social pressure to conform to power structures and social norms. Similarly, Smith et al. (2001) and Keil, Mann and Rai (2000) discuss this “mum effect” and its similarities to whistle blowing. While they discuss these phenomena in the context of information systems projects, they identify the studies applicability to other areas. They discuss how engineers, or project leaders, can choose not to speak up about risk to avoid undesirable social pressure, and potentially influence others to stay ‘mum’. Similarly, Keil et al. (2000) conclude that the escalation of software product development projects are heavily influenced by project members behavioural factors. This work is supported by Tan et al. (2003). Also from within a software development project, they go further to identify that these behavioural factors and willingness to deliver bad news to management can be described by organisational climate. However, in a partial return to the debate
between climate and culture, the work by Tan et al. (2003) suggests that senior managers do not hear about unsuccessful software development project with sufficient time to react due to either information asymmetry or organisational climate. The choice between the two depending on individual or collective cultures. However, other authors disagree and discuss the use of information asymmetry existing from within an organisational climate (Fey & Beamish 2001). This later opinion will be the default position within this study. Again, by keeping quiet, is it possible that unknown-unknown risk becomes perceived by other team members as known-unknown risks?

In an expansion on groupthink, Griffin (2002) demonstrates that conventional efforts to build close and productive multidiscipline teams within new product development projects often have a detrimental effect. She presents the idea that project teams strive to resolve project uncertainties and the resolution of these uncertainties can cause stresses (conflict) within the team. As a consequence there is evidence that team members may not chose decisions that are good for the project but poor for the sake of team harmony. By not challenging group think, and not pushing knowledge boundaries to reduce bounded rationality, uncertainties and risks remain unaddressed to keep the peace. To the wider group, unknown-unknown risks are left appearing as known-unknown risks. Ayers, Dahlstrom and Skinner (1997) support Griffin's view with Kyriazis and Massey (2006) discussing the complexities surrounding productive and non-productive conflict that is inherent between functions within the new product development process.

Lee (2011) discusses the creation of conflict within new product development teams, sighting its importance in creating new methods and products. However, these views differ with some supporters of concurrent engineering discussed above, that argue for reduced conflict within project teams to improve project outcomes by reducing conflict. Singh, Jain and Jain (2003) also cite the importance of reducing conflict during the design process. Similarly, Anderson and Gatignon (2005) appear to disagree with Griffin (2002). They present the view that separate functionally based teams become internally focused and hoard their own knowledge. Thus creation of a project team would be beneficial to reducing conflict. However, Griffin (2002) would argue that this is merely creating a larger team within which to conform, to the exclusion of outsiders.
Non project members may not be aware of risk decisions and/or tradeoffs made within the project team. Indeed as some of these decisions and/or tradeoffs may have been made to support team harmony rather than for the company's benefit, they may not agree with project outcomes, including those related to risks.

Information asymmetry describes the situation whereby one party has fundamentally more information about a situation than another, and the potential for this to be misused (Grover 1993). Herein lays potential for information asymmetry between the technically skilled project team and those not within the project team. Known-unknown risks, are identified by the project team. When these are not communicated, not fully communicated, or not communicated in a non-technical manner to the rest of the company, it seems likely that these risks become unknown-unknown risks to the wider company, including directors.

2.6 The Creation of Unknown-Unknown Risks As Seen by Non-Project Members Including Directors

Purchasing departments with mid-lifecycle products will buy components according to documented design, and manufacturing will build according to the documented design. So inherent design defects leading to premature field failure will not be corrected by them. Quality control will inspect the components and product according to the documented design. So again, inherent design defects leading to premature failure will not be corrected by them (Kumar & Schmitz 2011). As discussed previously, tolerance distribution can have a critical impact on reliability. At some time in the products lifecycle component supply may shift from one end of the distribution to the other while still being within design specification (Singh et al. 2003). If the design engineers used intuition and experience to judge that a detailed tolerance analysis was not required, as its impact is not worth considering, then this judgement created a known-unknown risk from the design engineers perspective. If, for the reasons above, this causes the sudden onset of field failure and thus recall, what the design engineers thought was a known-unknown risk may actually be described as actually an unknown-unknown risk. That is, they thought they knew what they did not know but actually, they didn't know what they didn't know. From the directors perspective, given the illusion of certainty created by
the design review processes diligently undertaken, having successfully built and sold reliable product for some time before this recall, and the overarching perception that design and engineering are absolute disciplines, recalls start to behave like a Black swan as discussed by Taleb (2005a).

Specifically, Taleb identifies that this situation requires three criteria to be met. First, that the event has a significant impact such as a product recall. Second, that the probability of occurrence is considered so low as to be not worth considering, such as in the tolerance decision in the paragraph above and the manner in which it is proposed unknown-unknown risks may emerge. Third, the event should have been apparent in retrospect.

Initially applied to the disciplines of Finance and History, Black Swan theory has been applied to an increasing number of disciplines and industries. For example Black Swan theorists have applied its methodologies to art, (Taleb 2005b). Taleb discusses the way in which works of art have become an outstanding success despite initial expectations of failure, and that after the fact their success should have been obvious. Thus becoming a black swan event to an investor that failed to invest. Similarly a study by MacLean (2010) that discusses past waste disposal public policy, it's impact on the environment and the creation of future black swan events. Being successfully applied to a number of other fields of study demonstrates its generalisability and thus suitability of its application to engineering. The application of Black Swan theory to engineering is supported by Kenett and Tapiero (2009). Mentioning engineering and product development as a relevant sub-set of quality management, they link the nature of some risks involved in quality management to Black Swan based risks discussed by Taleb (2008). Further, Nafday (2009) has extended Black swan theory to engineering decisions at a macro level. Specifically, he discusses how engineers using narrative, bias, tunnel vision and ignore uncertainty while justifying decisions. This is aligned with the behavioural phenomena described by Taleb (2009) whereby professionals within the financial establishment identified the same traits as mentioned by Nafday (2009) above within their industry before being seen as whistle blowers and subject to ridicule. However, Nafday (2009) tends to discuss large civil engineering decisions and risk assessments such as geographical placement of power stations and the decision
making around risk assessment and the impact of natural disasters. Review of literature demonstrates that there is a dearth of literature exploring the Black Swan theory as it relates to engineering and product development at the micro level and more specifically product recall.

As discussed above, design and design review are not perfect and are intertwined within social factors. After the fact, this recall may come as no surprise to project members. In light of the tolerance design process such an event was more likely than initially anticipated. As described by Taleb (2005a), it is common for professionals to think of risk in terms of a perfect bell curve, with reducing tails. However, for companies that employ simplistic design process and/or an organisational climate that supports the social factors discussed, this risk distribution should actually viewed as having "fat tails", reflecting the true situation (Taleb 2005a, p. 15).

However, not all literature agrees with Taleb and Black Swan theory's view of risk. Paté-Cornell (2012) proposes taking an engineering approach to risk management. She discusses the engineering process as though it is devoid of social factors, and can give a complete understanding of all variables and the system they are employed within. Thus creating a perfect understanding of the situation and thus all risks, and therefore removing the third criteria of a black swan event; i.e. the event was only apparent in retrospect, removing the relevance of Black Swan theory. Similarly, Senders (2004) discusses the influence of social factors and human-error that limit the usefulness of FMEA generally and within medicine. However, he contrasts its successful use in engineering inferring that FMEA works because the social factors do not exist within engineering. Sjöberg (2008) links trust to a perception of risk. Thus it seems possible that the belief in the de-anthropomorphised engineering process, demonstrated by Paté-Cornell (2012) and Senders (2004) could turn known unknown risk into unknown-unknown risk through the creation of excessive trust in engineering and thus the product design process.

However, Hansson (2005, p. 4) seems to agree with Taleb (2005a), using the term "Tuxedo Syndrome" whereby people undertaking risk analysis act as though the risks and consequences can be clearly identified and quantified. He cautions that the reality is
the exact opposite and often lead to "an illusion of control". This is supported by Chermack (2004) who does indeed cite bounded rationality as a source of poor decision making and the ability of scenario planning to reduce this phenomena. In contrast, Brown et al. (2009) do not appear to address information asymmetry, bounded rationality and whistle blowing issues and how these may limit the information flowing to the audit committee, and aid the illusion of control.

However, the idea that social factors limit directors ability to understand the true operations and risks within their company is supported by agency theory as discussed by Shapiro (2005) and Hill and Jones (1992). Agency theory suggests that managers will use company resources for their own goals rather than shareholders and that this social factor will further reduce transparency. This inherent conflict is discussed by Spremann (1987). They suggest that information asymmetry can deliberately or accidently lead to a gap between managers understanding of risks within an organisation and risk that are communicated and ultimately understood by directors as the representatives of shareholders. In a link back to discussions above, Bahli and Rivard (2003) suggest the use of engineering risk assessment methods within an IT outsourcing context to reduce accidental agency issues between agent and principle. This again, denies the existence of social factors within the engineering process and engineering risk assessment methods, further demonstrating this gap within literature. In a rare acknowledgment of these social factors, Zenger (1994) discusses the conflict within literature whereby some authors believe R&D efforts within big companies outperform those of small companies. He argues that due to the relatively high performances of engineers within small companies (due to increased job satisfaction through numerous incentives mechanisms), there are less agency issues for management to address. He points out that engineers observable behaviour does not always indicate cognitive skills or outcomes and that there can be hidden actions or inactions. By extension then, using the work by Johnson and McIntye (1998) demonstrating that job satisfaction can be understood using an organisational climate model, the degree to which engineers may hide information, based on their job satisfaction and thus influencing agency risks, may be understood by using this model.
Also, by extension of Agency theory and applicable to this study, is the question of whether managers within the product development process deliberately use information asymmetry to avoid accountability to their own benefit, and to the detriment of directors and shareholders (Ford & Sterman 2003). Does the inherently technical product development processes that creates highly technical causes for complex risks, thus facilitate convenient sources of information asymmetry? Coupled with the other social factors and theories discussed above, such as bounded rationality, whistle blowing, knowledge asymmetry, the Dunning Krugger effect and Black Swan theory, then understanding the true nature of risk by directors within an organisation comes under challenge. Understanding how these social factors interact within the product development process and impact governance structures is a central aim of this study. Indeed, literature does not appear to fully explore this interaction within an SME OEM setting. It seems possible then, that excessive trust in the product development process by directors that are restricted to considering process through the confines of governance, may create an illusion of risk control at board level and can create unknown-unknown risk.

Maluf, Gawdiak and Bell (2005) describes known unknown risks as risks whereby the boundaries are understood and that individuals or teams are prepared to accept. Unknown-unknown risks are risks that individual or teams do not know they have and thus cannot be prepared for the consequence. Through the social factors discussed above, is it possible that known-unknown risks transition to unknown-unknown risks. Literature does not appear to address this question directly, and certainly not within a product development environment? Starting at the individual project member, known unknown risks are likely to be identified and through the social factors discussed transitioned to unknown-unknown risks at the team level. These newly formed unknown-unknown risks are retained within the project (or product), with new known-unknown risks determined at the project level. Again through social factors, it seems likely that some of these known unknown risks transition to the management level adding to the growing pool of unknown-unknown risks. The same transition may occur between the management and the board level. This system of transition and propagation through the company is how design risks at an engineering level create business risk at the board level. This literature creates the basis for the last three research questions:
Q2) Why and how have hidden risks emerged, and do directors understand such risks within product design processes?

Q3) How has their knowledge from Q1 and Q2 helped them to influence design process and risk management structures and how do they ensure their influence achieved its intended outcome?

Q4) How have these directors considered and cultivated an organisational climate and social factors that contribute to the attainment of the directors expectations of governance structures and product design processes discussed in Q3?

2.7 Summary

Directors have an obligation to ensure there are sufficient risk management structures and processes within their organisation to effectively manage risk. Certain organisational climates will foster social interactions that are not favourable to open discussion and disclosure of risk. If managers encourage an organisational climate that is contrary to identifying and managing risks while also employing design processes that inherently create risk, do they magnify the probability of unknown-unknown risk?

What are the characteristics of this high risk climate? These questions do not appear to be addressed within literature. Further, there is evidence that the design processes employed by SME OEM's in the UK are not well studied. Consequently, it appears that there is insufficient literature that seeks to uncover how directors of SME OEM's ensure that product reliability based risks are being sufficiently managed when managers are employing simplistic design methods and how social factors and organisational climate interact with these.

Taking the PDP model outlined in Figure 1, Figure 7 summarises the interaction of organisational climate and social phenomena (or factors) on the PDP and it's governance structures as described by literature.
Figure 7: A graphical representation of a generic PDP demonstrating the phenomena, organisational climate and gaps within literature leading to study's research questions.
Similarly, how risks can be broken down into known and unknown risk and how literature suggests these evolve throughout the PDP. It is clear that literature supports the idea that Agency theory is a source of unknown-unknown risk that could become a liability to directors. (Shapiro, 2005) and (Hill and Jones, 1992). However, with regard to unknown-unknown risk, the other theories do not typically appear to be applied beyond project teams and their interactions between themselves and management. Particularly when applied to the PDP. For this reason, literature suggests unknown-unknown risk is created during the design process, and again when managers report, or fail to report, risks to directors. At other places within the product development process as per figure 7, the emergence of unknown-unknown risk and possible linkages to other theories seem to go un-discussed.

Although extant literature contains discussions of the impact of the Black-swan theory in engineering environments there remains paucity in regards to the theory’s application specific to PDP or the nature and emergence of unknown-unknown risk within the PDP and whether these risks can create a Black Swan event, rather than simply an unexpected and undesirable event. Lastly, the PDP exists within the context of an organisations climate.

A summary of the gaps within literature as applicable to this study is found in table 3:
<table>
<thead>
<tr>
<th>What Is Happening</th>
<th>What We Know</th>
<th>What We Still Do Not Know</th>
<th>Research Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a. The product design process creates risks.</td>
<td>1b. All forms of risk emerge out of design process. (known, known-unknown and unknown-unknown). Known risks being corrected during design.</td>
<td>1c. Few gaps exist within literature, with the existence of risks as an output of design well established.</td>
<td>1d. RQ1. What product design methods are used within the case study company and how informed are the directors of these methods? Addressing this question aids our understanding of Directors knowledge in being cognisant of existing risks based on their response</td>
</tr>
<tr>
<td>What Is Happening</td>
<td>What We Know</td>
<td>What We Still Do Not Know</td>
<td>Research Question</td>
</tr>
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</tr>
</tbody>
</table>
| 2a. Risks are insufficiently discovered and then managed or accepted. | 2b. Through the design review process all risk types are potentially discovered and turned into known risk, or known-unknown risk. The project teams and management review these and risks are either accepted as believed to have minimal impact and/or likelihood of occurrence, or managed, thus becoming a known risk. Theory suggests some unknown-unknown risks will always exist within projects, as the design review process is not perfect. However, literature suggests there is a social root cause to recalls and engineering disasters influencing the process above. | 2c. Literature does not adequately define these social root causes. Do the theories and events considered during literature review (see below) individually or collectively, alter or distort the discovery and/or reporting process turning known risks or known-unknown risks from the design process into unknown-unknown risks? Some theories and/or events discussed in the literature review suggest this is possible, such as discussion surrounding whistle blowing and the mum effect. However, many either insufficiently, or not explicitly, describe the impact on governance reporting as it relates to unknown-unknown risks and product recalls. For example subjective design review, groupthink, tuxedo syndrome, wilful denial, Dunning Kruger effect. Further, literature does not adequately discuss the impact on governance structures and unknown-unknown risk when or if these occur simultaneously. Theories and events reviewed/considered:  
- Keeping Mum  
- Whistle blowing  
- Subjective risk/design assessment.  
- Dunning Kruger effect  
- Wilful denial  
- Bounded Rationality  
- Limited Search  
- Agency Theory  
- Tuxedo Syndrome  
- Groupthink  
- Information Asymmetry | 2e. RQ2. Why and how have hidden risks emerged, and do directors understand such risks within product design processes? | 2f. RQ3. How has their knowledge from research question one and research question two helped them to influence design process and risk management structures and how do they ensure their influence achieved its intended outcome? |
<p>| | | | Addressing this question helps us to explore Director’s degree of recognition of what they may not know (e.g. hidden risks) and if Directors have acted upon this. |</p>
<table>
<thead>
<tr>
<th>What Is Happening</th>
<th>What We Know</th>
<th>What We Still Do Not Know</th>
<th>Research Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>3a. Risks are insufficiently reported to directors, and directors ability to influence the company is limited.</td>
<td>3b. Agency theory supports the concept that management act in their own interest by limiting influence of directors. An example is to alter reports to their own benefit, and thus under report the likelihood and/or severity of unknown-unknown risk. Literature does discuss Black Swan theory within the context of engineering disasters.</td>
<td>3c. Literature does not specify the actions directors take within high technology companies to understand unknown-unknown risk within their company as this specifically relates to product recall. When there is a product recall, directors are not expecting this severe event to occur. Literature does not adequately explain if or how recalls can be described as a Black Swan event rather than simply a serious unexpected event.</td>
<td>3d. RQ4. How have these directors considered and cultivated an organisational climate and social factors that contribute to the attainment of the directors expectations of governance structures and product design processes discussed in research question three? Addressing this gap is important as it addresses the fundamental question raised by authors of recent product recall literature questioning social root cause.</td>
</tr>
</tbody>
</table>

Table 3: Summary of gaps within literature
3.0 Chapter Three: Research Method

3.1 Research Paradigm/ Philosophy

Taking an interpretivist position, (Travis 1999) this study seeks to understand the following:

1. The social interactions between the roles and participants within the product development process. In reference to research question one, by understanding the interactions between roles, the actual (rather than official) product development process being employed will become understood and can be compared to director's opinion of the process.

2. How the product development process itself influences these interactions, and the existence of hidden recall risk. In reference to research question two, this approach will provide data by discovering the outcomes and effects of the product development process, and the social and procedural causes.

3. The combined impact of social interactions and the product development process on governance structures. In reference to research question three, this will provide data that will help to explain existing governance structures, and how these have been reviewed and/or modified by directors.

4. How the participants themselves perceive these interactions. In reference to research question four, by understanding the participants perceptions, the organisational climate can be understood, and the nature of directors efforts to modify climate determined.

Exploration will be achieved via an inductive method (Bowen 2008) employing methods such as semi structured interview, surveys and collection of organisational artefacts. (Gioia, Corley & Hamilton 2013) Conjectures will be iteratively created, questioned, modified and re-questioned until a point of saturation is reached typical of an inductive method (Bowen 2008). Eisenhardt and Graebner (2007) propose the use of
inductive method when "... the research question is significant, and why there is no existing theory that offers a feasible [complete] answer." Indeed this study into the phenomena described is significant in its importance to organisations experiencing both product reliability and recall issues, with conventional literature failing to fully consider the governance level impacts of the social elements within the product design process. In this way, the inductive methodology will be well placed to achieve the aims of the study. That is to understand directors’ awareness of unforeseeable risks in their company's product design process and to understand the methods directors use to ensure there is sufficient governance and management oversight to mitigate, control or eliminate these risks.

3.2 Research Strategy

3.2.1 Case Study Research

The choice of a typical case method was influenced by the desire to see why and how the phenomena being studied influenced an organisation with the characteristics described above. To observe an atypical case would not have provided opportunity for discovery as it is likely that the phenomena would not exist in sufficient depth. Specifically, this study seeks to explore social factors, their affect on product development to create risk, and how this risk is governed within an SME OEM. Arguably it would be difficult to explore these phenomena and their interactions in any way other than to observe them in the typical and within case method. As such, the use of a typical and within case study qualitative methodology will be employed (Ayres et al. 2003). As suggested by Noor (2008), the choice of research methods to use is determined by the nature of the phenomena to be explored. Further Noor (2008, p. 1602) suggests that case studies are well suited to "...understand the complex real-life activities in which multiple sources of evidence were used." Particularly where there is need to understand a situation in great depth. To fully explore the depth and complexity of these phenomena a single company will be chosen, a methodology supported by Yin (1981). Indeed, while the use of a single company may present this study as context specific, Whetten (2009, p. 49) presents a counter view, whereby he concludes "... restricting research to a single context does not make it context sensitive".
Therefore, while this study is restricted to a single context, it is typical case. Thus the ideas and findings are applicable outside the case and have some degree of generalisability. Quantitative methods such as surveys and organisation artefacts will be used to aid validity of the findings via triangulation. It is anticipated that significant quantities of data will be generated, further supporting the need to restrict the case study to a single company. Further, the use of case study research within an interpretivist research philosophy is supported by Darke, Shanks and Broadbent (1998).

3.2.2 Mixed Mode Research

Many researchers debate the benefits of utilising only quantitative and/or qualitative research methods within individual studies (Firestone 1987; Smith & Heshusius 1986; Denzin 2009). Numerous researchers support one methodology over the other, while some support a combination of the two, often referred to as Mixed Mode research (Sale, Lohfeld & Brazil 2002; Creswell 2013, pp. 3-26; Johnson & Onwuegbuzie 2004; Teddlie & Tashakkori 2009; Teddlie & Tashakkori 2006). Some suggest this debate has been on-going since Plato (Johnson, Onwuegbuzie & Turner 2007).

Indeed it can be argued that the weaknesses of one method over the other can be compensated by the use of both within the same study (Kaplan & Duchon 1988). Proponents of quantitative research often cite the benefits of numerate scientific rigour inherent within their approach, and the lack of this within qualitative methods (Caelli, Ray & Mill 2008; Rolfe 2006).

Similarly, supporters of qualitative methods argue that quantitative study can be dangerous in that the scientific rigour created though numerate calculation loses context (Kaplan & Duchon 1988). Further, supporters will argue that qualitative research can demonstrate rigour through the use of tools such as audit trails and respondent validation (Meyrick 2006; Carcary 2009).

Many authors have since moved past this long standing debate, and have proposed methods to integrate qualitative and quantitative methods such as Bryman (2006), Malterud (2001) and Leech and Onwuegbuzie (2009). Bryman (2006) debates the
many ways in which both methods can be used, including the use of triangulation, but ultimately concludes that so long as both methods are used in tandem in a complementary and integrated manner then the study is strengthened through unexpected discovery. Similarly, Malterud (2001, p. 487) supports the combination of both methods to increase the "meaning and implication of findings." thus enhancing rigour and making finding more robust. She goes further to suggest that semi-structured interviews can be constructively combined with survey items to this end. She too cites triangulation as a common tool used during mixed mode studies. This study adopts both of these principles. Johnson et al. (2007) support the use of mixed mode studies. Aside from the traditional validity benefits brought by concepts such as triangulation, they give an example whereby quantitative methods reduce elite bias, while qualitative methods can aid the collection of quantitative data. A particularly pertinent consideration, given this study's span within organisations heirachy. Leech and Onwuegbuzie (2009) move past the qualitative versus quantitiave debate and propose a standardised nomenclature for mixed mode studies. Indeed, using their terminology, this study would be described as partially mixed concurrent with a dominant qualitative design method.

Eisenhardt (1989b) supports Noor (2008) view above, and identifies the suitability of mixed mode, inductive research within a case study. Further, Seawright and Gerring (2008) describes the approach taken in this case study as both typical and within-case.

Harrell and Bradley (2009) discuss two main forms of data collection. Specifically, semi-structured interviews and focus groups, and identifies when these are best used, and used in conjunction with surveys. They identify the following conditions upon which semi-structured interviews and/or surveys are more applicable than a focus group: Determining relative emphasis on an issue, generalisability, sensitivity of an issue, classification of an issue. This study fits within the need to determine the relative emphasis given to governance, risk management and product design, and certainly the issue would be considered sensitive and classified. Harrell and Bradley (2009) also propose that both focus groups and semi structured interviews, rather than surveys are most applicable when seeking full responses to seemingly conflicting information. Given the sensitive nature of the phenomena being explored, the use of semi structured
interviews present a greater opportunity for discovery through the interpersonal exchange of meaning that occurs in a private interview. This is in keeping with the primary use of interviews and secondary use of surveys thus qualitative methodology as the dominant methodology for this study. Rowley (2002) also supports the use of multiple sources of data from within a case study. Specifically, the use of documents, exploratory artefacts, interviews and observations. However, the use of surveys within the mixed mode study is still important (Gable 1994), and complimentary to the other sources of data proposed by Rowley (2002).

As discussed above triangulation forms a principle aspect of mixed mode research. Correctly used, it is an attempt to use one form of research to create validity in another (Seale 1999; Scandura & Williams 2000; Malterud 2001). Moran-Ellis et al. (2006) are quick to point out however that just like mixed mode research, triangulation is useful but is not without its limitations and critics. Indeed, in this study, triangulation will be used to lend validity to the qualitative study comprising a series of semi-structured interviews and internal document review, by also concurrently conducting a quantitative study in the form of a survey.

Further, the use of qualitative methods, such as semi-structured interviews and organisational artefacts, supported by quantitative surveys, aligns with the research questions in that they seek to know 'how', 'why' and 'in what way'. It is unlikely that surveys could be used as the primary tool to discover the organisation's history as required to answer research questions of this nature. Given the potentially controversial and sensitive nature of the phenomena being explored, qualitative methods, such as interviews, are more likely to reveal subtleties and nuances in interview responses than surveys alone (Gable 1994).

3.2.3 Research Design

3.2.3.1 Purpose (Exploratory)

In its attempts to understand 'Why' and 'How' directors exert governance influence and direction within complex high technology OEM's, this study is well described as
exploratory (Rowley 2002). As discussed by Gable (1994), the research strategy is complementary to the exploratory nature of this study. Specifically, when ranking explorability [discoverability] case study and survey methods are described as having high and medium strengths respectively.

3.2.3.2 Context

The respondent company is a fully owned subsidiary of a publically listed investment company, listed on the London Stock exchange. Over the last decade, their products have transitioned from electrically driven mechanical devices to being mostly electronic with some plastic and metal devices. Indeed, this transition has seen the introduction of wireless communication for remote access. This introduces the need for increased electronic and software security and significantly increases the products design complexity and creates challenges relating to compliance. The respondent company is a significant player in their market. They design, manufacture, distribute and service a range of electro-mechanical systems.

The respondent company consist of a number of legally separated business units. Further, the business is diverse, with operations in many countries. Most of these being themselves separate legal entities. This study will focus on a single legal entity. This business unit has approximately 75 employees, and a revenue of approx £35M per annum and is defined as a Small to Medium Enterprise under the guidelines defined by Her Majesty's Revenue Centre (HMRC). To determine the strategic direction, governance, success and integrity of these business a number of global roles have been created to oversee the activities of local management. Local management formally reporting to the local MD, with dotted line responsibility to one of the global roles.

The rapidly changing marketplace has introduced many challenges for the respondent company. Over the last three years, the respondent company has struggled with manufacturability and field reliability issues. In 2013, they experienced their first significant product recall, and this has been followed by a number of recalls or poor reliability events that were almost product recalls. Given this history, there is growing concern within the respondent company at the director level that product will meet
future company and customer expectations. They are starting to question why the company is experiencing recalls and reliability issues, questioning if this is related to manufacturing or design processes or both. By their own admission, the respondent company does not utilise modern design for reliability methods, but relies heavily on design practices of long serving employees, many of whom have decades of experience in the respondent company's industry.

3.2.3.3 Unit Of Analysis

Governance structures and processes

The respondent company employs matrix based governance and management structures with functional directors leading each discipline across Europe and in some cases Asia. Assuming responsibility for regional teams performance, and answerable to the main shareholder, their task is to provide procedural oversight to regional management teams. Functional managers at each region have periodic reviews as a group with functional directors and heads to raise risks and seek direction. This occurs most weeks. Every month, the functional directors meet to review financial performance, risks, issues and determine strategic direction. Where required new instructions are provide to, or clarifications requested from, functional management to ensure they are aligned with strategic direction.

Organisational systems

The respondent company operates within an ISO9001 structured environment, inclusive of a multi-departmental product development process including a stage and gate system. Over-arching this standard, is an ISO27001 information security system and a number of industry specific regulatory compliance regimes. These systems are established to underpin organisational performance and minimise product and/or process non-conformance. Functioning within UK and thus EU law, there is a requirement for systems to ensure employees are not exposed to harassment, exploitation and discrimination (Baderian, Bloom & Wilde 1999). Further, being owned by a publically
listed company, the organisation is required to have systems to facilitate whistle blowers (Bowers et al. 2007).

**Group dynamics**

As a company specifying, design and manufacturing product, the group consist of numerous disciplines. Each discipline reports to a regional functional manager, who in turn reports to the national manager as well as dotted line to the functional director. Departmental conflict is evident due to competing goals between groups and teams, as well as conflict between regional requirements and functional requirements. The need to reduce this dynamic is recognised, and there are numerous regular multi-discipline group meetings to improve communication and co-operation.

**People Process**

Proud of their long standing as a company with over 60 years in their industry, many have seen the company shrink from several thousand to less than one-hundred employees within the UK. These employees are mainly UK nationals, with many employees proud of how many on them have been with the company for decades. Individuals have a strong sense of connection with their discipline, encouraging the creation of groups and increasing competition between them. Aware of the recent product recalls, individuals have express fears over job tenure, why and how these occurred and who is to blame and this does not help increase cross department harmony.

**3.2.3.4 Level Of Analysis**

This within case study (Ayres et al. 2003) seeks to understand the 'how' and 'why' of governance as it relates to product development process and product reliability within a single organisation. Hitt et al. (2007) indicate the importance of multi-level research to fully examine research questions. This necessitates study at a number of organisational levels within the company, from directors through management to design engineering. Further, Rousseau (1985) points out the importance of understanding and defining the level of the study. Figure 8 demonstrates the levels within this study as well as the
expected interactions both within levels and between levels. This study does not seek to focus solely on the micro level (individual employees), but rather on the meso level (governance) and the interactions between and within the micro and meso levels. Specifically the interactions between and within the individuals and departments responsible for product development, through the rest of the company, including management, senior management and extending out to the company directors. For this reason the unit of analysis is defined as the company itself. The departments (and thus the roles within these departments) that will be defined as 'responsible for product development' include project management, research and development, product management, new product introduction, production and quality engineering. The theory and phenomena underpinning the study will act as tools to understand interactions at the meso level and thus contribute to answering the research questions.

As discussed by Klein and Kozlowski (2000) and Diez-Roux (1998), care must be taken to ensure that when multilevel research is conducted that observations made at the individual level are not extrapolated to the group level and vice versa without justification. The research design in this study is expected to address this risk, through the ability to identify groups and individuals to confirm common observations. Further, through the use of multiple sources of data, claims and beliefs by individuals can be
confirmed and correlated with wider evidence allowing for extrapolation between levels.

### 3.2.3.5 Data Collection Method

This study consists of three main data collection methods:

1. **Semi-structured Interviews**
   These interviews were the primary source of data for the study.

2. **Survey**
   Surveys were used to create data for triangulation.

3. **Organisational artefacts**
   Artefacts were sought to provide further triangulation, with data created within interviews identifying the existence or potential existence of artefacts. These artefacts were used in turn to further modify the structure of the interviews where required.

The data collection process is described in detail in the following three sub chapters.

#### 3.2.3.5.1 Semi-structured Interviews:

Following a purposive methodology, there are two sets of semi-structured interviews. See Appendix A. One will be applied at the director level and the other at the employee/manager level. The data collection process employed is described below in Table 4. For both the employee and managers interview as well as the director's interview, questions within the semi-structured interview was divided into a number of groups:

**Group one:** Purpose: To establish the depth and breadth of the employee/managers understanding of the companies risk management structures, processes and organisational climate. The main focus of this group is to aid discovery to answer Question one: What product design methods are used within the case study company and how informed are the directors of these methods?
**Group two:** Purpose: The questions within this section are similar to above; however, they are designed to narrow the questions down to the implementation of the product development process. The main focus of this group is to aid discovery to answer Question two: Why and how have hidden risks emerged, and do directors understand such risks within product design processes?

**Group three:** Purpose: The questions within this section will identify what the employee expects from the product development process, and then allow comparison to what he knows their process is. For instance, the safety requirements expectation of a domestic camera is not the same as that for an aeroplane. The product development process should follow accordingly. (...or not). The main focus of this group is to aid discovery to answer Question three: How has their knowledge from research question one and research question two helped directors to influence design process and risk management structures and how do they ensure their influence has been effective? Also Question four: How have these directors considered and cultivated an organisational climate and social factors that constructively impacts on governance structures and product design processes discussed in research question three?

These groupings have been defined to provide structure to the interview process, by starting with the general case and narrowing to the specific to increase the potential for discovery.

As identified by Noor (2008), it is common for case studies to include interviews as a form of data collection, and often semi-structured interviews. Noor (2008) also suggests that semi-structured interviews allows for flexibility while still ensuring a consistent approach. To achieve this, there are a number of critical considerations when establishing an interview process, two of which are suitable planning and establishment of usable instruments (Boyce & Neale 2006). This forms the basis for the following interview protocol and data collection process (Table 4):

<table>
<thead>
<tr>
<th>Process</th>
<th>Action Proposed (Boyce &amp; Neale 2006)</th>
<th>Action Taken within study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>• Identify stakeholders who will be involved.</td>
<td>Directors, managers and employees at the professional level</td>
</tr>
<tr>
<td></td>
<td>• Identify what</td>
<td>• Evidence of risk management</td>
</tr>
</tbody>
</table>

66
<table>
<thead>
<tr>
<th>Process</th>
<th>Action Proposed (Boyce &amp; Neale 2006)</th>
<th>Action Taken within study</th>
</tr>
</thead>
</table>
|                       | information is needed and from whom.                                                               | governance - from within the company  
- Understanding (or not) of the product development process and risk management structures and processes.  
- Signs of social phenomena such as whistle blowing, bounded rationality.  
- Seek contradictory answers within and between individuals, as evidence of social phenomena |
|                       | • List stakeholders to be interviewed.                                                              | Directors, managers and employees at the professional level.                                                                                                                                                            |
| Development of Instruments | • What to say to interviewees when setting up the interview.                                        | • An confidential invitation letter and consent form was sent to potential organisational and individual participants declaring the content of the study, its intention and confidentiality. Consent was given by participants when they returned their signed consent form into the confidential locked box. |
|                       | • What to say to interviewees when beginning the interview, including ensuring informed consent and confidentiality of the interviewee. | • Meetings were held in a discrete closed room at a time of the participants choosing, with only the participant and interviewer present with a single recording device.  
- There was Re-iteration of the voluntary nature of the study, and reconfirmation that they consent to the study.  
- There was re-iteration of the confidential nature of the study, and providing them access to the recording device.  
- The recording device was placed within the participants reach so they could control what was recorded. |
|                       | • What to say to interviewees in concluding the interview.                                         | • The interviewer thanked them for their participation, reminding them that they will receive a follow-up summary for review.                                                                                              |
|                       | • What to do during the                                                                            | • A series of semi-structured                                                                                                                                                                                         |
Process | Action Proposed (Boyce & Neale 2006) | Action Taken within study
--- | --- | ---
interview. | questions was followed
- Open questions were asked to reduce closed answers.
- Notes were taken against each question while recording the interview.
- Participants were allowed to drift away from the question to enhance discovery. However, they were brought back to the interview structure once the opportunity had been exhausted.

* What to do following the interview. | Document my thoughts on the interview. (Diary)
- The researcher reviewed the existing theory to consider how the information in the interview has changed this.
- Consider additional questions for following interviews.

* Develop an interview guide that lists the questions or issues to be explored. | The university's approved semi-structured interview questions was used, but modify slightly based on emerging theory.

Table 4: Interview protocol based on instruments proposed by Boyce & Neale (2006).

3.2.3.5.2 Survey

**Administration:**

To ensure confidentiality, surveys were discreetly supplied to potential respondents. A room was provided for confidential completion, as well as several weeks notice of the requirement to complete the survey. Within this room sat a locked 'suggestion box', the key being held by the secretary to the Managing Director to ensure confidentiality. Each week the box was opened to extract survey results and review response rate.

While not presented to the participant in this manner, the survey is divided into three sections.
Section One: This section was created to complement the mechanical questions of the semi-structured interviews. Being yes/no or short answer style questions, the intention was to assess respondents knowledge of the organisations product development processes and to determine if they belong to management or employee groups and to establish their tenure. This was required to contextualise latter survey questions.

Section Two: This section employed a Likert scale to understand the respondents opinion on the deployment of the company's product development, product design and design review processes and their effectiveness. It is expected that the response from these questions may act as a direct comparison to the interview questions, forming an opportunity improve trustworthiness via triangulation (Shenton 2004).

Section three: Constituting the majority of the survey, this section was a whole scale application of the survey proposed by Patterson et al. (2005). Their survey, itself a series of sub-groups designed to explore and quantify aspects of organisational climate using a completing values model, was applied in this research study with the results being analysed using the organisational climate rationale Patterson et al. (2005) have defined. In their quantitative study across 49 UK manufacturing companies, analysing 6869 respondents, Patterson et al. (2005) validate the use of their organisational climate measures using concurrent and predictive validity gained through interviews with respondent organisations. Similarly, the study demonstrated discriminate validity by being able to discriminate between respondent organisations. To measure internal consistency, Cronbach's alpha coefficients were determined for the final 17 scales with all but the autonomy scale demonstrating a score of above 0.73.

3.2.3.5.3 Organisational Artefacts

As identified in interviews, surveys or during interaction with participants, relevant documents may be uncovered that either provide proof of claims made during interviews, or provide further opportunity for discovery of issues disclosed during interview. With approval already being given by the participating organisation, any documents deemed necessary will be made available, however, it is recognised that this
scope needs to be constrained to artefacts created by the product development process. These documents may take the form of:

1. Engineering designs and design reviews (Such as peer and FMEA documentation).
2. Project and/or management team meetings or emails.
3. Engineering change notification.
4. Production released and production hold documents.
5. Customer released literature, such as recall or rework notices.

It is anticipated that the above documents would provide insight into when and how reliability issues have occurred through recall notices, production hold and release notices. In reviewing the design and design review documentation, the methodologies used and their effectiveness can be considered. By reading through project and/or management team meetings it may be possible to perceive inconsistencies between reports, biases or dominant personalities.

Consistent with a purposive sampling approach, the full scope and depth of the documents required cannot be pre-prescribed before the interview process has commenced as this would presume the outcome if interview is known.

3.2.3.5.4 Trustworthiness

As discussed by (Morse et al. 2008) there is long standing debate surrounding the evaluation of Qualitative research. Specifically the use trustworthiness as defined by (Guba 1981) and the more traditional criteria of reliability and validity. Consistent with (Guba 1981) the work by this study seeks to provide evidence of rigour through the use of trustworthiness.

To establish trustworthiness within the interview and artefact based data collection methods the following has been considered:

Dependability - This can be demonstrated by the use of multiple different methods within the study. In response to the research questions, qualitative semi-structured
interviews are triangulated against surveys and organisational artefacts. This is consistent with the methodology discussed by Shenton (2004).

**Credibility** - Shenton (2004) discusses the use of multiple sources of data during triangulation to demonstrate credibility. Indeed participants within this study come from a number of levels within the company from employee and manager through to company director. Similarly, participants come from a number of different functions, including internal sales, engineering, purchasing and manufacturing.

**Confirmability** - To demonstrate confirmability during the interview process, a diary was kept to form an audit trail (Krefting 1991). Specifically, following interviews a written record was kept expressing the researchers thoughts and opinions on both the actual response from the respondent as well as potential meaning behind the responses.

**Transferability** - Efforts have been made within this document to provide a thick description so that future readers can understand the context of the research and the assumptions made within (Davis 1995). In this manner, future readers will be able to judge for themselves if this study is sufficiently transferable for their purposes.

3.2.3.6 Sampling Design

3.2.3.6.1 Organisation

In keeping with the research strategy, literature review and in alignment with the research questions, the sampling frame is defined as an OEM, SME within the UK market. As this study is limited to a single SME OEM, it is anticipated that the board would have between three and six directors, the senior management team between four and six members, other management would make up between five and fifteen with an engineering staff of between ten and fifteen. Thus it is expected that there would be less than approx 45 participants. The above composition is expected to vary depending on the organisational structure of the company selected. Indeed, this configuration closely matches the participating company.
Similarly, to identify the typical case, and the rationale for the purposive sampling method (Tongco 2007), there needs to be sufficient scope within the case study’s design activities with sufficient product complexity to maximise the potential for simplistic design methods to produce reliability risks. Thus the company will be an OEM with in-house product design capability manufacturing low to medium volume electromechanical devices due to their inherent complexity. However, the participating company should not be operating within a high risk safety environment as this is not a principle requirement of the study. Further, it avoids the study needlessly entering the High Reliability Organisation (HRO) versus normal accident theory debate described by Rijpma (2003), and any complications this may create. As discussed by Hopkins (2007), many HRO theorists do not include petro-chemical or railway industries as sufficiently high risk to be considered within HRO theory. The respondent company does indeed design and manufacture product, which, due to the changing nature of their market, have become highly complex electro-mechanical systems. However, their products still contain less inherent safety risk than those seen in either the petro-chemical or the railway industries. Indeed, despite this change, The respondent company does not employ design methods specifically created to increase product reliability.

Further, this study seeks to understand operational risk governance when complex (or modern) design methods are not used, whether they are still effective and meet directors’ expectations. Thus, a company whereby the directors are uncertain what product design methodology is used, or know a complex methodology is not used, should be selected. Wessel and Burcher (2004) and Kondic (2009) believe the barrier to SME’s employing six-sigma (an example complex design method, other design methods are also known to improve reliability such as Taguchi methods and Weibull Analysis) is the belief that it is a large company process and that SME’s have insufficient resources. This suggests the typical case should be an SME. With a 2013 revenue of £35,000k, the respondent company fits the definition of an SME as defined by Her Royal Majesty’s Revenue and Customs (HRMC). The respondent company directors have clearly indicated that they either do not know a reliability based design method has not been used, or do not actually know what processes are used in product design.
Companies where director(s) know, rather than suspect, there are insufficient operational risk management structures should be excluded as this provides little opportunity for discovery. Indeed, while the respondent company directors have identified concerns relating to product reliability and have experienced recalls, it has not been fully concluded that this is due to product design and design review processes.

To capture companies that have an expressed governance obligation to manage operational risk, only Public Limited Company (PLC) should be selected. While The respondent company UK does not specifically have a board of directors, it can be argued that the local MD and global roles mentioned above act in this capacity. The definition of director is determined by the membership rules of the Institute of Directors UK (IOD). The IOD website defines a director as "...responsible for the strategic business direction of an entity and the implementation of its corporate governance and which makes the decisions that determine its success and integrity". It is clear that these global roles fulfil the above definition.

Despite their physical and procedural distance from local businesses, and lack of formal line responsibility, these roles are required to provide oversight of the local management functions and business performance. This is important, as it is consistent with formal director roles. Thus, they are likely to experience similar challenges to positions formally entitled "director". This is expected to afford discovery through the existence of the phenomena and theory underpinning the study, including agency theory, whistle blowing, knowledge asymmetry, keeping mum and bounded rationality.
Further, it is not expected that the lack of formalisation of these pseudo director roles will impact on the significance or value of the research as this defacto status has merit given genuine work undertaken in their roles. Consequently, the case study company "directors" should have gained governance level insight into the product recall risks within their company.

In keeping with the purposive approach, as the respondent company was a close match to the above sampling frame, they were chosen as the participating company for this study. Identifying key attributes, as described above, when selecting a participating organisation as well as participating individuals is constant with the use of non-random purposive approach, which advocates the selection of participants based not on underlying theories or minimum qualities of samples, but on the inherent value and nature of the participants (Tongco 2007).

3.2.3.6.2 Individuals

There were three sources of data.

I. Semi Structured Interviews

Participants for semi-structured interviews were limited to three main groups. Directors, senior managers and employees at the professional level involved directly or indirectly with the design process. As the study is specifically focused at the Meso level, that is the interactions between the micro and macro level of the company, it was also important to explore the interactions both within the core team, the product design extended team, management and the directors. Factory assembly workers, receptionists, accounts departments, and external sales teams were excluded as their interaction within and or upon the product development process is minimal. This left a population of thirty nine including directors. Consequently, the following groups were asked to participate within the semi-structured interview (Table 5):
<table>
<thead>
<tr>
<th>Group</th>
<th>Invited</th>
<th>Participated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Project</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Management</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Director</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Totals</td>
<td>39</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 5: Groups invited to participate in semi-structured Interviews.

Non-core roles involved in the project and management roles were interviewed first to understand the wider organisational perspective. This was followed by the core design team, with the intention of being able to compare opinions within the two groups and challenging the emerging theory. With these two groups completed, an understanding of the risk management and product design methods coupled with the company's product reliability and recall experience as it is on the ground can be created. This view was expanded upon, and theory challenged, by further comparing this to experience and opinions at director level. Thus this third group, directors, went last.

II. Survey

Consistent with the rationale applied to the semi-structured interviews above, and with the exception of the directors, surveys were distributed to managers and employees directly or indirectly involved in product development. The surveys were designed to capture details on the product development process, and organisational climate as it actually is. In their roles as directors, it is not expected that they could know this level of detail and thus they were not required to complete these surveys.

III. Organisational Artefacts

To provide supporting evidence, organisational artefacts were sort. These could come from any documented source such as engineering drawings, project planning documents, meeting minutes or indeed emails. As agreed with directors any document within the company could be used within scope of this study, and all documents would be made available.
The parameters defining and criteria for artefact selection is defined in section 3.3.4.3

3.3 Data Collection

Forty-one directors, manager or employees were invited to participate in semi-structured interviews and surveys. Consistent with the defined unit and levels of analysis, these participants were chosen as they represent all staff members of the company that are involved either directly or indirectly in product development. This represents approx 55% of the workforce. The other 45% is made up of those in roles such as factory floor assemblers, finance and accounts professionals and secretaries. These roles do not contribute to product development, nor in many cases interact with the roles that do. This is reflected by their physical separation, with core design teams, administration, factory support and factory floor being compartmentalised within their building. In this way, the respondent company informally contains a product development unit forming a majority of the roles within the company. It was this informal product development unit that was approached for a response to this study.

3.3.1 Semi-Structured Interview Participants:

The response rate for the semi-structured interviews was (Table 6):

<table>
<thead>
<tr>
<th>Directors</th>
<th>Managers</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invited</td>
<td>Responded</td>
<td>Invited</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 6: Semi Structured Interview response rate.

As is best practice for an in-case case study, the study achieved a significant participation rate, lending credibility to the data.

The following describes the breakdown of managers and employees that responded and what proportion are either directly influential (core) or indirectly influential (non-core) on the outcome of the product development process (Table 7):

<table>
<thead>
<tr>
<th></th>
<th>Manager (respondents)</th>
<th>Employee (respondents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core project team</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Non-core project team</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 7: Breakdown of semi-structured interview respondents based on demographics.
This demonstrates that the data was obtained across the levels required by the study (manager and employee) as well as within and just outside the core product development team, as is required by the study methodology.

Interviews were conducted in a private room set aside for the purpose. Participants were reminded that the interviews were both confidential and voluntary. As the interviews were recorded, the recording device was placed within reach and control of participants so that they could terminate the recording as required.

Interviews proceeded according to the research design, with interviewer following the interview structure while still permitting an expansion on points of interest when expressed by the participant. Expansion on points of interest was common place for most interviews as most participants appear engaged in the topic of the study. This level of engagement can be evidenced by the high participation rate.

Initial interviews were conducted with participants that were not within the core product development team. This was done to capture a wider view of the phenomena surrounding the product development process and include this into future interviews with participants within the core project teams. This approach also facilitated the creation of a coding structure which developed throughout the interview process.

Following the interview, participants were provided with a written summary of their answers and invited to comment. Corrections were accommodated accordingly, however, these were minimal.

3.3.1.1 Coding Structure

The following coding structure was created as directed by literature with the exception of the 'inconsistency' node. This node emerged as interviews progressed and it was discovered that respondents would seemingly make contradictory statements. When researching the potential existence and impact of social factors, such as the Mum effect and agency theory, associated with deliberate or unintentional non-disclosure of facts the addition of this node becomes important.
<table>
<thead>
<tr>
<th>Node</th>
<th>Primary Sub Node</th>
<th>Secondary Sub Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inconsistency</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Within interview</td>
<td></td>
</tr>
<tr>
<td>Product design</td>
<td>Design Testing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FMEA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Process</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Production Testing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Review</td>
<td>Process review</td>
</tr>
<tr>
<td></td>
<td>Tolerance</td>
<td>experience and intuition</td>
</tr>
<tr>
<td></td>
<td>unknown risk</td>
<td></td>
</tr>
<tr>
<td>Recalls</td>
<td>[PRODUCT 1]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[PRODUCT 2]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Design based latent defects</td>
<td></td>
</tr>
<tr>
<td>Risk Governance</td>
<td>Behaviours</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Controls</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Goal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reporting</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Review</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Structures</td>
<td>Safety</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stage and Gate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Others</td>
</tr>
<tr>
<td>Social Issues</td>
<td>Agency</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bounded Rationality</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Denial</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Groupthink</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Keeping Mum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Knowledge Asymmetry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Limited Search</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pressure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Whistle Blowing</td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Coding structure derived from literature and modified during interview process.

### 3.3.2 Survey results

As described in the methods section, a 120 item survey was disseminated to 33 potential respondents. That is, 10 managers and 23 employees. The same management and employee roles approached for participation with semi-structured interviews were approached for participation in the survey. This was to form the basis of a quantitative
study that would be used for triangulation with the Qualitative aspects of the study. Of these, 23 responded (Table 9).

<table>
<thead>
<tr>
<th>Managers (invited) - 10</th>
<th>Employees (Invited) - 23</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 responded</td>
<td>16 responded (1 invalid)</td>
</tr>
<tr>
<td>80%</td>
<td>65% (After removal if invalid response)</td>
</tr>
<tr>
<td>Average served time (years)</td>
<td>Average served time</td>
</tr>
<tr>
<td>11.1</td>
<td>15.9</td>
</tr>
</tbody>
</table>

**Table 9:** Breakdown of survey respondents based on demographics.

Data integrity was improved by removing clearly erroneous entries, in keeping with the methodology suggested by Kalton and Kasprzyk (1982). There were four occasions where data required correction.

1. One survey respondent left all survey items unanswered. This whole survey response was removed from the study.
2. One survey did not contain information concerning the participant’s length of stay within the company. This survey was not considered during analysis involving Tenure.
3. One respondent did not answer Item 6. Another respondent did not respond to items 39 and 40. All other survey responses were complete and without any form of error.

### 3.3.3 Artefacts

Further described in detail in section 3.3.3, 11 organisational artefacts were collected. These documents were sought to clarify, support or challenge data discovered during interviews or surveys. By using formal control documents that confirmed design change scope and implementation, when product was stopped from being shipped and when it was released, root cause of the defects that caused product recalls were factually determined and compared against respondents opinions and recollections. Similarly, the content of the official documents used escalate the product recalls was compared to the data collected during interview and survey.
3.4 Data Analysis

3.4.1 Interview

Transcripts were created from audio recordings of interviews. (Hammersley 2010). These transcripts were imported in Nvivo for content analysis, coding and thematic analysis. (Welsh 2002) To aid discovery, common words were sort with the intention of seeking thematic relevance. Associated groups on interviews were grouped together to this end. Before doing so, the interviewers questions and comments were removed from transcripts to capture meaning and intention from interviewees, rather than the interviewers. To aid visualisation of high frequency words, and groups of words, word clouds were also produced. McNaught and Lam (2010) describe a word cloud as "A word cloud is a special visualization of text in which the more frequently used words are effectively highlighted by occupying more prominence in a representation". For example:

![Sample word cloud extracted from Nvivo.](image)

As interviews progressed themes were identified by the researcher, aided by the use of a diary and interview notes (Hancock, Ockleford & Windridge 1998). The themes were modified as the semi-structured interviews progressed consistent with grounded theory and the approach suggested by Nadpara et al. (2012). In this way, the focus of the semi-
structured interviews evolved to capture data as new themes emerged. The main themes that emerged during interview were:

1. Numerous product recalls.
   a. Design and design review process not linked to requirement for highly reliable product.
2. Use of waterfall product development method, despite claims otherwise.
   a. Stage and gate system ineffective.
3. Many social factors influencing governance and product development process.
   a. Pressure not to be a whistle blowing evident.
   b. Mum effect within core and extended project teams.
   c. Denial that there are design issues.
   d. Active use of information asymmetry during design review, and reporting of the cause of product recalls to avoid accountability.
   e. Interdepartmental conflict.
4. Directors generally unaware of social issues, and ineffectiveness of governance structures such as the stage and gate system.
   a. Directors not certain of cause of recalls, although there is some suspicion poor design has had an influence.

Nvivo was then used to code onto these themes or nodes. As coding nodes progressed, new themes emerged either directly through the transcripts or influenced by the word clouds. The final themes are shown in Appendix B:

3.4.2 Survey

3.4.2.1 Analysis of Survey Data

To aid discovery, and triangulation, descriptive statistics were applied to the response data. See Appendix C. This included calculating the mean of responses to items in an attempt to discover the trends in individual items. Further, the survey format facilitated the separation of responses for managers and non managers as well as staff with below mean tenure and above mean tenure. While perhaps not required given the survey data will be used for verification of the primary source of data, the semi-structured
interviews, to add rigour, an independent T-Test was employed to determine if there were any response that displayed statistical significance. This approach was useful to statistically support some of the data generated during interview and used to answer the research questions as discussed in section 3.4. For example, interviews identified the existence of interdepartmental conflict and personalities influencing the design review process. The survey supported this finding using statistically relevant data as demonstrated in Table 11, item 19 and Table 12 item 22. Similarly, interviews identified that tolerance methods were based on intuition and design review processes were highly subjective. Again this was supported by survey results. (Table 11 items 14 and 23). This helped to answer the research questions by describing the product development processes that are used (research question 1). How the product recalls were caused (research question two). How social factors contributed to the product recalls, and the mismatch between directors expectations of governance controls and reality (research questions three and four).

3.4.2.2 Factor Analysis of Survey Results for Organisational Climate Section of Survey

As described by Brown (2012) factor Analysis is used as a tool to reduce large quantities of data into a smaller number of underlying factors or phenomena. As a confirmatory exercise, It would be expected that applying factor analysis to the organisational climate data within this study would reveal a number of underlying factors. This would demonstrate the reliability of the data, and failing to do so potentially identifying a deficiency in the study. Consistent with the work conducted by Patterson et al. (2005) there should be at least one factor identified per quadrant, corresponding to one or more dimension. Given the competing values model underpinning the organisational climate model it is unlikely for an organisation to focus on every dimension or quadrant equally (Patterson et al., 2005).

Using SPSS, confirmatory factor analysis will thus be used to uncover the factors within the data. See Appendix D. Only factors with coefficient above 0.6 were considered as significant. Applying this to the data demonstrated that at least one dimension from
each Quadrant was found to be significant. This process thus demonstrating the reliability of the data.

### 3.4.3 Artefacts

Documented evidence for the existence, cause, evaluation and communication of risks relating to product recalls was sort. The search for organisational artefacts was directed by pertinent information derived from semi-structured interviews and in a snowballing manner (Millen 2000). For example, during interviews it was identified that there were product recalls. To establish facts, documents relating to containment actions were sort. This lead to the Production Holds Notice. The actions taken to rectify the recalls were identified in the Production Hold and this lead to the Engineering Change Note, which describes the change to Engineering Drawings. As a result, the following artefacts were collected and used within this study:

<table>
<thead>
<tr>
<th>Artefact Type</th>
<th>Description</th>
<th>Specific example</th>
<th>Use within study to support research questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Hold Notice</td>
<td>Document used internally to stop more defective product being built, and to co-ordinate rework of product already sent into the marketplace.</td>
<td>[PRODUCT 1], [PRODUCT 2] x 2 Production Holds</td>
<td>Provides physical confirmation of recalls identified in Semi-structured interviews. Between Feb 2012 and June 2014. Demonstrates when recalls emerged. Further, it provided evidence that engineers within the product design team knew the issue was design based. In later interviews this link to design was denied. This document demonstrates a formal governance</td>
</tr>
<tr>
<td>Engineering Drawing</td>
<td>Used to specify the engineering characteristics of a part, sub-assembly or product.</td>
<td>Drawing 1: Main PCB with Power resistor sub-assembly, demonstrating change to design in response to recall.</td>
<td>Comparison of design documentation before and after recall demonstrates that the root cause was indeed design based, thus how and why recalls emerged. This evidence is in contradiction to the email artefact discussed below. Used in response to research question two.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drawing 2: Earlier version of above showing no design specification relating to max height of power resistors.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drawing 3: Shows modification to power resistors design after recall</td>
<td></td>
</tr>
<tr>
<td>Engineering Change Note</td>
<td>Used to formalise the change of a design to Production and/or the supply chain</td>
<td>Demonstrated activation of engineering Drawings discussed above</td>
<td>Confirmed timelines and scopes of design changes to rectify recalls. This document demonstrates a formal governance structure that should have informed Directors the recall had its origins in the design process. Used in response to research question two.</td>
</tr>
<tr>
<td>Email</td>
<td>Document used to formalise verbal conversations. Often used to transmit formal and/or informal meeting minutes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Email confirming the content of the [PRODUCT 2] recall &quot;Deep Dive&quot; meeting. Used to capture the spirit of the meeting. That is, to convey to the newly employed director that the recalls did not have any design based root cause, even though the Production Hold Notices and Engineering Change Notes above demonstrates that they did. Thus controlling the information available to the director. i.e. evidence of information asymmetry. Used in response to research question two.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Email by the respondent that had claimed in interview that safety based design audits were comprehensively completed. In the email, respondent did not wish to pass on audit results as they were not complete. Used to evidence that when design engineers are asked directly regarding performance, they stay Mum. Thus controlling the information available to the director. i.e. further evidence of information asymmetry. Used in response to research question two.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier Communication</td>
<td>Notifications and discussions between</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Numerous discussions, generally in the form of emails, were found that were not used due to the potential for distorting results. For example, the supplier may deny being</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer Announcements</td>
<td>Notifications and discussions between company and its customers</td>
<td>Numerous discussions, generally in the form of formal releases, were found that confirmed much of the above.</td>
<td>Not used due to the potential for distorting results. For example formal announcement may be cleansed before release to the market.</td>
</tr>
<tr>
<td>------------------------</td>
<td>---------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>External audit results</td>
<td>Audit of design and manufacturing processes to assess company's ability to supply suitably reliable product.</td>
<td>Early 2014 a large well known auditing company extensively reviewed the company's operations on behalf of a strategic customer. This was specifically done to review the company's processes to assess product reliability.</td>
<td>Audit results did not focus on social factors or climate in any way. Further, there was some focus on design test, but minimal review of design or design review processes. Majority of focus was on manufacturing and Quality Control. This audit was highly visible to Directors. As there was nothing to suggest a link to social factors or design process, Directors could have been allowed to believe they have not impact on product reliability. Used in response to research question one and two.</td>
</tr>
</tbody>
</table>

**Table 10:** Organisational artefacts and their application within study.

Directed by semi-structured interview, and expanded on by the organisational artefacts above, three main events have been identified as important in understanding the product design processes and governance structures within the organisation.
1/ The [PRODUCT 2] series of product recalls.

This is a series of two product recalls that occurred in short succession, one after the other.

1a. The initial recall was due to power resistors touching each other and shorting-out when users pushed buttons on the front of the product. When users pushed buttons on the products front panel, there was a slight deformation of the cover plastics. As these power resistors were mounted vertically on the printed circuit board, they had the potential to touch the inner surface of the outer enclosure. The design tolerances should not have allowed for this. On units where the power resistors were supplied at the upper extreme end of their design tolerance small amounts of deformation translated to movement on the resistors encouraging them to touch. For units with power resistors supplied at the lower end of their designed height tolerance, a significant amount of deformation of the plastic cover would be required to cause this fault, as these resistors were not as tall. In fact, in this situation, components next to the power resistors would have touched the cover first protecting the power resistors from touching each other at all. As the power resistors could be correctly supplied to specification anywhere within its designed height tolerance band there was no reason to create an inspection or Quality Control process that recorded where within the tolerance band any given delivery and resultant production batch may lay. Therefore it was impossible to know which unit would contain this design defect.

It is rational to accept that with sufficient force, any plastic outer-cover will experience some form of deformation. However, the amount of deformation created relative to a given force was not quantified by design, other than it was evident that sufficient deformation was experienced when the buttons were pressed with above average (in a lay person sense), but still reasonable, amount of force. Minimising the flex and deformation as a function of button pressure in the range the product may experience in reasonable use, plus a safety margin, did not appear to be considered. As the control variables that limit flexibility were not considered during the initial design phase, and thus not considered at product launch, units that are more or less susceptible to
deformation could not be identified as product was supplied, inspected and built 'to specification'.

When the power resistors touched due to a button press, creating a short circuit, a small explosion resulted that had sufficient force to open the front cover of the product and potentially expose the user to excessive heat and/or the live components within the product. These defects were inherent and latent within the design. It required the convergence of both excessively high power resistors (but within specification) and the varying amount of button actuation force, and consequential plastics deformation, for the recall risk to be realised. As the product can be built to design specification and still have these latent defects, the simultaneous occurrence of these two latent defects may have been in the first production run, in any subsequent production run, or not at all. Making the occurrence of the recall event in any individual unit, effectively unknowable. Had these two factors converged during initial product testing, it is likely that it would have been found and rectified. That is, become known. However, there is no inherent reason why engineers should have discovered these defects during testing. As mentioned previously, the confluence of these two defects may have never occurred even though they had the potential to do so. It is equally possible to build product without these two defects, based on the within-specification variation of the supply chain. Thus even the best testing methods, if applied to thousands of units before the release of the product may have never detected the defect as it is possible or even likely the units being tested at the time did not contain both defects. Demonstrating the theory in literature review that poor tolerance methods restrict the effectiveness of product testing.

For the team managing the recall situation, the potential for failure of any individual unit already installed in the field, and the consequences of this failure became random in appearance. If the cause of the failure could be tracked back to an individual batch, then the number of affected units could be limited, along with the size of the recall, and along with the financial and market reputation damage. Indeed, it was possible that only a tiny number of product within the installed base was subject to this scenario. However, this just could not be determined, and thus, this random nature caused the recall of the all units installed since product release, maximising damage. As it
happened, this latent defect manifest after several years and many hundreds of thousands of products were released into the market.

Evidence that the defect was rooted in design, the rectification of the product was the following design modifications to be completed during recall in Feb 2012, and as evidenced by the Engineering Change Notes and Engineering Drawings the following design changes were made:

- "Elephant hide", a tough but flexible material known to provide electrical and thermal insulation was introduced to provide a barrier between the power resistors.
- The design of the resistors was changed to reduce their length (and this height).
- The bending of the conductors on the resistors was changed, thus 'leaning' the resistors to reduce their effective height

Indeed, it appears the recall was not decided easily. Following interview data, there were a number of attempts to minimise the internal perception of the issue by denial of the potential damage. During interview, it was revealed that in recall meetings some members felt they could not speak out, and that much of the focus by some strong personalities was on shifting responsibility. Similarly, there was discussion proposing the issue was not sufficient for a recall and an alternative was to ask users to wear protective equipment rather than recall the product. It was suggested this was an attempt to externalise the problem to user process, and therefore remove the perception that the issue related to a design based product defect.

1b. The second recall on the same product, occurring merely months after the first, and again occurring many years after the product was released into the field related to a failing Metal Oxide Varistor (MOV's) known colloquially within the respondent company as Voltage Dependant Resistors (VDR's). These sacrificial components are used to suppress large voltage spikes, and their consequential damage to the product. These began failing and rendering product unusable. Again here, the official root cause was externalised as the suppliers fault; the supplier's lack of control over the storage environment. That is, allowing the MOV to be stored in high humidity. The data from
semi-structured Interviews with a design engineer and a production engineer disputed this account. Indeed, there were conclusions by some technical employees that this defect was caused by an attempt to reduce the cost of the product by using a single MOV in a configuration that would use it close to, and possibly above, it's specified rating, thus potentially stressing the component potentially leading to premature failure. While this is inconclusive, it is clear that there are multiple and conflicting versions of actual reality from numerous credible sources. This too is pertinent, as the official report did not include both views. When seeking product failure information, the formal experts view is sought. This presents a potential conflict of interest when it may be the experts effectiveness that could come into question as a result of their own investigation. As there is little way for upper management or directors to personally supervise a truly neutral investigation without using the team of experts they have employed, this conflict of interest may reduce the potential for accurate governance reporting and controls, as conflicting views simply are not heard.


In April 2014, an additional and new Director was added to the team. Concerned by the numerous recalls or near misses, he requested a review of recent recalls to be certain there were no new reasons to be concerned. As is consistent with industry practice (Harreld, O’Reilly III & Tushman 2007), he attempted a Deep Dive analysis. A Deep Dive, is common method of reviewing a situation (technical and non-technical) within a business in an attempt to understand the real underlying causes of an issue in attempt to control them and resolve the issue. It is not intended that this methodology seeks technical root cause alone. Rather, any and all factors, including risk analysis, reporting and governance structures are open to review and modification. As supported by follow up artefact evidence, the initial meeting with numerous management and technical design representatives, concluded that the root cause of the issue was related to supplier mis-management, and lack of production controls. The result of this conclusion was that no further review of the design methodologies, or competencies within the design process were in need of further consideration and that indeed, there was no evidence to suggest that further investigation was required. However this contradicts other artefact evidence (as discussed), and indeed numerous accounts of the [PRODUCT 2] recalls.
As shown by the Organisation Artefacts in Table 10, and as discussed above, root cause of the resister height recall was indeed being based in the design process. This string of artefact evidence is important, as it links to a number of pertinent behavioural factors:

1. The director leading the Deep Dive was not trained or informed about electronics, nor the company's manufacturing processes. Knowing this, the engineers in the meeting presented the cause of the recall as a supplier defect, and not related to design in any way. The director had insufficient knowledge to challenge this assertion. As such, the engineers used knowledge asymmetry to avoid closer scrutiny of the recall.
2. This event removed the opportunity for the director to consider the potential to improve governance reporting, controls and risk analysis methods used during the design process.
3. As a result of point 2, the director was left with the confidence that further recalls caused by design were unlikely.


[PRODUCT 1] was built by a contract manufacturer on the company's behalf. The manufacturer installed software used to test the product during manufacture, but this software does not have final product functionality. On receipt of the product by the company, new software is installed. This includes updating default values. For example, if the product was a thermometer that can display in Celsius or Fahrenheit, one of these must be selected as the default before delivery, possibly based on market requirements.

Typical of modern manufacturing, as this product is required to be built in high volume with an expectation of high reliability, a test, calibration, software upgrade and default value setting automated machine was created. This was expected to create absolute certainty that the product was correct before shipment by removing all human error. The product, having internal computers, would report back to this automated machine if there was an error during any test, calibration, updating software or changing defaults. This process then, automated the quality control for the product.
Between early 2012 and August 2014, approx 100,000 of [PRODUCT 1] were released onto the market. During July and August 2014, customers started reporting that the product did not function correctly. It appeared that this happened approximately 1% of the time. For high reliability volume product this is a high error rate. Most people would reconsider flying on aircraft that has a 1% failure rate. After investigation, it was established that the software within the product was not reporting to the automated machine when default values had failed to be reset correctly. Therefore, these defective units (approx 1%) were allowed to go through the manufacturing process without their defect being found. This was the official report of the problem. The software within the product was re-written to ensure it always reported when default values had not been reset. Any units that were found would be isolated and corrected without being released to customers. Management and board were satisfied with this resolution as this stopped the problem going out into the market.

However, this resolution did not mention why the problem occurred in the first place and how to rectify it, rather than removing the problem in manufacturing. What was not reported, was that approximately 1% of the time, a hardware defect caused the computers within the product to be busy on a different task when they should have been updating their defaults.

The software blamed as the cause of the problem was written by a third party. The hardware that formed the root cause of this issue was created within the company using the company's product development process by the design team. The defect within the hardware was accepted by engineers, denied by managers and not reported nor corrected.

3.4.4 Triangulation

To validate the Qualitative research, triangulation was employed, to uncover linkage between the interviews, surveys and artefacts. Where confirmatory linkages between interview data, artefacts, survey data and theory has been found it has been identified in Appendix E.
3.5 Ethics

3-5-1 Consent

Consent to participate within this study will be gained at two levels. Firstly, written consent by authorised representatives within the company's board of directors and secondly, written consent by participants. Written consent took the form of an information document that described the purpose and goals of the study, gave a commitment to the confidential and voluntary nature of the study and provided a space for participants and/or directors to sign and approve their participation or the company's participation. Consent to participate in interviews took the form described above, as did consent to provide organisational artefacts. Due to the confidential and anonymous nature of the surveys, consent to participate in these was implied by the act of participation.

To ensure confidentiality, surveys were discretely supplied to potential respondents. A room was provided for confidential completion, as well as several weeks notice of the requirement to compete the survey. Within this room sat a locked 'suggestion box', the key being held by the secretary to the Managing Director to ensure confidentiality. Similarly, interviews were conducted within this room at a pre-arranged time agreed by the respondent to ensure the interview occurred at a time of their choosing to maximise confidentiality.

3-5-2 Data Storage

This study is expected to produce a significant amount of data and documentation. This data will be in the form of survey results, interview transcripts, organisational artefacts and consent forms. All data will be held in soft copy in password protected computers accessible only to the student researcher and project supervisor. Data will be stored until five years after the successful completion of the dissertation and then deleted.
4.0 Chapter Four: Findings

4.1 Introduction

This Findings chapter reviews data obtained by executing the research plan as outlined in Chapter 3. Through this review, the research questions are addressed.

4.2 Findings to the Research Questions:

Q1) What product design methods are used within the case study company and how informed are the directors of these methods?

Interview Data

Findings from the semi-structured interviews convincingly demonstrated that the main design method in use within the organisation was tolerance calculations via the use of experience and intuition. This was further evidenced within interviews by the design roles themselves, and indeed confirmed by the design manager. There was evidence of limited absolute tolerance analysis, but this was restricted to application as directed by intuition and experience. When asked in interview whether the organisation employs Six-Sigma, Weibull Analysis or Taguchi methodology's there was a uniform negative response evidenced in all interviews. Of particular note, is the response to the survey item that asked "Describe your company's design and design review requirements". This identified a general lack of understanding about design methods across functions within the organisation. While Agile product development methods were identified during interview, their application was limited to software and firmware development. Further, there was no evidence within the data of any other form of design methodology being identified with triangulation confirming the above interview results.

Design review, in the form of FMEA and peer review was identified as a process employed within the organisation. However, it was evident that it was restricted to the core design team alone. Other technical, and non-technical, functions within the company have limited involvement if any. This was confirmed in numerous interviews.
However, it was observed that two directors did identify the use of FMEA, although one of these felt they did not fully understand the process.

In questioning director's about their knowledge if the design methods used within the company, their ability to respond was limited. Indeed only one director managed to identify the tolerancing methods used. He stated:

"Interviewer : Is there something that formally determines our tolerance strategy?
Director: Yes, there is something, but that’s not how it should be. We have tolerancing but again I do not have myself penetration on it on that level of detail, because I have never checked myself...I cannot say no but I’m sure we are far away from where we should be on tolerancing, especially some issues we had proved we must improve that."

Similarly, when asked about design methods such as Taguchi, six sigma and Weibull Analysis. There was consistent lack of knowledge about these also:

"Interviewer: Do you know if we’re using anything like design for six sigma?
Director: Honestly, I do not know. I mean I hear it banded about in a number of circles, whether it’s specifically for design or otherwise, I do not know.
Interviewer: Taguchi, Weibull?
Director: Not heard those ones, six sigma, I’ve definitely heard."

However, one director did suggest the widespread use of Agile methods, even though this was only implemented during software development and not during plastic, electronic or printed circuit board assembly processes. As with the other directors, he demonstrated a lack of understanding of Six-Sigma, Taguchi or Weibull analysis.

The other two interviewed directors could not comment on the design methods employed within the company. Clearly, from the interview data, the directors have limited understanding of the design methods used within the company.
Survey Data

Further clarifying the design methods used, were the responses to the following survey items (Table 11):

<table>
<thead>
<tr>
<th>Survey item (score out of 5)</th>
<th>Manager</th>
<th>Non-Manager</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. When undertaking risk assessments (e.g. Failure Mode and Effects Analysis), we use hard evidence and data to quantify severity and/or likelihood of occurrence.</td>
<td>2.5</td>
<td>3.2</td>
<td>$t(21) = -2.27^*$</td>
</tr>
<tr>
<td>18. The project team defer to at least one technical experts when considering risk.</td>
<td>3.9</td>
<td>2.9</td>
<td>$t(21)=2.65^*$</td>
</tr>
<tr>
<td>19. There are one or two strong personalities that dominate the design review process (e.g. Failure Mode and Effects Analysis).</td>
<td>4.3</td>
<td>3.4</td>
<td>$t(21)=2.29^*$</td>
</tr>
<tr>
<td>23. Tolerance design and analysis is mostly based on compromises using experience and intuition?</td>
<td>3.6</td>
<td>2.9</td>
<td>$t(21)=2.43^*$</td>
</tr>
</tbody>
</table>

Notes: * $p < 0.05$ level, ** $p < 0.01$, *** $p < 0.001$

**Table 11**: Statistically relevant responses from design process section of the survey showing difference between management and non-management opinions.

The response to Item 23, demonstrated consistency with interview data that the tolerance methods used are limited to experience and intuition, and that this is known to the management of the company. The response to Item 14 demonstrates that management are generally aware that the project team do not use hard evidence when processing FMEA's, which is consistent with the response to Item 18, whereby the projects rely on expert opinions. Coupled with the interview data and survey items suggesting the company is slow to change its processes, and given the recent history of reliability and recall issues, the response to Item 19 should be no surprise. In this environment, it could be argued that experts are being seen as ineffective, rather than insightful. Their status as 'expert opinions' being protected by the companies underlying reverence for tradition, perhaps they are now being seen as 'dominant' contributors, that do not need to provide hard evidence. Indeed, the existence of long serving staff with
detailed industry and company knowledge was identified as a strength by some managers.

Similarly, Table 12 below, demonstrates a difference in opinion between respondents with below average and those with above average tenure. Importantly, the company scored highly in the Traditional dimension of the organisational climate, and these results correspond with that result. Responses to these items would imply that newer respondents challenge the existing process, and have identified struggles with existing power structures. On the surface of it, item 31 may suggest support for an existing process. However, when interview data is used to contextualise this response, it should be read that the company has too much dependence on initial customers to determine if the product is reliable.

Items that demonstrated a statistically significant difference long serving employees/managers and recent hires opinions are displayed below (Table 12):

<table>
<thead>
<tr>
<th>Survey item (score out of 5)</th>
<th>Tenure&lt;ave</th>
<th>Tenure&gt;ave</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. My company has a formal Product Development Process (PDP)</td>
<td>2.7</td>
<td>3.6</td>
<td>( t(20) = -2.20^* )</td>
</tr>
<tr>
<td>19. There are one or two strong personalities that dominate the design review process (e.g. Failure Mode and Effects Analysis).</td>
<td>4.2</td>
<td>3.3</td>
<td>( t(20) = 2.46^* )</td>
</tr>
<tr>
<td>22. Politics and interdepartmental conflict do not influence the project decision making process.</td>
<td>1.9</td>
<td>2.9</td>
<td>( t(20) = -3.05^{**} )</td>
</tr>
<tr>
<td>31. My company uses early adopters and/or beta sites to determine if the product is reliable</td>
<td>4.0</td>
<td>2.9</td>
<td>( t(20) = 3.18^* )</td>
</tr>
</tbody>
</table>

Notes: * \( p < 0.05 \) level, ** \( p < 0.01 \), *** \( p < 0.001 \)

Table 12: Statistically relevant responses from design process section of the survey showing difference between less than company average tenure and more than average tenure opinions.
In response to the research question, the following summary table emerges from the interview data, linking product design methods used within the company and the directors awareness of these (Table 13):

<table>
<thead>
<tr>
<th>Process</th>
<th>Method</th>
<th>Used within company?</th>
<th>Directors awareness of use?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Development Process</td>
<td>Waterfall</td>
<td>Used for Hardware and Printed Circuit Board Assembly (PCBA) design.</td>
<td>No directors aware of distinction between or nomenclature around Waterfall or Concurrent methods</td>
</tr>
<tr>
<td>Concurrent Engineering</td>
<td>Stated as used, however, insufficient non-design team to support, therefore not fully implemented. Insufficient planning.</td>
<td>As above.</td>
<td></td>
</tr>
<tr>
<td>Agile</td>
<td>Used by Firmware design team only.</td>
<td>Two directors demonstrated awareness of this process, but only one showed real understanding.</td>
<td></td>
</tr>
<tr>
<td>Design Process</td>
<td>Absolute Tolerance stack-up</td>
<td>Not Used</td>
<td>One director is aware of tolerance methods in depth.</td>
</tr>
<tr>
<td></td>
<td>Statistically based tolerance</td>
<td>Used Sometimes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experience and/or intuition based tolerance</td>
<td>Commonly Used</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Taguchi</td>
<td>Not Used</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Six-Sigma</td>
<td>Not Used</td>
<td></td>
</tr>
<tr>
<td>Design Review Process</td>
<td>Peer review</td>
<td>Commonly Used, But within design teams only</td>
<td>Three directors are aware of these being applied</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-------------</td>
<td>---------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>FMEA</td>
<td>Commonly Used, But within design teams only</td>
<td>One director is well aware of the process with one other director having heard of the methodology.</td>
<td></td>
</tr>
<tr>
<td>Testing</td>
<td>Commonly Used</td>
<td>Two directors understand how this is applied, with two directors having heard it is applied.</td>
<td></td>
</tr>
</tbody>
</table>

Table 13: Summary of Processes and methods employed compared to Directors awareness of them.

Q2) Why and how have hidden risks emerged, and do directors understand such risks within product design processes?

Interview Data

As covered within the literature review, certain design and design review processes inadvertently foster latent defects within the design process. Likewise, social interactions within these processes removes the ability for sufficient governance control and reporting, rendering risk management structures ineffective. Interviews and organisational artefacts (refer to the three events discussed in section 3.3.3 Artefacts) demonstrated that there have been a number of product recalls within the recent history of the company under study. As would be expected, these recalls were not expected and presented the company with significant reputational damage and remedial cost. Though recall hidden risks have emerged.

Why did they emerge? The interview data suggests that these recalls were influenced by the confluence of outdated tolerance design process that facilitate defects within projects influenced by personalities and interdepartmental conflict and accompanied by design reviews that are dominated by strong personalities. Similarly, denial and the use
of knowledge asymmetry helped continue the use of these old and outdated methodologies.

During interview, each director clearly identified concerns over frequent product recalls or near misses. Similarly, suspicions that the design processes the company use is a significant contributor to this. However, aside from one director they failed to specifically identify details. Indeed one director understood the inherent limitations of the design processes within the company such as tolerance design using experience and intuition alone, and how this can impact product reliability. He went on to discuss the requirement to create a Mean Time Before Failure (MTBF), and how this is can only be used if supported by rigorous design process such as absolute tolerancing.

"Interviewer: If we’re talking about things like MTBF calculations, do you have any concerns how that fits if our tolerancing methodology may be not sufficiently looking at the product at a system level? If that’s true, does one render the other ineffective?

Director: That could be well the case. When we do the MTBF calculation, if we’re not considering fully the tolerancing we are maybe not using the component as specified and we take the MTBF factors from the manufacturer, or they take it as the component should be used. So they consider we are using it within tolerancing and everything. So it could be completely useless if we are not using the right tolerancing.

Interviewer: And is it possible then that you could product out into the field in that circumstance, and even though somebody at your level may expect that it would last for 15 years, actually it could fail anywhere from a minute after it’s put in the field, all the way through to ten years later.

Director: Yes. And it happened already for products which we had an MTBF returning positive result. So it was clearly a tolerancing thing.

Interviewer: So therefore if you do not do your tolerancing correctly, would you agree that you effectively create the potential for random defects in your product?

Director: I think this is the tolerancing, it’s the basis. I would say first we should talk about that, we should make sure that we are considering that, that we
are within the tolerance we know. And then we can really have an MTBF which is relevant, because we get that, we know where we are. And as well all the other risks may be affected if we are using a component which has been stressed outside limits"

Although the director demonstrated awareness from the interview above, there is no implementation of design processes that lead to high reliability. Another director did not know the specific functions within the design process that concerned him, however, he effectively touched upon this point when taking a macro view of the situation:

"...But what I haven’t seen, that concerns me is when you take something like [PRODUCT 1], which is a low margin, high volume, high yield product, we’ve still gone about it in exactly the same way as we have our traditional products. And that’s the failure with saying, “This is all we normally do.” And it’s kind of not got us into trouble before. Nobody’s actually assessed to say, “Is that good enough for this product in this mode.” And the answer is clearly no, because you cannot achieve the volumes, the yields that we need, with those same statistics ...So that’s where I’d say there is a sort of an operational risk blind spot in product development and product management.”

Despite the awareness of the overall limitations somewhere in the product development process, none of the directors mentioned social or behavioural issues within their company as having an influence on the risks within the design process. Directors typically exemplified managers as competent but over worked going through a significant period of change and as a result were reactive rather than assertive in managing risks over-all. A simplistic response, the directors seem to be assuming that managing risks within the design process is mechanistic and achievable, so long as the managers involved have sufficient time to do so. The directors seem to then justify managers competency by clarifying that managers do not have sufficient time because of the recent recalls and/or near misses. However, this justification by the directors may be explainable. As presented in the data, and as an example of agency theory, there has been effort made by managers to ensure that the root cause of recalls have been externalised, shielding directors from the real situation. It appears that these efforts have been successful.
The use of inadequate design methods within ineffective governance structures dominated by the social factors discussed explains the emergence of hidden risks.

**Survey Data**

As per tables 11 and 12 items 14, 19 and 22, in the response to research question one, and the discussion surrounding the statistically relevant survey results, it is evident that few of the social factors identified within the data were also identified by the directors. Specifically, that the company uses inadequate design methods supported by dominant personalities and inter departmental conflict. As such, this data acts as confirmation of the interview results and helps to demonstrate that these phenomena are why the hidden risks emerged.

In response to the research question, the following summary table emerges, describing how hidden risks emerged as recalls, why they emerged and directors awareness of both:

<table>
<thead>
<tr>
<th>How? Through the recalls below:</th>
<th>Directors Awareness</th>
<th>Why did the recall happen?</th>
<th>Directors Awareness</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCT 1</td>
<td>All directors fully aware of these recalls</td>
<td>Defects within firmware design plus hardware design that may have been resolved by using reliability based design methods and/or caught during a non-conflict based design review.</td>
<td>All directors informed via production hold document that recall was due to firmware defect, although one suspects something more related to the overall design process</td>
</tr>
<tr>
<td>[PRODUCT 2] (MOV)</td>
<td>Controversial. MOV possibly supplied out of specification, but design also stresses component as it was used at limits of its specification</td>
<td>All directors informed via production hold document that MOV was supplied &quot;Not to Spec&quot;. Use of MOV close to specified limits</td>
<td></td>
</tr>
</tbody>
</table>
Table 14: Summary of how hidden risks emerged as recalls, why they emerged and Directors awareness of both.

Q3) How has their knowledge from Q1 and Q2 helped them to influence design process and risk management structures and how do they ensure their influence has achieved its intended outcome?

Interview Data

Further to research question two, despite one director clearly understanding the technical link to process and product reliability no directors identified the limitations of their knowledge within their governance structure based on social factors and how this may influence the product design process. However, data suggests there had been long standing concerns regarding product recalls and whether this could be related to design. In an attempt to reduce this, and in an attempt to influence product design process and risk management structures the directors implemented a stage-and-gate system. As stated by one director "we have gate model, which takes priority all the way through, preproduction, approval to actually commit development resource. And then various gate sign-offs all the way through to pilot production and ultimate delivery." A stage-and-gate system takes the lifecycle of a product development project and divides it into a number of stages. Each stage is then reviewed by a multidepartment management team, and then if successful, the project continues to the next stage of development (Cooper & Kleinschmidt 1991). This process has the expressed purpose of improving multi-departmental co-operation and communication, ensuring project risks (including design) are identified and escalated. Directors explained that this process has been reviewed a few times in the last few years in response to on-going reliability and recall...
issues, but did not describe the changes as comprehensive and deep reaching. Despite being employed before the [PRODUCT 1] project, it failed to prevent it's recall. Most directors and many managers identified the stage-and-gate system as the main source of governance control and reporting process that ensures design and risk management structures are effective. As mentioned by one manager: "...from the development side anyway, we have this high level gate process where the gates are actually serious gates now whereas they used to be less onerous." and a director: "... within D&D, which is the gate model/rate approval model that they use. We all work within a defined structure." The principle being, that each gate would be reviewed to ensure the underlying processes have been correctly and diligently employed. These underlying processes include design tolerances, FMEA, peer reviews and the like. It was also mentioned by one director that it is not unusual for managers to deliberately allow projects to by-pass the stage-and-gate as they feel appropriate. Another example of agency theory, this further undermines the company's stage-and-gate system as an effective governance control mechanism.

Further, the stage-and-gate process has failed to address the inherently qualitative nature of risk assessments such as FMEA. Similarly, the consequences of choosing to use inadequate design methods coupled with the social factors discussed in this dissertation and demonstrated by the data. As identified by Item 19 in Table 11, and within survey results, risk assessments are dominated by strong personalities. Therefore, FMEA's and peer reviews would likely be presented by managers to the stage-and-gate review team as completed with risks mitigated, when they may not be. Directors lack of understanding of the social factors discussed within this study and how they influence the design and design review process would ensure they do not know to challenge the governance reporting that comes out of the stage-and-gate process. Thus further reducing the effectiveness of the stage-and-gate system as a governance reporting tool.

In addition to the above, one director did identify that a central team of directors do attend a monthly risk assessment meeting. However, this is limited to financial risks. The director did admit, that while this process is reviewed periodically, it generally does not change. Further, he admitted that he believed, but was not certain, that engineering
and operations risks are typically reviewed within other functional structures within the company.

Survey Data

The findings of the interview data discussed above are consistent with the survey results of items 14, 18 and 19 (Table 11) in that the phenomena they describe impacts the effectiveness of FMEA. Similarly, the response to item 22 (Table 12), demonstrating that politics and intercompany conflict tends to dominate project decisions is in competes with the stage-and-gate systems goal of creating cross departmental cooperation. While directors did indicate there had been some review of the stage-and-gate process within the interviews, the depth of this change was not well answered. The survey results show that the organisation has statistically relevant scores on the Tradition Dimension. Specifically items 73, 74 and 75 (Table 15). The responses to these items demonstrate an inability to adopt new ideas, with a preference to adhering to existing and long standing methods. This seems consistent with the Stage-and-gate process not being reviewed following so many product recalls.

<table>
<thead>
<tr>
<th>Quadrant/Dimension/Survey item (score out of 5)</th>
<th>Tenure &lt;ave</th>
<th>Tenure &gt;ave</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 61 (Training Dimension) People receive enough training when it comes to using new equipment</td>
<td>2.4</td>
<td>3.1</td>
<td>t(20)=-2.25*</td>
</tr>
<tr>
<td>Item 63 (Training Dimension) People are strongly encouraged to develop their skills</td>
<td>3.0</td>
<td>1.9</td>
<td>t(20)=2.29*</td>
</tr>
<tr>
<td>Item 73 (Tradition Dimension) Senior management like to keep to established, traditional ways of doing things</td>
<td>4.5</td>
<td>3.5</td>
<td>t(20)=2.86**</td>
</tr>
<tr>
<td>Item 74 (Tradition Dimension) The way this organisation does things has never changed very much</td>
<td>4.4</td>
<td>3.4</td>
<td>t(20)=2.54*</td>
</tr>
<tr>
<td>Item 75 (Tradition Dimension) Management are not interested in trying out new ideas</td>
<td>3.9</td>
<td>3.0</td>
<td>t(20)=2.19*</td>
</tr>
</tbody>
</table>
Item 77 (Autonomy Dimension) New ideas are readily accepted here

<table>
<thead>
<tr>
<th></th>
<th>1.9</th>
<th>2.7</th>
<th>$t(20)=-2.59^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tradition Dimension</td>
<td>4.3</td>
<td>3.5</td>
<td>$t(20)=2.79^*$</td>
</tr>
<tr>
<td>Pressure to Perform Dimension</td>
<td>4.0</td>
<td>3.5</td>
<td>$t(20)=2.5^*$</td>
</tr>
</tbody>
</table>

Notes: * $p < 0.05$ level, ** $p < 0.01$, *** $p < 0.001$

Table 15: Statistically relevant aggregated scores per dimension, comparing manager, non-manager, less than average tenure and greater than average tenure scores.

Both the interview and survey data would suggest that directors have not significantly modified design processes or governance structures despite a number of product recalls as discussed in responding to the second research question. Similarly, data suggests directors have not taken effective measures to ensure the existing structures are effective. This may be influenced by a lack of knowledge of the company's existing design processes, or reliability based alternatives, as shown in response to research question one.

In response to the research question, the following summary table emerges, summarising the manner in which directors have influenced design and risk management structures, and then ensured their effectiveness:

<table>
<thead>
<tr>
<th>Director</th>
<th>Accept a part in influencing design process?</th>
<th>Accept a part in influencing risk management structures?</th>
<th>Review of Design Processes or risk management structures?</th>
<th>Ensure effectiveness of design process or risk management structures?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director one</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Some - Stage-and-gate</td>
</tr>
<tr>
<td>Director two</td>
<td>No</td>
<td>Yes</td>
<td>Some</td>
<td>Financial only</td>
</tr>
<tr>
<td>Director three</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Financial only</td>
</tr>
<tr>
<td>Director four</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Director five</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Table 16: Summarising the manner in which Directors have influenced design and risk management structures, and then ensured their effectiveness:

Q4) How have these directors considered and cultivated an organisational climate and social factors that contribute to the attainment of the directors expectations of governance structures and product design processes discussed in Q3?

Interview Data

Interview results suggests that some employees and managers have concerns regarding their political, social and employment positions should they speak out, identifying reliability risks. Indeed, a small number of employees identified withholding information or distorting risk assessments. One employee stated that he was instructed to state that an FMEA review had been completed, knowing it had not. This is despite directors attempts to provide whistle blowing mechanisms such as an anonymous reporting channels. This mechanism was identified by some employees and managers, but similarly many did not identify knowledge of this. Surveys similarly showed only moderate knowledge of the existence of this anonymous reporting scheme.

In response to on-going reliability and recall issues, the Directors supported and approved the appointment of a system level test team. This team was to improve the testing effort and thus it was assumed, the reliability of the product. As discussed in the [PRODUCT 2] and [PRODUCT 1] recall examples, the tolerance method renders the process of testing to improve product reliability ineffective.

During interview, the director's generally felt the stage-and-gate process presented some rigour to their governance by promoting interdepartmental cooperation and participation. As discussed by one director:

"So there are specific things that have to be completed timely during the phases before getting to the gate. Then the teams, the quality, operations and design & development, product management get together on a kind of audit through the deliverables when they are identified as complete, so they are marked so, and at the end there will be or not a recommendation to the CT (Central Team), which I mentioned before, to declare approved or to not approve. So that happens for all the gates, from the gate two to the
gate seven, basically all are relevant but the development starts after passing gate two and after finishing gate five it's then handed over to manufacturing. So those are the two most important handovers and its deliverables are controlled".

As discussed by another director:

"**Respondent:** ...within D&D [the design and development team], which is the gate model/rate approval model that they use. We all work within a defined structure.

**Interviewer:** With controls within that structure?

**Respondent:** Yes."

This was despite the director accepting that the processes underpinning the stage-and-gate reviews did not have sufficient resource to function effectively, thus undermining the governance controls that he claims to exist. Specifically, the use of inadequate tolerance design methods, and the resulting MTBF calculations that erroneously report high reliability prediction. Another director questioned if MTBF calculations were just a paper exercise. As stated by one director regarding reliability and design process "...they as well understand that to achieve that we may need a level of resources which we cannot always afford." Similarly, reliability and recall issues continue, under the governance of the stage-and-gate system, with only one or two (there was no conclusive statement in the data), minor reviews in that period. As mentioned above, one director knows that projects bypass the governance structure that is the stage-and-gate system. Aside from undermining the governance control and reporting it is attempting to enforce, it's arbitrary application is likely to have a negative effect on the organisational climate as it relates to governance structures.

Similarly, product development processes such as agile and concurrent engineering were mentioned by directors and managers but were not actually present beyond software development. In reality, the product development process being used was close to the waterfall method. This was shown by design project team members stating that they are not involved in the design process, and wait for the finished product to be presented to them to manufacture or sell. As discussed in the literature review, agile and concurrent engineering processes have been created with the expressed intent of
reducing the dysfunctional aspects of the social factors outlined in this study. Further implementation of these processes would demonstrate the cultivation of an organisational climate that positively impacts governance structures.

**Survey Data**

In alignment with the social factors uncovered during interview, the survey identified numerous dimensions that combine to suggest that directors have so far not been able to constructively cultivate a climate that minimises negative social factors. Of note, is the low score for performance feedback and low efficiency dimension scores (Table 15), evidence of conflict, dominant individuals and politics influencing decisions and review. (Items 19 and 22, Tables 11 and 12). These combined results, and in support of interview data, suggests the organisation would benefit from introducing a comprehensive performance review process. A functioning performance feedback process is likely to increase role clarity and procedural transparency, and thus improve governance. However, the directors goal of increasing organisational cooperation through the use of the stage-and-gate system has clearly not been successful as evidenced by the results of Item 22 (Table 8).

In reviewing the statistically relevant results comparing the responses between relatively new respondents and long serving respondents, it was clear the recent recruits were struggling with the strong tradition focus of the organisation (Table 19) and their perception that the management team were not willing to consider new ideas. (Table 15, Item 73,74,75 and 77). Similarly, the management and non-management comparison of statically relevant results identify the senior management team of not embracing change (Table 20, Q73). This is supported by the low scores for the reflexivity and innovation and flexibility dimensions (Table 19). Identifying change projects and supporting new recruits to combat resistance to change is likely to improve governance structures.

As discussed above, managements active support for existing long serving staff with extensive industry and company knowledge and experience would seem a rational attempt assertively nurture an open and cooperative organisational climate to improve the design processes. As one director stated in respect to the stage-and-gate process that
governs the design and development process: "it doesn’t tell you exactly how to do things. But it puts appropriate gate reviews in where knowledgeable … or stakeholders, or knowledge base holders will review to say, 'Have we got to a situation where we can move onto the next stage?'" However, as data within this case study would suggest, the result would appear to be the opposite. As mentioned by one director "I do not think we do enough to encourage people to question.". Given this, the use of experts may have potentially increased the occurrence of social factors such as dominance by individuals, i.e. experts (Item 19 Table 12), interdepartmental conflict (Item 22 Table 12), keeping mum and whistle blowing. As such, this would reduce the effectiveness of the risk assessment process by underpinning and strengthening the opinion based content of the FMEA process.

It is clear then that directors have made attempts to constructively nurture a climate that supports governance structures and product design processes. However, these attempts have not achieved this goal as both interview and survey data demonstrate. Indeed it could be argued that these attempts may have had an inverse effect. Consistent with this, is the statistically relevant supervisor support dimension (Table 19). Non-Managers rank the support they receive highly, however, managers have recorded a low score. While there were no statistically relevant scores indicating a principle focus of the organisation, or difference of opinion between managers, non-managers, long serving or short serving respondents, (Tables 17 and 18), there were significant individual dimensions as discussed above. This did tend to support a slightly high average internal process score and a low average open systems score. Indeed these descriptive statistics are consistent with the above discussion and interviews, in that they describe a company struggling to change. Specifically, a high tradition dimension (Internal process) and low innovation and flexibility and reflexivity scores (Open Systems).

A high internal process score is consistent with a company focused on Tradition, while a low open systems score is consistent with the company. Similarly, low average efficiency scores (Table 19) coupled with statistically relevant and low outward focus (Table 120) scored by management and high pressure to perform scores (Table 15) reported by new recruits also suggests a management team struggling to deliver on
expectations by customers as would be expected by a company challenged by on-going product recalls in a market demanding high reliability product.

<table>
<thead>
<tr>
<th>Quadrant (Score out of five)</th>
<th>Total</th>
<th>Manager</th>
<th>Non-manager</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Relations</td>
<td>2.8</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Internal Process</td>
<td>3.3</td>
<td>3.4</td>
<td>3.2</td>
</tr>
<tr>
<td>Open Systems</td>
<td>2.5</td>
<td>2.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Rational Goal</td>
<td>2.7</td>
<td>2.7</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Table 17: Aggregated scores per Dimension, comparing manager, non-manager, less than average tenure and greater than average tenure scores.

<table>
<thead>
<tr>
<th>Quadrant (Score out of five)</th>
<th>Total</th>
<th>Tenure&lt;ave</th>
<th>Tenure&gt;ave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Relations</td>
<td>2.8</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Internal Process</td>
<td>3.3</td>
<td>3.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Open Systems</td>
<td>2.5</td>
<td>2.3</td>
<td>2.6</td>
</tr>
<tr>
<td>Rational Goal</td>
<td>2.7</td>
<td>2.7</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Table 18: Aggregated scores per Dimension, comparing manager, non-manager, less than average tenure and greater than average tenure scores.

<table>
<thead>
<tr>
<th>Dimension (out of five)</th>
<th>Total</th>
<th>Manager</th>
<th>Non-Manager</th>
<th>Tenure&lt;average</th>
<th>Tenure&gt;average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort</td>
<td>3.3</td>
<td>3.3</td>
<td>3.4</td>
<td>3.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Autonomy</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Integration</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Involvement</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Supervisor Support</td>
<td>3.3</td>
<td>2.8</td>
<td>3.6</td>
<td>3.3</td>
<td>3.4</td>
</tr>
<tr>
<td>Training</td>
<td>2.5</td>
<td>2.6</td>
<td>2.5</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Welfare</td>
<td>2.7</td>
<td>2.9</td>
<td>2.7</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Formalisation</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
<td>2.6</td>
<td>3.1</td>
</tr>
<tr>
<td>Tradition</td>
<td>3.8</td>
<td>4.0</td>
<td>3.7</td>
<td>4.3</td>
<td>3.5</td>
</tr>
<tr>
<td>Innovation and Flexibility</td>
<td>2.3</td>
<td>2.2</td>
<td>2.3</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>Outward Focus</td>
<td>2.9</td>
<td>2.4</td>
<td>3.2</td>
<td>2.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Reflexivity</td>
<td>2.3</td>
<td>2.2</td>
<td>2.4</td>
<td>2.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Table 19: Aggregated scores per Dimension, comparing manager, non-manager, less than average tenure and greater than average tenure scores.

<table>
<thead>
<tr>
<th>Quadrant/Dimension/Survey item (score out of five)</th>
<th>Manager</th>
<th>Non-Manager</th>
<th>T-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 56 (Supervisor Support Dimension) Supervisors show that they have confidence in those they manage</td>
<td>2.5</td>
<td>3.8</td>
<td>$t(21)=-3.36^*$</td>
</tr>
<tr>
<td>Item 73 (Traditional Dimension) Senior management like to keep to established, traditional ways of doing things</td>
<td>4.4</td>
<td>3.7</td>
<td>$t(21)=2.17^*$</td>
</tr>
<tr>
<td>Item 83 (Outward Focus Dimension): This organization is quite inward looking; it does not concern itself with what is happening in the market place</td>
<td>2.5</td>
<td>3.5</td>
<td>$t(21)=-2.13^*$</td>
</tr>
<tr>
<td>Item 85 (Outward Focus Dimension): Customer needs are not considered top priority here</td>
<td>2.3</td>
<td>3.2</td>
<td>$t(21)=-2.07^*$</td>
</tr>
<tr>
<td>Supervisor support Dimension</td>
<td>2.8</td>
<td>3.6</td>
<td>$t(21)=-2.53^*$</td>
</tr>
<tr>
<td>Outward Focus Quadrant</td>
<td>2.4</td>
<td>3.2</td>
<td>$t(21)=-2.55^*$</td>
</tr>
</tbody>
</table>

Notes: * $p < 0.05$ level, ** $p < 0.01$, *** $p < 0.001$

Table 20: Aggregated scores per Dimension, comparing manager, non-manager, less than average tenure and greater than average tenure scores.

In response to the research question, the following summary table emerges, summarising the manner in which Directors have cultivated an organisational climate and social factors that constructively impact on governance structures.
<table>
<thead>
<tr>
<th>Director</th>
<th>Considered importance of climate and/or social factors?</th>
<th>How shown?</th>
<th>Cultivated productive climate and/or social factors?</th>
<th>How Shown?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director one</td>
<td>Yes</td>
<td>Suggested risk assessment is dependent on people. Identified there is sometimes reluctance to bring forward risks.</td>
<td>Yes</td>
<td>Attempted to control social factors and climate by introduction of Stage-and-gate system.</td>
</tr>
<tr>
<td>Director two</td>
<td>Yes</td>
<td>Describes managers as diligent, but used to fighting. Discusses the constructive use of back door projects to bypass governance.</td>
<td>No</td>
<td>None Shown</td>
</tr>
<tr>
<td>Director three</td>
<td>Yes</td>
<td>Identified the dangers of inhibiting open speech &quot;I do not think we do enough to encourage people to question.&quot;</td>
<td>No</td>
<td>No formal escalation path for risk. Leaves it up to individuals to speak up.</td>
</tr>
<tr>
<td>Director four</td>
<td>No</td>
<td>Not Shown</td>
<td>No</td>
<td>Not Shown</td>
</tr>
<tr>
<td>Director five</td>
<td>Yes</td>
<td>Believes there is only a small team, and therefore, people would be free to speak up and communication would be effective</td>
<td>No</td>
<td>Not Shown</td>
</tr>
</tbody>
</table>

**Table 21:** Summarising the manner in which Directors have cultivated an organisational climate and social factors that constructively impact on governance structures.
5.0 Chapter Five: Discussion and Conclusion:

This chapter reviews the study's results, analysis and answers provided to the research questions and then attempts to understand and discuss further contributions to knowledge and impact on practice.

5.1 Contribution to Knowledge

This study has contributed to knowledge by increasing the body of literature surrounding product development processes within SME OEM's in the UK. More importantly it proposes one reason why companies are still experiencing product recalls even though there is a plethora of well proven reliability based design methods. Further, it contributes to knowledge by demonstrating a link to black swan theory, opening up the potential for further research in tools to address unknown-unknown risks. Lastly, it contributes by demonstrating a link between organisational climate, design methods, governance structures and product recall risks.

These contributions are illustrated in Figure 10. Building on the outline of the PDP shown in Figure 1 and with the addition of events and theories, Figure 10 demonstrates the manner in which specific organisational climate characteristics, as demonstrated in this study, helps to explain the occurrence of these events and the application of existing theory and theory that has emerged from this study. With reference to the boxes on the right side of figure 10, events that occur and the relevant theories are grouped together and linked to the relevant stage of the PDP. Specifically, this demonstrates where the study found these events and theories to have the greatest impact on the product development process. More importantly, Figure 10 demonstrates the cyclic manner in which events and theories were found to group together in an eclectic confluence to support the organisational climate to create unknown unknown risk (Boxes A to G).

Acting in a cyclic manner and starting with the creation of risks within Box A, through inadequate design process and poor tolerance methods, the application of theories above act to transition risks within the design process from known to unknown-unknown as shown on the left side of figure 10. Through the events of keeping mum, and knowledge asymmetry as explained by theories such as group think and bounded rationality
coupled with the use of subjective FMEA, the project teams intentionally or unintentionally hide risks from senior management (Box B). As the risks are now not reported to senior management they can not be reported to directors. The previous use of subjective FMEA and the managers’ use of inappropriate risk assessment methods further remove managers knowledge of risks as described by bounded rationality theory. (Box C). Similarly, where agency theory has encouraged managers to use knowledge asymmetry to hide known risks from the participant company’s directors, these risks further transition to unknown-unknown risks. (Box D).

Now unaware of all the risks, directors are unable to make informed decisions about risks within new product development projects nor the improvement of governance structures or product development processes. The result is the tuxedo effect as directors do not challenge the information they are given, through wilful denial of the management team and as the Dunning-Kruger effect begins to have a stronger influence over time (Box E). As such, risks that exists in projects, processes and structures are not rectified (Box F), and this is perceived and understood by project teams as lack of desire for management and/or directors to change the status quo. (Box G). This then acts as positive re-enforcement of the existing climate, creating more of the events as described above and further ensuring known risks are hidden from management. (Box B). In summary then, this cycle dis-empowered the participating companies directors from addressing the causes of these risks and they can no longer be perceived by the directors. In doing so, events and applicable theories act together to influence the organisational climate. This organisational climate is then reflected across the company, which provides the environment for further events, which increasingly influences the organisational climate. This reduces the directors ability to act and so the cycle continues.

The applicability of Black Swan theory is demonstrated, in that participants within the product development project are cognoscente of the risks as at their level within the company the risks are still known. Risks that were previously known or known-unknown have transition through the review and reporting process into unknown-unknown process, rather than having originated from the design process itself. These unknown-unknown risks cannot be perceived by directors. In this way, when there is a
product recall the three criteria for a black swan event may have been met, and most importantly the second criteria below

1. That the event has a significant impact. Clearly product recall meets this criteria.
2. That it in retrospect is should have been obvious. The risks were known to the participants within lower levels of the organisation, and to them 'obvious'.
3. The probability of occurrence is so unlikely as to not be considered. Once risks have transitioned to unknown-unknown, then this is clearly the situation.
Black Swan - “How did we get a recall? We do not hear about issues within the PDP?”

Events Demonstrated in the Study
- Wilful Denial Theory Demonstrated in study
  - Agency Theory
  - Tuxedo Theory
  - Dunning Krugger effect

Theory Demonstrated in study
- Risk Assessment Methods
- Reluctance to whistle blowing
- Knowledge Asymmetry

Events Demonstrated in study
- Subjective FMEA
- Bounded Rationality
- Keeping Mum

Events Demonstrated in study
- Group think

Organisational Climate Demonstrated in study: (RQ4. 3e.)
- Low scores in: Outward Focus and Autonomy
- High Scores in Tradition and Pressure to Perform
Figure 10: The cyclic manner in which specific organisational climate characteristics, support social phenomena to transition known risk to unknown-unknown risk.

5.1.1 Contributing To Knowledge By Providing Insight Into Why Do Recalls Still Occur?

Despite decades of product development and design methods specifically created to increase product reliability, product recalls continue to occur. Similarly, increased focus on directors requirement to ensure diligence when managing operational risk. In this environment, it would be expected that recalls would decline. In response to the enquiry into the cause of the GM ignitions switch recall, the study by Eifler et al. (2014) asks why product recalls still occur. It is identified within their study that inadequate design methods created the latent defects that cause the recall, and similarly that there were some social factors also involved, such as pressure on employees to keep silent. Without sufficiently exploring the intersection of these two phenomena, the researchers initial question remained unanswered. It is this researcher’s opinion that the answer to their question was potentially within their own work. By focusing on design methods in isolation to social factors, and failing to explore their collective impact on risk governance, Eifler et al. (2014) failed to answer their own question. Certainly, the same could be said of the study by Pritchard and Kotow (2010) into the Deep Water Horizon disaster as the failure of design practice and existence of social factors were briefly acknowledged and discussed, but not fully explored. With the focus being heavily skewed towards technical design failures, how social factors interacted with the technical failures and their collective impact on governance structures went largely unanswered. Certainly in both examples, organisational climate was not discussed. As such, this study contributes to knowledge by proposing that one reason recalls continue is that there does not appear to be an integrated approach within literature, and by extension practice, that addresses social factors, as demonstrated by climate, in conjunction with design processes and how this impacts risk governance through the creation of unknown-unknown risk. Consequently, there does not appear to be active debate within literature nor tools in practice that take a holistic approach to the issue. This study further contributes to knowledge by addressing this gap in literature and starts that debate.
5.1.2 Design Methods In SME OEMs In The UK

As previously stated in the Literature Review, there is not a wealth of literature on the product development practices of SME OEM's in the UK. This study contributes to knowledge by confirming literature that OEM SME's in the UK have not taken up Six-Sigma with vigour (Antony et al. 2008; Kondic 2009). As discussed in literature review, Six-Sigma being a commonly used example of a design tool created to improve product reliability and thus reduce probability of recall. Indeed, few directors, managers and employees within the case study knew of the methodology, and none identified how it would have been an asset in their desire to improve product reliability. Similarly the other common design tools such as Taguchi, or Weibull Analysis created to improve product reliability by design. However, this case study does present the way in which one UK SME OEM does function, their organisational climate and governance structures and the challenges they face. Potentially a precautionary tale, this case study contributes to the body of knowledge relating to UK based SME OEM's.

5.1.3 An extension Of Black Swan Theory To Product Development

As discussed in the literature review, three things are required for an event to be described as a Black Swan, (Taleb 2005a). Specifically, that the event has a significant impact, that the probability of occurrence is considered so low as to be not worth considering and that the event should have been apparent in retrospect. This study expands on Nafday's (2009) application of Black Swan theory to engineering, product development and product recall, by exploring the above behavioural phenomena in depth at a micro level and attempting to understand them using organisational climate. This understanding is then applied to governance structures and processes to explore how product design decisions during product development create the potential to become Black Swan Events.

As an expansion of the literature by Bogle (2008), Efatmaneshnik and Reidsema (2007), MacLean (2010), Nafday (2009), Rizzi (2008) and (Taleb 2005a), this study contained a
number of areas whereby the results supported their work, but within a high tech OEM context:

1. There was, and still appears to be, over confidence by the case study company's directors that managers are diligent in their contribution to governance structures and reporting, despite evidence to the contrary. Although past recalls were commercially damaging, they did not bankrupt the company. Survival in the past creating complacency when they consider the future as equally survivable. In this way, they reflect the concept of the thanksgiving turkey that assumes everyday will be the same as the last until the day it will be dispatched for the table. (Taleb & Blyth 2011)

2. As presented by (Rizzi 2008) and Taleb (2008) experts within the financial industry use narrative in the form of graphs and statistics to demonstrate a level of rigour that is not actually in place. Externalising failures and internalising success creates a sense of overconfidence in predictive skills. Similarly within this study, externalising failures and internalising successes as well as narrative, was also evident and employed to demonstrate diligence to managers and directors. However, the results section demonstrated that the rigour behind tolerance calculations, audits and design reviews did not match the narrative.

3. As demonstrated in this study, engineers use intuition and experience when to use nominal dimensions, employ statistical methods and when to include tolerance stack-up during design. The use of nominal dimensions and simple statistical tools was identified as a contributing cause of the GM recall (Eifler et al. 2014). While experience and intuition is a desired trait in any discipline, it should not be used as a replacement for rigorous scientific methods as appears to have occurred in the respondent organisation. As discussed in the literature review, the dependence on these statistical methods can have a negative impact on product reliability as this approach assumes the product being supplied to the OEM will present a normal distribution (Evans 1974). However, this is not always the situation. Similarly, Taleb (2007) and Bogle (2008) discusses how this same assumption of normal distribution contributes to fragility within the financial systems and the creation of potential for Black Swan events.
5.1.4 Combining Black-Swan's, System Level Engineering And Designing Quality Into Product To Create Recall Resistant Design Processes.

Indeed, even the pattern of the phenomena underpinning Black Swan theory as described by Taleb's works corresponds to that of the pattern of the phenomena within this study. Specifically, that technical aspects within the financial industries have practices that are not as robust as they seem. Coupled with social factors the system becomes fragile due to 'latent defects' and inherent unknown-unknown risks that governance structures are ill-equipped to discover. This case study's Black Swan, the numerous product recalls described, could be considered synonymous with the financial industries collapse, which itself could be considered the failure of product albeit within a service industry.

Much of Taleb's literature discusses the need to consider and design systems that are both tolerant of the outcomes of Black Swan events, while also discouraging their creation through removing the illusions of control over sub components within the system. He calls this approach system robustness (Taleb 2009). Having demonstrated through this case study, that Black Swan risks and the phenomena that create them are evident within the product development environment of the organisation researched, Taleb's work can be shown to mirror that of Taguchi and Clausing (1990), whose work also relates to the creation of reliable product through the creation of robust product design at the system level. Taleb (2009), Taguchi and Clausing (1990) suggest that rigour not created by optimising components within the system, but by optimising the system itself by reducing the impact of components on the system. This corresponds to work by Kenett and Tapiero (2009) linking quality management, designing quality into product and the creation of rigour. Similarly, the study completed by Efatmaneshnik and Reidsema (2007) which also focuses on system level design within R&D processes to produce robust systems as discussed in the literature review. Consequently, this study has further contributed to knowledge and Black Swan theory by demonstrating its compatibility with traditional researchers in the field of product design and reliability. This compatibility will facilitate further study into the use of Black Swan theory within engineering. As explored below, lessons learnt from the financial industry can be cross referenced to engineering. It may also facilitate the application of tools used to manage
Black Swan risks within the financial industry within engineering practice and vice versa. The creation of a diagnostic tool for use within product development as proposed below, maybe adapted to the financial industry as part of further study.

5.1.5 Governance, Risks And The Intersection Of Design Methods And Organisational Climate

There is a plethora of literature that discusses organisational climate within numerous industries such as Wallace et al. (1999), Neal, Griffin and Hart (2000) and Flin et al. (2000). Similarly, there are many studies into design methods and their relation to product reliability such as Du, Sudjianto and Huang (2005), Wang, Huang and Du (2010) and Stocki (2005). However, there is a dearth of literature that reviews the interaction of these theories, with their impact specifically on risk governance. More so within the setting of a High Technology organisation. Even further, when exploring the design practices of OEM SME’s in the UK. Some literature does discuss product development methods in conjunction with social factors displayed by engineers (Ford & Sterman 2003; Lloyd & Busby 2003; Smith et al. 2001). However, these authors discuss individual behaviours or social factors such as the manner in which engineers will keep mum, lie to avoid accountability and use morals based arguments and judgements to influence project decisions. For example, (Lloyd & Busby 2003) discuss how engineering design can start to resemble social negotiation rather than carefully considered options determined by knowable probabilities. This study examines design methods, how numerous social factors culminate within organisational climate, how this creates unknown-unknown risk and how these restrict risk governance. As such, this unique end to end view is in itself a contribution to knowledge with the resulting whirlpool model addressing the paucity in the literature as indicated in section 2.6 in the literature review chapter.

Further, this study is an important contribution as it has demonstrated that it is not only the existence of inadequate design methods, or social factors alone that reduce the effectiveness of risk governance structures as they relate to product recalls, but the co-existence of both. For instance, and as shown in this study, in an organisational climate that supports whistle blowing and reduces multi-departmental conflict, design issues are
more likely to be reported during design review. As such, managers and/or directors would have an improved view of the risks, and the design processes that created them. Similarly, reliability based design methods, with the transparency and interdepartmental cooperation they require to be effective may influence organisational climate, if actively supported and enforced by directors.

As mentioned above, the study by Johnson and McIntyre (1998) demonstrated that job satisfaction can be measured by organisational climate models. Specifically, they found positive correlations between Communication, Goals, Creativity, Innovation and Decision Making measures and job satisfaction. Similarly, the findings from this study propose that within an organisation going through a period of market change certain dimensions can describe a climate that encourages the existence of social factors. These social factors diminish the effectiveness of governance. The organisational climate that encouraged these social factors is evidenced by the low scores on Outward Focus and Autonomy dimensions coupled with high scores on the Tradition and Pressure to Perform. The detrimental social factors encouraged were also found to be fear of whistle blowing, keeping mum, agency issues, information asymmetry and the tuxedo syndrome.

Effectively, the organisational climate was limiting employees ability to look to customers' needs during a time of market change, encouraging them to focus on how the company has historically done business, thus consequently reducing people ability to initiate change and not holding employees accountable for performance. These barriers to effective governance, promoted by the organisational climate, all but guarantees directors could not perceive the risks and exacerbates the effects of bounded rationality. The risks produced by the practice of subjective design reviews and poor product design methods are further encouraged employees to keep mum, and the fear of blowing the whistle. This study does not seek to determine cause and effect, but proposes that for the purpose of understanding the existence of unknown-unknown reliability and recall risk and its impact on governance structures within high technology companies, that the two phenomena (inadequate design methods and social factors) are linked and should not be separated. As demonstrated above this point is not typical in most literature and as such this study presents an important contribution.
5.2 Implications For Practice

No organisation is free from risk. However, in practice, directors have an obligation to manage operational risk and its impact on their company through the creation of suitable governance reporting and control processes. Product recalls, caused by product field reliability issues and as an unwanted by-product of the product development process, clearly threatens companies survival when they occur. This presents legal risk to directors.

5.2.1 Lessons To Be Learnt From Recent Examples Of Recalls

Despite significant progress in the area of reliability based design methods, and a significant body of literature supporting this as outlined in the literature review, recalls continue to occur. This is evidenced by two recent, and significant engineering disasters. Namely the Deep Water Horizon incident and the General Motors ignition switch recall.

**Deep Water Horizon drilling rig blow-out**: On April 20, 2010 in the Gulf of Mexico, there was an incident on board the Deep Water Horizon drilling rig. The consequence of this incident was 11 people killed and significant environmental damage. (Griggs 2011). With liabilities yet to be finalised, but likely to be both substantial and punitive, business practices and effective governance structures have come under scrutiny as has the question of wilful misconduct and negligence (Martin 2010). This has clearly exposed the Directors of BP, the owners of the drilling rig, to risk.

**General Motors Ignition Switch recall**: As discussed by Eifler et al. (2014), the General Motors recall of 2.6 million cars following the death of 13 people and fine of USD $35million. Stretching over several years, directors have come under criticism, and this has again placed them at risk.
In both examples, social factors were identified as a cause of these recalls. As stated by Pritchard and Kotow (2010, p. 1), regarding the Deep Water Horizon disaster: "At first blush, this issue may be viewed as a purely technical matter but it is primarily a human one, grounded in the forces that inspire to create false choices in risk and reward." They describe how risk denial, group think and narrative is used to normalise (and thus underestimate) high risk in a risk averse environment, creating the illusion of high payoff (reward) for low risk. Further, Pritchard and Kotow (2010, p. 32) state, "The current design model must be challenged. Sound and unbiased engineering design is the fundamental precursor to safety, sustained success and full life cycle reliability." Similarly Eifler et al. (2014, p. 51) identify that the recall was not only caused by design process but also by "...misjudgements" and "...a culture of silence rather than confrontation and remedy" contributed to the recall.

This very recent literature surrounding these events supports this study's findings that it is not just poor design process alone that may cause product recall or engineering failure. However, it is addition of social factors that surround the product development processes and governance structures that shift engineering risk from manageable and foreseeable situations to unforeseeable black swans events. To be specific, manageable and foreseeable to company directors. In practice, this effect magnifies the damage of product recalls to companies and increases directors liabilities, by creating the illusion of diligence within risk management and governance structures. For example, and as found within this study, managers can distort official reports to avoid being challenged or held to account. Consistent with agency theory, (Eisenhardt 1989a) this shifts the liabilities from managers to directors. This study suggests that the illusion of diligence may be reduced by directors by understanding their organisational climate, and thereby gaining greater understanding the social factors surrounding risks within their product development process and governance structures.

This study and the recalls above, demonstrate that practice has not progressed far since the challenger space shuttle disaster. Specifically that recalls do occur, and that they continue to occur. In their study on the General Motors ignition switch, Eifler et al. (2014) pose the question that recalls seem to continue even though robust and rigorous design methods are well understood, and thought to be employed. Indeed management practice clearly still perceives engineering as a mechanistic process whereby money is
injected into R & D and product will be produced with an idealised identification and evaluation of risk. Again, directors would be better placed by improving the rigour of their risk governance processes by understanding the companies organisational climate and how it interacts with their product development processes, than by understanding them in isolation. This would encourage them to adopt reliability based design methodologies to reduce risks.

5.2.2 Improving Governance And Corporate Social Responsibility

While some studies suggest well implemented Corporate Social Responsibility (CSR) programmes can shield companies, and directors, from the impact of product recalls, (Minor & Morgan 2011), this claim must have its limits. No CSR programme could have shielded GM from the impact of the deaths caused by the ignition switch design fault and consequential product recall. Certainly following the Deepwater Horizon incident, BP’s CSR programme has come under challenge as questionable (Mobus 2011). By proposing a model by which directors can understand the potential for design based product recalls and the risks they create (Section 5.2.9), this study is improving governance transparency and empowering directors to reduce product recall risks. Further, implementation of this model by directors may contribute to CSR by limiting the potential for life threatening or environmentally damaging design based recalls and disasters.

5.2.3 Addressing The Black Swan Theory

It is common practice for companies to seek to understand unknown-unknown risk and/or black swan events. The value to high technology companies in gaining insight into these phenomena in an attempt to reduce black swan event occurrence or impact cannot be understated. (Flyvbjerg & Budzier 2011). Taleb, Goldstein and Spitznagel (2009) provide generic advice on the management of unknown-unknown risk or Black Swan event, in the form of six mistakes to be avoided when managing risk. As this case study links organisation climate, design process and governance structures to unknown-unknown risks, or Black Swans, it is rational to extrapolate this advice to the environment being studied as this will provide further contribution to practice.
Mirroring the approach by MacLean (2010), whereby he took the six mistakes made by executives discussed by Taleb et al. (2009) and extrapolated these to his study:

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<th>Six Mistakes</th>
<th>Recommendation to practice</th>
<th>Phenomena/concepts observed within case study</th>
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| Do not try to predict the actual Black Swan events; Instead concentrate on managing its impact. | Recalls caused by latent design defects are difficult to contain as they reduce traceability. Systematically manage the impact of recalls by creating a robust design process and organisation climate. Then, only recalls created by defects arising from manufacturing mistakes and QC errors are likely to occur. The impact of these is easier to contain. | • Tolerance by intuition and experience, created unforeseeable latent design defects. These defects materialised long after product was released into the market.  
• Qualitative tools for design risk analysis (FMEA) were limited by social factors.  
• The above attempts to control design and risk were ineffective. Recalls worsened as design based latent defects could not be captured through the QC process.  
• Improved design process would have restricted the recall to manufacturing based defects only. These are generally traceable and therefore the recall more containable. |
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<th>Do not use the past to predict the future.</th>
<th>Through test methods, and initial periods of product reliability, engineers and managers present to directors that the product reliability is acceptable. However, latent defects can occur at any time in the product's life, therefore periods of reliability do not predict future exposure to recall risk.</th>
<th>Bounded rationality and group think created the illusion that current methods are suitable, and that the recalls were unavoidable. At each stage directors were assured that now this fault has been found, there should not be any more, and that the design team have always found a way to solve problems in the past.</th>
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<td>Failure to listen to advice about what we shouldn't do.</td>
<td>Create an open and transparent organisation climate that encourages whistle-blowing and cultivates health and productive conflict. Despite decades of improvements around product development methods advising best practice, many companies are still doing what they shouldn't do. (i.e. using ineffective design tools)</td>
<td>The respondent companies’ climate demonstrated support for traditional values. Data suggested evidence of whistle blowing and keeping mum. These phenomena reduced directors’ ability to realise the existence of recall risk inherent in their traditional design methods, therefore limiting their need to search for improved methods.</td>
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<td>Do not assume risk can be measured by standard deviation.</td>
<td>Some design engineers assume that supplied product tolerances are likely to follow a normal distribution, and then use this assumption during the design process. They then extrapolate this to a reliability/risk figure</td>
<td>Statistical tolerance tools that assume a standard deviation were should to be used. Thus underpinning the likelihood of latent design based defects.</td>
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<td>What's mathematically equivalent isn't psychologically so.</td>
<td>Engineers and managers can present arguments to directors that product will be 99% reliable. However, when the 1% occurs, it has a bigger impact than is typically understood by the director accepting the risk at product launch.</td>
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<td>Incorrect belief that redundancy does not equal efficiency or value.</td>
<td>Some engineers argue that absolute tolerance methods take too long, and is over-kill thus adding little value. However, failure to do so builds-in unknown-unknown risk. As the use of absolute ‘tolerancing’ encourages the use of reductive methods to simplify design by taking a system approach, absolute tolerance methods could be considered as removing fragility.</td>
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<td>In the recalls within this case study were design related. For these recalls, the 1% that failed precipitated a 100% recall as it was impossible to know exactly which unit had the fault and which did not. Thus creating an unknowable consequence far beyond initial expectation of likelihood.</td>
<td>Within this case study, there was little evidence of absolute tolerance methods influenced by a neither system approach nor reductive methodology. Therefore small changes to supplied product created recalls i.e. fragility.</td>
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Table 22: The 6 risk management mistakes proposed by Taleb et al. (2009), cross referenced to data demonstrated in study.
5.2.4 The implications of this study on auditing practice

Reducing risk is an obvious benefit to company directors in their attempt to preserve their company and/or discharge their inherent legal obligations. This was a central topic of this dissertation. To ensure they are managing risk within organisations, company directors and managers undertake a number of audit activities to understand and assess organisational risk. (Sarens & De Beelde 2006). This includes operational risk (Romney et al. 2000), and undoubtedly Black Swan based risk. As discussed in the study, it is usual for companies that provide auditing services to employ specialists within the audited companies’ field to understand the subtleties of their business. This is believed to add value to the auditing process (Dunn & Mayhew 2004). As demonstrated by Beattie and Fearnley (1995) the ability to understand and assess culture was not identified as a reason companies employ an auditing company, implying that procedural considerations are separated from cultural considerations during audit. In support of this, there are auditors that evaluate companies culture for the purposes above implying that this service is a specialise function of product (Carleton 1997). However, these are generic cultural evaluations and tend to lack the specific industry specialisation to determine how culture impacts product development which then impacts product recall risk. Consequently, taking the results of this study, these two seemingly opposite audit methods would achieve a greater level of discovery if they functioned in tandem. Separately they may uncover important risks. However, without assessing the underlying social factors and organisational climate, unknown-unknown risks are likely to go unobserved within the complex product development processes within high-tech OEM's. Clearly then, there is a commercial benefit of this study to organisational practice. If a methodology, similar to that employed in this case study, was formalised and thus facilitate a third party to audit or review a company's product development processes and governance structures in the context of its organisational climate, then risk assessment processes would be more comprehensive and thus more effective. Audits would be more likely to identify the likelihood of unknown-unknown risks and potential Black Swan Events. Specifically, third party audits and thus directors would have a greater probability of understanding the company's organisational climate and it's
interaction with design processes and governance structures. This may then allow them to identify if a company has a likelihood of product recall, as described below.

5.2.5 Implications Of This Study On Directors Competencies.

This case study also demonstrates the increasing complexity surrounding the role of directors and corporate governance. As discussed by Ingley and Van Der Walt (2008), directors often fear they do not have the core competencies in their particular field to adequately discharge their governance obligations. The results of this study propose that indeed their plight may be more difficult than they fear. Core skills may well be insufficient. However, this study suggests that to manage the risks to which they are subject, they also need to manage organisational culture and social factors and how they interact with the technical and procedural aspects of the company. This is an additional core skill that directors may also be ill-equipped to face. The continued product recalls suggested by Eifler et al. (2014), suggest that perhaps this is indeed a contributing factor.

5.2.6 Principle themes extracted from results

With reference to Appendix E, tabulating and cross referencing interview and survey results with theories and concepts, the following themes were extracted from the data:

**Theme 1: The company's organisational climate does not reflect the company's strategic direction, and its supporting governance is not aligned to the company's strategic direction.**

While numerous interviews confirmed that reliability and safety by design were very important, many respondents failed to confirm directors’ vision of reliability. Directors generally expressed the need for extreme reliability given the high volume product being manufactured as it re-positions the company into the volume supply market. The Managing Director went further, and discussed the social obligations to ensure that their product functions reliably due to the duty of care associated with reliable electricity supply. These thoughts by the Managing Director failed to be presented by any other respondent. As demonstrated by the organisational climate survey, the company has a
strong focus on traditional values, with low clarity of organisational goals, reflexivity, innovation and flexibility scores. Supported by interviews with some employees that felt management has a reluctance to change, it was thus consistent that design and design review methods specifically created to ensure the level of reliability required by the board has not been adopted. As a company in transition from a medium volume high reliability market to a high volume ultra-high reliability market, it is clear that the company's organisational climate has not aligned with its organisational goals and governance structures.

Theme 2: Design and design review processes that reduce the risk of recall are not being used.
As discussed in the literature review, there are a number of design methodologies that expose companies to recall risk. However, over the last few decades, these have been superseded with processes that reduce this risk. Interviews, artefacts and surveys demonstrated that these inadequate design and design review methods are still being used, with minimal awareness of neither the other methods nor why they would be of benefit. As with the first theme, this is consistent with the results of the organisational climate section of the survey, where tradition was a strong organisational focus. Artefacts demonstrated that recalls have occurred as a consequence of using these methods.

Theme 3: Governance structures ineffective to report and control above.
Interviews with some engineers and managers demonstrated that the governance structures were generally ineffective, with artefacts demonstrating this point. Specifically the stage-and-gate structure used as both a reporting and control measure failing to stop the product recalls over the last few years. Despite this, review of governance and/or design and design review methods has happened infrequently and only on an ad-hoc basis. Two directors did not manage to explain the governance structures that lead to product reliability, and all but one did not manage to explain the basic principles behind their product development methodologies. Consequently, it is clear that there are ineffective governance reporting and controls in place.
Theme 4: Social Factors within the companies organisational climate are supporting inadequate design methods and ineffective governance structures.

Semi-structured interviews demonstrated the evidence of whistle blowing, keeping mum, bounded rationality and knowledge asymmetry within the organisation. Consistent with agency theory, artefacts demonstrated that reporting from engineers through managers to directors did not always contain leading opinions but rather the opinions that assisted with avoiding accountability. Further, interviews demonstrated directors were unaware of this. Interviews were supported by survey results reporting that conflict and personalities play a significant part in risk assessment and project decisions. This further reduced directors ability to understand the risks being designed into product. Similarly interviews and surveys reported whistle blowing and keeping mum to a similar end. Mercifully, product recalls occur infrequently, even for a company struggling with them such as the one being studied. As such, and because of the social factors discussed within this study ensuring directors generally receive good news until the rarely occurring product recall, it is understandable that directors view there are minimal risks within their company. Similarly that their management team are competently discharging organisational goals and managing risks accordingly. On both points, this is because the social factors discussed have ensured directors cannot look to closely to develop a counter view. Data suggested that this has occurred within the respondent company.

5.2.7 Creation Of A Diagnostic Tool

Indeed, the sample frame was created in advance of identifying the specific respondent organisation. It is proposed that the characteristics of a high technology company whereby the directors are concerned that their product development processes may be exposing them to product recall risk. Through the use of triangulation, semi-structured interviews coupled with survey results and organisational artefacts, this case study demonstrated that for this company, due to the phenomena above, reliability and recall risk management and governance reporting and structures were rendered less effective. By extension, and from a practice perspective, the sample frame being analogous to defining the characteristics of a customer group with the method being a form of audit or assessment. It may be possible that further study would validate the sample frame
and methodology used in this study as a diagnostic tool. Certainly the organisation climate assessment method has been validated by Paterson et al. Similarly the phenomena identified in the literature review have been verified in its own right. However, such a diagnostic tool resulting from this study would be the amalgamation of these theories and phenomena. Based on seeking understanding within the company being analysed using the proposed Recall Risk Governance Opacity model above, this diagnostic tool would be the process of applying the data collection methods and results analysis applied within thus study.

In summary:

1. Multi-level semi-structured Interviews.
2. Survey consisting of product design and review processes, and organisational climate assessment questions.
3. Collection of organisational artefacts as directed by above.
4. The use of thematic coding, descriptive and statistical tools to understand and contextualise the above data.

This case study, coupled with the rigour of individual theories and the existence of well established phenomena identified in the study, may be sufficient validation for use in practice. It is probable that the approach taken in this study could be used to assess an organisations likelihood of experiencing product recall and/or product reliability issues in the form of unknown-unknown risks and/or black swan events. However, this diagnostic tool would require further study and validation to demonstrate academic rigour and credibility. As such, It is the researchers opinion that this study takes practice a significant step closer to the development of a tool, possibly used during audit, to predict the likelihood of unknown-unknown risks and therefore product recall within high technology OEM's.
5.2.8 Application Of The Diagnostic Tool

Third party auditing companies typically perform auditing services for the following reasons, and why the diagnostic tool discussed above would be of benefit in practice:

1. Due diligence during merger and acquisition: It is common practice, as one of the final contractual steps, for the acquiring company to seek the services of a third party professional auditing company to assess the company to be acquired. Aside from assessing that the company to be acquired is as expected, risks are considered and evaluated. (Puranam, Powell & Singh 2006). The ability to extend this evaluation of their risk to product reliability and recall would have a profound effect on the negotiation.

2. Third Party Supply chain assessment: Strategic supplier selection often presents critical risks to companies. Particularly during large multinational outsourcing projects (Quélin & Duhamel 2003). It is common for third party auditors to assess risks associated within the supply chain. However, these third party audits often have varying results. (Johnson 2006). Where product development has been outsourced, the benefit to principals is that of being able to assess the suppliers organisational climate and design processes to thus understand the likelihood of product recall would be significant.

3. Company Audits: As has been the main topic of this study, and discussed in the literature review, Directors have obligations under numerous legal acts. Third party audit of internal controls are common, and required by the Sarbanes-Oxley Act 2002 for example(Ashbaugh-Skaife, Collins & Lafond 2009). The findings of this study, and the possibility of using the method as a tool to uncover potential weaknesses in governance structures during audit, would be beneficial to Directors of high technology OEM's seeking diligent audit results.

With most auditing practice it is worth noting that a typical obstacle is the Hawthorn Effect whereby people being observed change their behaviour to meet expectations (Wickström & Bendix 2000).
Consistent with the experience of this study's research, it is likely that the methodology used within this study would aid in overcoming the Hawthorne effect. That is, most respondents assumed the main focus and point of investigation was the design process, and had not fully understood that the main focus on was on uncovering social factors and the companies organisational climate. This presumption by respondents to the true nature of the audit, (despite being informed in writing) may act as a form of inadvertent covertness. Thus compensating in small part for the Hawthorne effect during audit.

The above audits, and/or the proposed diagnostic tool, may discover specific products with specific deficiencies that may cause a recall. However, more likely and of more importance is the ability to identify the existence of the inadequate design processes and organisational climate that support the existence of latent design defects that could cause future product recalls. Indeed, once companies have accepted the possibility of unknown-unknown risks within their organisation, and having conducted an assessment similar to this case study and of the like described in this chapter, they would be presented with the opportunity to manage these risks. For example, if following an assessment, possibly using the tool proposed above, social factors have been identified that may limit the identification and rectification of risk during design review, then there is potential for a specific and directed risk assessment to be undertaken. External consultants could be contracted to re-review the design of specific product developed while under the influence of the identified social factors. This activity would produce the specifics of previously unknown design based risks. The company could then chose to rectify them by modifying the product and/or creating a contingency for product already released into the field. In this way, this targeted activity would have the potential to turn unknown-unknown risks into known risks that can then be managed by some form of risk mitigation.

5.2.9 Proposed Model - Recall Risk Governance Opacity

In consideration of the phenomena within this study and themes as they, the following integrated model is proposed:
This study demonstrates the linkage between inadequate design methods, social factors and their effect on risk governance. As discussed in this study, design methods and social factors interact to support each other, to create unknown recall risks. In doing so they both respond in sympathy with, and influence, the organisational climate. As the dysfunctional design methods and social factors increase in quantity and severity, they limit the effectiveness of governance structures such as reporting and control. This reduces organisational transparency and thus the directors ability to understand the recall risks within the organisation they govern. Hence the term 'Recall Risk Governance Opacity'. However, by understanding a company's organisational climate and its design processes directors may be able to compensate for this effect.

This model takes the analogy of a chaotic whirlpool, powered by the design methods and social factors discussed in this study. The whirlpool exists within a body of liquid symbolising organisational climate. The amount of energy required to form and change the speed of the whirlpool is proportional to the nature of the liquid it is in, while at the same time the whirlpool influences the form and shape of the liquid.

The centre of the whirlpool is the resulting vortex. The vortex is symbolic of the existence and nature of design based product recall risk. When the whirlpool is small, the vortex is small, and looking through the whirlpool from the side, perhaps from

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**Figure 11** Proposed Whirlpool model demonstrating Recall Risk Governance Opacity concept developed within this study.
within the liquid itself, the viewer looks straight through the middle and through to the other side. With a small vortex there is little to be observed other than spinning liquid. As the whirlpool increases in speed, the ability to see the growing vortex becomes increasingly difficult as the liquid is becoming increasingly turbid and thus opaque rather than transparent. Again, all that can be seen is spinning liquid. If the observer (director) did not know the whirlpool has increased in speed he/she would not know anything had changed. That is, that the vortex (recall risks) had grown.

Only by viewing from the top of the whirlpool can it's impact on the liquid be seen, because of the change in the whirlpools diameter. But still, the chaotic twisting and turning vortex itself cannot be understood or controlled as it rarely takes a vertical path through the liquid. The vortex column bends and shifts left and right unpredictably. However, in some liquids, and with a given amount of energy, it is easier to produce a whirlpool than others. (Social factors will interact with organisational climates differently in each case). Thus by understanding the nature of the liquid (organisational climate), and by understanding the source of the vortex's power (social factors and design methods), the size of the vortex (recall risk) may be understood. Once understood, it may be controlled.

5.2.10 Limitations Of Study And Future Research

As the methodology selected within this research is a case study, there is limited ability to generalise across other industries or organisations. As such, there is potential for future research to explore case studies within other industries and compare results to assess generalisability. Similarly, there is potential to explore the phenomena in this case study by adopting a bigger sample across a number of industries.

While an outcome of this study is that organisation climate and inadequate design processes interact to restrict the effectiveness of governance structures, the study cannot determine the full nature of this interaction. For instance the study has not determined if climate influences inadequate design processes or vice versa, only that both phenomena are required and that they do interact. It is likely that further research would be able to determine the nature of this interaction. Understanding this via a quantitative study that
determines correlation may aid practice by facilitating a targeted approach to reducing recall risk.

The method of this study, coupled with the sensitive nature of the topic, contains inherent risk that respondents distort their response. This may be due to fear of reprisal, or lack of trust in anonymity. This is a particular risk when keeping mum and whistle blowing are themselves both the phenomena being studied and shown to be evident in the respondent company. As such, the topic may benefit from additional research using covert observation.

As this organisation has experienced recalls in all of the products it has released in the last few years, there is likely to be benefit in a longitudinal study. This study would review the progress of the company in either overcoming its challenges in transition into a high reliability market or failing to do so. Either result would contribute to this study by either confirming or dispelling its findings.

This study has considered the link between Black Swan Theory, that has largely been derived from the financial industry, and engineering. As mentioned previously, it is probable that with further research, tools and methods for managing Black Swan Events within one discipline may be used within another. Indeed, there may be potential create generic tools that are not industry specific.

Of further importance to practice is the transition of the ISO9001:2008 standard to ISO9001:2015. This significant restructure refocuses the standard around risk management (Avanesov 2009). Interestingly, it attempts a basic consideration around social factors by highlighting the importance of leadership. It will be of interest to observe if the focus of the methodology of this emerging standard shifts towards managing culture as equally important as process and risk as it matures. Further, it is probable that the use of an assessment tool as described above could be integrated into ISO9001 compliance audits to increase effectiveness of risk management activities.
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Glossary and Definition of Terms:

**Director:** The definition of Director is determined by the membership rules of the Institute of Directors UK (IOD). As viewed on 20/10/2014, the IOD website defines a director as "...responsible for the strategic business direction of an entity and the implementation of its corporate governance and which makes the decisions that determine its success and integrity".

**Product Development Process (PDP):** is the over-all series of methods that take a product from conception, through to production (Veryzer 1998).

**Design Processes and methods:** The calculations, drawings, evaluation methods, and risk assessment tools used by design teams within product development projects to create product (Brown & Eisenhardt 1995).

**Design test:** Following theoretical calculation and analysis of the products design, it is then subjected to testing using prototypes to ensure the product conforms to requirements before releasing the product into the manufacturing process (Van Campenhout, Mudge & Hayes 1999).

**Production Test:** These are the applied to product during its manufacture to ensure that the product conforms to the requirements defined during the product design process (Voorakaranam, Cherubal & Chatterjee 2002).

**Quality Control:** Inspection and the application of production tests coupled with statistical analysis used to create control methods ensuring only product conforming to the product design is released to customers (Jebb et al. 1989).

**Small to medium enterprise (SME):** Defined by the HMRC as a company of less than 250 employees and revenue of 50M euro (Her Majesty's Revenue and Customs 2014).

**Original Equipment Manufacturer (OEM):** These companies purchase raw materials, component and/or subassemblies and integrate these into products that can be on-sold (Parunak, Savit & Riolo 1998).
**Listed company:** A company is considered to be a 'listed' once it has been met minimum performance and disclosure requirements and been made available on a stock exchange for the public to acquire (Pagano & Roell 1998).

**Known-unknown risk:** Maluf et al. (2005) describes known-unknown risks as "*we know that there is a risk and the risk is modelled*"

**Unknown-unknown risk:** Maluf et al. (2005) describes unknown-unknown risks as "*unknown-unknown -- we don’t even know there is a risk.*"

**Field failure:** This is where product fails while in usage by the end user (Murthy & Djamaludin 2002).

**Premature failure:** This term is used to define a field failure that occurs within warranty, or unreasonably early within the expected products life (Murthy & Djamaludin 2002).

**Tolerance:** This term is used to describe the amount of variability that a component is allowed to demonstrate within the manufacturing process before the component will malfunction (Singh et al. 2003).

**Tolerance stack-up:** By taking the cumulative effect of the tolerances on all components within a system, the tolerance stack-up is calculated that defines the allowable variation in each component (tolerance) that ensures the whole product will not malfunction (Recchia et al. 2005).

**Governance reporting:** This term is used to describe the reporting methods and documents that are created within and throughout companies to provide information to directors to allow them to ensure the organisation is acting in shareholders' interest (Kolk 2008).
Governance controls: Controls are established to ensure that decisions within and throughout companies are made by suitably authorised individuals to protect shareholders (Kolk 2008).
Appendix A - Semi Structured Interview Questions

*Semi structured interview items applied to directors:*

Can I confirm that you are a member of the IOD and a director for [the respondent company]

How long have you been a director of [the respondent company]

Would you describe [the respondent company] as an SME OEM that produces electro-mechanical product?

With regard to your company’s structures and processes please describe the following mechanisms: (Please include detail such as roles/responsibilities, reporting, company risk profile, etc...)

- Governance
- Risk management
- Internal control.

How often are they reviewed as a system?

How does the board/management team modify these mechanisms?

What type of operational risks would you expect your management team to be ‘managing’?

Which of these risks are unique, specific or unusually important to your business?

How confident are you that your management team are effectively managing risk generally within your company?

Why?

How do you ensure your management team are effectively reporting risk within your company?
How do you determine what risk management structures/methods are effective and those that are not?

Tell me about your managers and employees behaviours regarding risk management, product development and product reliability.

In regards to your company wide Product Development Process, how do you ensure your management team are effectively managing the risk of product recall? That is:

- Customer safety,
- Legal and regulatory compliance
- In-house compliance and product reliability?

Again looking at your Product Development Process, how do you know what risk management structures are effective and those that are not?

What actions are, or have been, taken to remedy ineffective structures and process?

How often are they reviewed and/or modified?

How does your product development process differentiate between known and unknown risk?

How do you ensure your management team are effectively reporting product recall risk generally within your company?

How reliable does your market(s) expect your product(s) to be?

How safe does your market(s) expect your product(s) to be?

How well has your Product Development Process achieved these goals?
Describe the product design and review methods used within your company?

What has influenced the company’s selection of these methods?

How would you describe the product risk assessment methods used within your company?

What has influenced the company’s selection of these methods?

How do managers know which reliability/safety/feature/cost/time to market trade-offs to accept relative to the companies risk tolerance?

If an employee disagreed with the trade-off above, and felt the company was at risk, how would this be managed and reported? Do you know if this has ever happened? If so, tell me about it.

How do you feel about the growing change to director’s role in ensuring the management of operational risk?

**Semi structured interview items applied to employees and managers:**

Can I confirm that you are employed by [the respondent company]?

Do you hold a management position within [the respondent company]?

Have you been employed by [the respondent company] for more than six months?

Do you specify, design or manufacture product for [the respondent company] as part of your role?

Do you have engineering design training/education?

Do you have engineering design experience?

Are you involved in risk management within the company?

Tell me about this? In what way could they be more effective?

Are there any risks that are unique, specific or unusually important to your business?

How confident are you that risks are managed within your company?

  Why?
Tell me about the way employees/managers contribute to risk management, product development and improving product reliability.

Looking at your company wide Product Development Process, and within the scope of your role, what do you do to ensure you effectively managing the risk of product recall?

- Customer safety,
- Legal and regulatory compliance
- In-house compliance and reliability?

How does your product development process differentiate between known and unknown risk?

Again looking at your Product Development Process, how do you know the tools you use are effective at managing risk?

What actions are, or have been, taken to remedy these tools?

How often are they reviewed and/or modified?

How do you report a risk concern?

How reliable does your market(s) expect your product(s) to be?

How safe does your market(s) expect your product(s) to be?

How well has your Product Development Process achieved these goals?

Describe the product design methods used within your company?

What has influenced the company’s selection of these methods?

How would you describe the product risk assessment methods used within your company?

What has influenced the company’s selection of these methods?

How would you speak up if you identified a risk? Would you do this if you manager disagreed?

How do you know which reliability/safety/feature/cost/time to market tradeoffs to accept relative to the companies risk tolerance?

If an employee disagreed with the trade-off above, and felt the company was at risk, how would this be managed and reported? Do you know if this has ever happened? If so, tell me about it
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| Nickname:   | 12                | 19                          | 5,701                 | 245                       |               |
| Classification: |                 |                             |                       |                           |               |
| Aggregated: | No                |                             |                       |                           |               |
| Document    |                   |                             |                       |                           |               |
Appendix C- Descriptive Statistics Applied to the Second Section of the Survey as Discussed in Section 3.3.4.2

Survey Item Results Item 1 to 38

<table>
<thead>
<tr>
<th>Survey item (score out of 5)</th>
<th>Total</th>
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<th>Non-Manager</th>
<th>&lt;ave** Tenure</th>
<th>&gt;ave** Tenure</th>
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</thead>
<tbody>
<tr>
<td>1. Product features are the most important project consideration</td>
<td>3.7</td>
<td>4.1</td>
<td>3.4</td>
<td>3.9</td>
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<tr>
<td>2. Project cost is the most important project consideration</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
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<tr>
<td>3. Product unit cost is the most important project consideration</td>
<td>3.6</td>
<td>4.0</td>
<td>3.3</td>
<td>3.8</td>
<td>3.3</td>
</tr>
<tr>
<td>4. Product time to market is the most important project consideration</td>
<td>3.4</td>
<td>3.6</td>
<td>3.3</td>
<td>3.8</td>
<td>3.0</td>
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<tr>
<td>5. Field reliability is the most important project consideration</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
<td>3.8</td>
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<tr>
<td>6. Regulatory compliance is the most important project consideration</td>
<td>4.2</td>
<td>4.6</td>
<td>4.0</td>
<td>4.4</td>
<td>4.0</td>
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<tr>
<td>7. My company has a formal Product Development Process (PDP)</td>
<td>3.2</td>
<td>3.4</td>
<td>3.1</td>
<td>2.7</td>
<td>3.6</td>
</tr>
<tr>
<td>8. Project teams adhere to the PDP</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>2.6</td>
<td>3.1</td>
</tr>
<tr>
<td>9. My company’s PDP achieves it goals</td>
<td>2.7</td>
<td>2.1</td>
<td>2.9</td>
<td>2.3</td>
<td>3.0</td>
</tr>
<tr>
<td>10. My company uses multi-department design teams.</td>
<td>3.6</td>
<td>3.5</td>
<td>3.7</td>
<td>3.7</td>
<td>3.5</td>
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<tr>
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<td>Manager</td>
<td>Non-Manager</td>
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<td>&gt;ave** Tenure</td>
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<tr>
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<td>-------</td>
<td>---------</td>
<td>-------------</td>
<td>---------------</td>
<td>--------------</td>
</tr>
<tr>
<td>11. My company uses formal multi-department design review teams.</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>3.0</td>
<td>2.8</td>
</tr>
<tr>
<td>12. My company uses formal multi-department Failure Mode and Effects Analysis (FMEA) processes.</td>
<td>3.0</td>
<td>2.9</td>
<td>3.1</td>
<td>2.9</td>
<td>3.2</td>
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<tr>
<td>13. When undertaking risk assessments (e.g. Failure Mode and Effects Analysis), we often find ourselves guessing at the nature of risks, their severity and/or their likelihood of occurrence.</td>
<td>3.4</td>
<td>3.9</td>
<td>3.1</td>
<td>3.6</td>
<td>3.2</td>
</tr>
<tr>
<td>14. When undertaking risk assessments (e.g. Failure Mode and Effects Analysis), we use hard evidence and data to quantify severity and/or likelihood of occurrence.</td>
<td>3.0</td>
<td>2.5</td>
<td>3.2</td>
<td>3.0</td>
<td>2.9</td>
</tr>
<tr>
<td>15. The company provides formal guidelines describing which risks are acceptable and which are not.</td>
<td>2.8</td>
<td>2.5</td>
<td>3.0</td>
<td>3.1</td>
<td>2.6</td>
</tr>
<tr>
<td>16. The project team seek management input when deciding which risks to accept</td>
<td>3.2</td>
<td>3.4</td>
<td>3.1</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td>17. The project team use mutual</td>
<td>3.3</td>
<td>3.1</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Survey item (score out of 5)</td>
<td>Total</td>
<td>Manager</td>
<td>Non-Manager</td>
<td>&lt;ave** Tenure</td>
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</tr>
<tr>
<td>agreement when deciding which risks to accept</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>18. The project team defer to at least one technical experts when considering risk.</td>
<td>3.3</td>
<td>3.9</td>
<td>2.9</td>
<td>3.1</td>
<td>3.4</td>
</tr>
<tr>
<td>19. There are one or two strong personalities that dominate the design review process (e.g. Failure Mode and Effects Analysis).</td>
<td>3.7</td>
<td>4.3</td>
<td>3.4</td>
<td>4.2</td>
<td>3.3</td>
</tr>
<tr>
<td>20. Personal or professional targets/ goals do not influence the project decision making process.</td>
<td>2.8</td>
<td>2.9</td>
<td>2.8</td>
<td>2.5</td>
<td>3.1</td>
</tr>
<tr>
<td>21. Personalities do not influence the project decision making process.</td>
<td>2.4</td>
<td>2.0</td>
<td>2.6</td>
<td>2.1</td>
<td>2.7</td>
</tr>
<tr>
<td>22. Politics and interdepartmental conflict do not influence the project decision making process.</td>
<td>2.4</td>
<td>2.1</td>
<td>2.6</td>
<td>1.9</td>
<td>2.9</td>
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<tr>
<td>23. Tolerance design and analysis is mostly based on compromises using experience and intuition?</td>
<td>3.2</td>
<td>3.6</td>
<td>2.9</td>
<td>3.3</td>
<td>3.1</td>
</tr>
<tr>
<td>24. Tolerance design and analysis is a statistical process. (e.g. 95% of the time the parts will assemble/function correctly. The rest of the time the</td>
<td>3.2</td>
<td>3.3</td>
<td>3.1</td>
<td>3.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Survey item (score out of 5)</td>
<td>Total</td>
<td>Manager</td>
<td>Non-Manager</td>
<td>&lt;ave** Tenure</td>
<td>&gt;ave** Tenure</td>
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<td>--------------</td>
</tr>
<tr>
<td>manufacturing or service teams can find and fix the problem)</td>
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<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
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<tr>
<td>25. Tolerance design and analysis is an absolute process. (e.g. If supplied to specification, 100% of the time parts will go together and function reliably.</td>
<td>2.8</td>
<td>2.5</td>
<td>3.0</td>
<td>2.7</td>
<td>2.9</td>
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<tr>
<td>26. My company’s PDP aligns with my view of tolerance design above.</td>
<td>3.2</td>
<td>3.1</td>
<td>3.2</td>
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<td>3.3</td>
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<tr>
<td>27. My company identifies critical design tolerances and applies a tolerance accordingly</td>
<td>3.2</td>
<td>3.1</td>
<td>3.3</td>
<td>3.1</td>
<td>3.3</td>
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<tr>
<td>28. My company reviews the first few production builds to see where there are tolerance clashes</td>
<td>3.3</td>
<td>3.1</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
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<tr>
<td>29. My company reviews the first few production builds and modifies the design to remove tolerance clashes</td>
<td>3.2</td>
<td>3.3</td>
<td>3.2</td>
<td>3.6</td>
<td>2.8</td>
</tr>
<tr>
<td>30. My company releases the product and awaits field failure feedback to determine reliability</td>
<td>3.4</td>
<td>3.4</td>
<td>3.5</td>
<td>4.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Survey item (score out of 5)</td>
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<td>Manager</td>
<td>Non-Manager</td>
<td>&lt;ave** Tenure</td>
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<tr>
<td>reliable</td>
<td></td>
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<tr>
<td>32. My company completes a product wide tolerance stack-up analysis before product is released</td>
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<td>2.8</td>
<td>2.9</td>
<td>2.9</td>
<td>2.8</td>
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<tr>
<td>33. Employees/managers are presented with meaningful field failure information and its root cause throughout the life of the product</td>
<td>2.3</td>
<td>2.1</td>
<td>2.4</td>
<td>2.2</td>
<td>2.4</td>
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<tr>
<td>34. Project progress and/or risk assessments reports are circulated to the project team before presentation to the management team and/or the board?</td>
<td>2.8</td>
<td>3.1</td>
<td>2.7</td>
<td>2.8</td>
<td>2.8</td>
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<tr>
<td>35. Project member’s opinions are considered and addressed accordingly.</td>
<td>3.1</td>
<td>3.1</td>
<td>3.1</td>
<td>2.8</td>
<td>3.3</td>
</tr>
<tr>
<td>36. If I disagree with the outcome of a design/risk review, design decision/compromise or project report presented to senior management and/or the board, I feel comfortable raising this within the project team for consideration.</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
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<td>3.5</td>
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<tr>
<td>37. Having raised my concerns with the project team, if I</td>
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<td>2.6</td>
<td>3.1</td>
<td>3.0</td>
<td>2.9</td>
</tr>
<tr>
<td>Survey item (score out of 5)</td>
<td>Total</td>
<td>Manager</td>
<td>Non-Manager</td>
<td>&lt;ave** Tenure</td>
<td>&gt;ave** Tenure</td>
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<tr>
<td>still disagree with the outcome of a design/risk review, design decision/compromise or project report to senior management and/or the board I feel comfortable raising this to the management team.</td>
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<tr>
<td>38. The company has a formal escalation mechanism for employees to raise risk concerns?</td>
<td>2.7</td>
<td>2.4</td>
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<td>2.5</td>
<td>2.9</td>
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** Average Tenure = approx 8.5 years. This was used as the defining cut off period between long serving and non-long serving employees/managers
Appendix D - SPSS Output Demonstrating Factor Analysis of Organisational Climate Survey Results.

Factor Analysis- HR Dimension Component Matrix

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<th>Component 1</th>
<th>Component 2</th>
<th>Component 3</th>
<th>Component 4</th>
<th>Component 5</th>
<th>Component 6</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Management let people make their own decisions much of the time</td>
<td>.714</td>
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<tr>
<td>2</td>
<td>Management trust people to take work-related decisions without getting permission first</td>
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<tr>
<td>3</td>
<td>People at the top tightly control the work of those below them</td>
<td></td>
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<td>.698</td>
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<tr>
<td>4</td>
<td>Management keep too tight a reign on the way things are done around here</td>
<td></td>
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<td></td>
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<tr>
<td>5</td>
<td>It’s important to check things first with the boss before taking a decision</td>
<td></td>
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<tr>
<td>6</td>
<td>People are suspicious of other departments</td>
<td></td>
<td></td>
<td></td>
<td>.706</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>There is very little conflict between departments here</td>
<td></td>
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<tr>
<td>8</td>
<td>People in different departments are prepared to share information</td>
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<td>.632</td>
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<tr>
<td>9</td>
<td>Collaboration between departments is very effective</td>
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<td>.669</td>
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<tr>
<td>10</td>
<td>There is very little respect between some of the departments here</td>
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<td>.690</td>
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<tr>
<td>11</td>
<td>Management involve people when decisions are made that affect them</td>
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<td></td>
<td>.797</td>
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<tr>
<td>12</td>
<td>Changes are made without talking to the people involved in them</td>
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<td>.886</td>
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<tr>
<td>13</td>
<td>People don’t have any say in decisions which affect their work</td>
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<td>.870</td>
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<tr>
<td>14</td>
<td>People feel decisions are frequently</td>
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<td>.855</td>
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<td>Statement</td>
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<td></td>
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<tr>
<td>15.</td>
<td>Information is widely shared</td>
<td>.717</td>
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<tr>
<td>16.</td>
<td>There are often breakdowns in communication here</td>
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<tr>
<td>17.</td>
<td>Supervisors here are really good at understanding peoples’ problems</td>
<td></td>
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<tr>
<td>18.</td>
<td>Supervisors show that they have confidence in those they manage</td>
<td>.603</td>
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<tr>
<td>19.</td>
<td>Supervisors here are friendly and easy to approach</td>
<td>.755</td>
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<td>20.</td>
<td>Supervisors can be relied upon to give good guidance to people</td>
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<tr>
<td>21.</td>
<td>Supervisors show an understanding of the people who work for them</td>
<td>.738</td>
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<tr>
<td>22.</td>
<td>People are not properly trained when there is a new machine or equipment</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>23.</td>
<td>People receive enough training when it comes to using new equipment</td>
<td></td>
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<tr>
<td>24.</td>
<td>The company only gives people the minimum amount of training they need to</td>
<td>.696</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>do their job</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>25.</td>
<td>People are strongly encouraged to develop their skills</td>
<td></td>
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</tr>
<tr>
<td>26.</td>
<td>This company pays little attention to the interests of employees</td>
<td>.750</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>27.</td>
<td>This company tries to look after its employees</td>
<td>.779</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>28.</td>
<td>This company cares about its employees</td>
<td>.755</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>29.</td>
<td>This company tries to be fair in its actions towards employees</td>
<td>.776</td>
<td></td>
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</tr>
</tbody>
</table>
### Factor Analysis - Internal Process Dimension Component Matrix

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<tr>
<th></th>
<th>Component</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>30. It is considered extremely important here to follow the rules</td>
<td></td>
<td>.613</td>
<td>.635</td>
</tr>
<tr>
<td>31. People can ignore formal procedures and rules if it helps get the job done</td>
<td></td>
<td>.818</td>
<td></td>
</tr>
<tr>
<td>32. Everything has to be done by the book</td>
<td></td>
<td>.810</td>
<td></td>
</tr>
<tr>
<td>33. It is not necessary to follow procedures to the letter around here</td>
<td></td>
<td>.813</td>
<td></td>
</tr>
<tr>
<td>34. Nobody gets too upset if people break the rules around here</td>
<td></td>
<td>.733</td>
<td></td>
</tr>
<tr>
<td>35. Senior management like to keep to established, traditional ways of doing things</td>
<td></td>
<td>-.608</td>
<td>.674</td>
</tr>
<tr>
<td>36. The way this organisation does things has never changed very much</td>
<td></td>
<td>-.612</td>
<td></td>
</tr>
<tr>
<td>37. Management are not interested in trying out new ideas</td>
<td></td>
<td>-.795</td>
<td></td>
</tr>
<tr>
<td>38. Changes in the way things are done here happen very slowly</td>
<td></td>
<td>-.700</td>
<td></td>
</tr>
</tbody>
</table>

### Factor Analysis - Open System Dimension Component Matrix

<table>
<thead>
<tr>
<th></th>
<th>Component</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>39. New ideas are readily accepted here</td>
<td></td>
<td>.748</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40. This company is quick to respond when changes need to be made</td>
<td></td>
<td>.808</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41. Management here are quick to spot the need to do things differently</td>
<td></td>
<td></td>
<td></td>
<td>.831</td>
</tr>
<tr>
<td>42. This organization is very flexible; it can quickly change procedures to meet new conditions and solve</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>---</td>
<td>--------------------------------------------------------------------------------------------</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>43.</td>
<td>Assistance in developing new ideas is readily available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44.</td>
<td>People in this organization are always searching for new ways of looking at problems</td>
<td>.812</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45.</td>
<td>This organization is quite inward looking; it does not concern itself with what is happening in the market place</td>
<td>.721</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46.</td>
<td>Ways of improving service to the customer are not given much thought</td>
<td>.689</td>
<td></td>
<td></td>
</tr>
<tr>
<td>47.</td>
<td>Customer needs are not considered top priority here</td>
<td>.617</td>
<td></td>
<td></td>
</tr>
<tr>
<td>48.</td>
<td>This company is slow to respond to the needs of the customer</td>
<td>.723</td>
<td></td>
<td></td>
</tr>
<tr>
<td>49.</td>
<td>This organization is continually looking for new opportunities in the market place</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50.</td>
<td>In this organization, the way people work together is readily changed in order to improve performance</td>
<td>.680</td>
<td></td>
<td></td>
</tr>
<tr>
<td>51.</td>
<td>The methods used by this organization to get the job done are often discussed</td>
<td>.716</td>
<td></td>
<td></td>
</tr>
<tr>
<td>52.</td>
<td>There are regular discussions as to whether people in the organization are working effectively together</td>
<td>.712</td>
<td></td>
<td></td>
</tr>
<tr>
<td>53.</td>
<td>In this organization, objectives are modified in light of changing circumstances</td>
<td>.649</td>
<td></td>
<td></td>
</tr>
<tr>
<td>54.</td>
<td>In this organization, time is taken to review organizational objectives</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Factor Analysis - Rational Goal Dimension Component Matrix

182
<table>
<thead>
<tr>
<th>Component</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>55. People have a good understanding of what the organization is trying to do</td>
<td></td>
<td></td>
<td></td>
<td>.753</td>
<td></td>
<td></td>
</tr>
<tr>
<td>56. The future direction of the company is clearly communicated to everyone</td>
<td></td>
<td></td>
<td></td>
<td>.858</td>
<td></td>
<td></td>
</tr>
<tr>
<td>57. People aren’t clear about the aims of the company</td>
<td></td>
<td></td>
<td></td>
<td>.849</td>
<td></td>
<td></td>
</tr>
<tr>
<td>58. Everyone who works here is well aware of the long-term plans and direction of this company</td>
<td></td>
<td></td>
<td></td>
<td>.871</td>
<td></td>
<td></td>
</tr>
<tr>
<td>59. There is a strong sense of where the company is going</td>
<td></td>
<td></td>
<td></td>
<td>.799</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60. Time and money could be saved if work were better organized</td>
<td></td>
<td></td>
<td></td>
<td>.661</td>
<td></td>
<td></td>
</tr>
<tr>
<td>61. Things could be done much more efficiently, if people stopped to think</td>
<td></td>
<td></td>
<td></td>
<td>.695</td>
<td></td>
<td></td>
</tr>
<tr>
<td>62. Poor scheduling and planning often result in targets not being met</td>
<td></td>
<td></td>
<td></td>
<td>.796</td>
<td></td>
<td></td>
</tr>
<tr>
<td>63. Productivity could be improved if jobs were organized and planned better</td>
<td></td>
<td></td>
<td></td>
<td>.735</td>
<td></td>
<td></td>
</tr>
<tr>
<td>64. People here always want to perform to the best of their ability</td>
<td></td>
<td></td>
<td></td>
<td>.797</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65. People are enthusiastic about their work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>66. People here get by with doing as little as possible</td>
<td></td>
<td></td>
<td></td>
<td>.616</td>
<td></td>
<td></td>
</tr>
<tr>
<td>67. People are prepared to make a special effort to do a good job</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.740</td>
</tr>
<tr>
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<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>68.</td>
<td>People here don’t put more effort into their work than they have to</td>
<td>.698</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>69.</td>
<td>People usually receive feedback on the quality of work they have done</td>
<td>.805</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70.</td>
<td>People don’t have any idea how well they are doing their job</td>
<td>.607</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71.</td>
<td>In general, it is hard for someone to measure the quality of their performance</td>
<td>.809</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>72.</td>
<td>People’s performance is measured on a regular basis</td>
<td>.736</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>73.</td>
<td>The way people do their jobs is rarely assessed</td>
<td>.669</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>74.</td>
<td>People are expected to do too much in a day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75.</td>
<td>In general, peoples’ workloads are not particularly demanding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>76.</td>
<td>Management require people to work extremely hard</td>
<td></td>
<td></td>
<td>.612</td>
<td></td>
<td></td>
</tr>
<tr>
<td>77.</td>
<td>People here are under pressure to meet targets</td>
<td></td>
<td></td>
<td>.610</td>
<td></td>
<td></td>
</tr>
<tr>
<td>78.</td>
<td>The pace of work here is pretty relaxed</td>
<td></td>
<td></td>
<td>.701</td>
<td></td>
<td></td>
</tr>
<tr>
<td>79.</td>
<td>This company is always looking to achieve the highest standards of quality</td>
<td></td>
<td>.771</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80.</td>
<td>Quality is taken very seriously here</td>
<td></td>
<td></td>
<td>.805</td>
<td></td>
<td></td>
</tr>
<tr>
<td>81.</td>
<td>People believe the company’s success depends on high-quality work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>82.</td>
<td>This company does not have much of a reputation for top-quality products</td>
<td></td>
<td></td>
<td>.714</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix E - Tabulated Results From Triangulation.

To formalise the triangulation process, the following table summarises and compares Interview data with survey and artefact data against the theories and concepts explored within the study.

<table>
<thead>
<tr>
<th>Interview</th>
<th>Survey and Artefact data</th>
<th>Theory/Concepts</th>
</tr>
</thead>
</table>
| Use of old design methods and reliance on “meter” experts rather than modern design experts – “the way it has always been done.” | • Low score on ‘Open Systems’. "Organisational inertia, limited ability to adopt new ideas." Paterson et al.  
• Highest score of ‘Tradition’ dimension. Low score in 'innovation and Flexibility' dimensions.  
• Statistically relevant score Q23: relating tolerance calculation to old methodology of "Intuition and experience"  
• Statistically relevant scores (Tenure) in :  
  o Q35: Senior management like to keep to established, traditional ways of doing things  
  o Q36 The way this organisation does things has never changed very much  
  o Q37 Management are not interested in trying out new ideas | • Design methods - tolerance  
• Bounded rationality  
• Pressure to keep mum |
Inability to realise product reliability must be > 99.9%, confirmation by MD that reliability is paramount. Yet design process is based on intuition and experience rather than reliability based processes.

Examples were given of keeping silent during design projects rather than speaking out.

- As above
- Low Clarity of Organisational goals dimension score
- Statistically relevant response for Q 23. 'Tolerance design and analysis is mostly based on compromises using experience and intuition?'

- Shape of ‘Rational Goal’ dimension implies -Inefficient, little direction, no feedback but pressure to perform anyway.
- Statistically relevant scores (manager) in:
  - Q19. There are one or two strong personalities that dominate the design review process (e.g. Failure Mode and Effects Analysis). Politics and conflict
- Statistically relevant scores (Tenure) showing the existence of politics and conflict:
  - Q22. Politics and interdepartmental conflict do not influence the project decision making process.

- Design methods - tolerance.
- Denial
- Risk Governance - Goal

- Keeping mum
- Whistle blowing
- Low average score for Q19 and Q22 (above), plus Q21. Personalities do not influence the project decision making process.
- Low "Performance feedback" score - that is, if scope and coverage of employee appraisal is poor, then people may fear they are "on the outer" for speaking out as they may not really know where they stand.
- Low "Involvement score" encouraging people say nothing as decisions are made by bosses and to challenge them is to threaten this.

<table>
<thead>
<tr>
<th>A portrayed view by some respondents that &quot;The best is behind us&quot;</th>
<th>Employee Tenure and number of long term employees</th>
<th>Group think</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insufficient clear project management or product development process</td>
<td>Low Reflexivity dimension score, demonstrating an inability to modify process and practice.</td>
<td>Design process</td>
</tr>
<tr>
<td></td>
<td>Statistically relevant response to Q7. My company has a formal Product Development Process (PDP), whereby new recruits do not feel the process is adequate.</td>
<td>Reporting structures and Control structures</td>
</tr>
<tr>
<td>Risks aren’t understood or their reporting is getting “blocked”.</td>
<td>Statistically relevant scores (manager) in:</td>
<td>Risk governance - Poor reporting, control, review</td>
</tr>
<tr>
<td></td>
<td>- Q19. There are one or two strong personalities that</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
FMEA restricted to design team members. These methods dominate the design review process (e.g. Failure Mode and Effects Analysis). Politics and conflict

- Statistically relevant scores (Tenure) in:
  - Q22. Politics and interdepartmental conflict do not influence the project decision making process.
- Low average score for Q19 and Q22 (above), plus Q21 Personalities do not influence the project decision making process.
- High score in agreement with Q13: When undertaking risk assessments (e.g. Failure Mode and Effects Analysis), we often find ourselves guessing at the nature of risks, their severity and/or their likelihood of occurrence.
- Statistically relevant and negative response to Q14. 'When undertaking risk assessments (e.g. Failure Mode and Effects Analysis), we use hard evidence and data to quantify severity and/or likelihood of occurrence.'

Inappropriate and effective use of:

- Artefact evidence in the form of the [PRODUCT 2] and
- Design methods

- Bounded Rationality
- FMEA - Qualitative and prone to social factors
<table>
<thead>
<tr>
<th>Product test to ensure product reliability</th>
<th>[PRODUCT 1] recalls. Due to tolerance methods, test batch could be ideal, therefore removing discovery during test.</th>
<th>Bounded rationality</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Product Development process is causing product recalls</td>
<td>High scores for: Q5 'Field reliability is the most important project consideration' and Q6 'Regulatory compliance is the most important project consideration'. But a relatively low score for Q9 'My company’s PDP achieves it goals.'</td>
<td>Design process and Review, Keeping mum, Whistle blowing, Governance control and reporting</td>
</tr>
<tr>
<td>Insufficient design risk guidelines</td>
<td>Response to’ Q15 The company provides formal guidelines describing which risks are acceptable and which are not' has a slightly low average response</td>
<td>Risk governance structures and reporting</td>
</tr>
</tbody>
</table>
| Denial, lack of admission there are problems even though there has recently been recalls suggesting all is fine with design - similar to that told to the executive level. | - Statistically relevant scores (manager) in :  
  o Q19. There are one or two strong personalities that dominate the design review process (e.g. Failure Mode and Effects Analysis).Politics and conflict  
- Statistically relevant scores (Tenure) in :  
  o Q22. Politics and interdepartmental conflict do not influence the project decision making process.  
- Low average score for Q19 and | Keeping mum, Group think, Risk Governance - Goal, denial |
<table>
<thead>
<tr>
<th>Q22 (above), plus Q21</th>
<th>Polities and interdepartmental conflict do not influence the project decision making process.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personalities do not influence the project decision making process.</td>
<td></td>
</tr>
<tr>
<td>High scores for: Q5 'Field reliability is the most important project consideration' and Q6 'Regulatory compliance is the most important project consideration'. But a relatively low score for Q9 'My company’s PDP achieves its goals.'</td>
<td></td>
</tr>
<tr>
<td>Artefacts show recalls, and influence of root cause reporting</td>
<td></td>
</tr>
</tbody>
</table>

Within interview contradictions, where it was clear the interviewee wanted to avoid either linking design with recalls and/or saying they would not speak up if they found a risk. This seemed in continuance with 'standard practice'.

* Artefacts showed recalls reported to be based on manufacturing/supply not design. Later within interview identifying the design issue based defects.
* Some interviewees saying they would not hide issues. Later in interview identifying risks not brought forward.
* Statistically relevant scores (Tenure) in:
  * Q22. Politics and interdepartmental conflict do not influence the project decision making process.

<table>
<thead>
<tr>
<th>Lack of knowledge of a formal risk</th>
<th>Slightly low average response to Q38 'The company has a formal escalation mechanism for</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Risk Governance - Reporting</th>
</tr>
</thead>
<tbody>
<tr>
<td>knowledge asymmetry</td>
</tr>
<tr>
<td>denial</td>
</tr>
</tbody>
</table>

<p>| Whistle blowing |</p>
<table>
<thead>
<tr>
<th>Escalation process (outside the Director’s)</th>
<th>Employees to raise risk concerns?” Lack of risk escalation process&quot;</th>
</tr>
</thead>
</table>
| Old governance reporting/controls that did not change from several years ago when company ownership changed | • Low Reflexivity dimension score  
• Low Clarity of Organisational Goals dimension score |
| Poor governance structures and risk assessment. Few risk structures, reporting structures and review of risk structures were identified. | • Low Clarity of Organisational goals dimension score  
• Statistically relevant scores (manager) in :  
  o Q19. There are one or two strong personalities that dominate the design review process (e.g. Failure Mode and Effects Analysis).Politics and conflict  
• Statistically relevant scores (Tenure) in :  
  o Q22. Politics and interdepartmental conflict do not influence the project decision making process.  
• Low average score for Q19 and Q22 (above), plus Q21 Personalities do not influence the project decision making process. | • Risk Governance - Reporting, Control and Goal. |
| Directors view that management is capable but reactive and not assertive in managing risk | • Low Reflexivity dimension score  
• Low Clarity of Organisational Goals dimension score | • Denial  
• Risk Governance Reporting  
• Risk Governance Controls, Reporting, Goal  
• Denial  
• Design processes |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly risk averse owners and tight financial risk analysis, yet lack of understanding that the design risks underpin the financial risks</td>
<td>• Low reflexivity, innovation and flexibility dimension scores</td>
<td></td>
</tr>
<tr>
<td>Poor customer satisfaction, caused by reliability and recall issues, yet little focus on change.</td>
<td></td>
<td></td>
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<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Low Innovation, Flexibility and Outward focus dimension scores</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Statistically relevant score (Manager) for Q45: 'This organization is quite inward looking; it does not concern itself with what is happening in the market place'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Statistically relevant score (Manager) for Q47: 'Customer needs are not considered top priority here'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Highest score of ‘Tradition’ dimension. Low score in 'innovation and Flexibility' dimensions.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Statistically relevant scores (Tenure) in:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Q35: Senior management like to keep to established, traditional ways of doing things</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Q36 The way this organisation does things has never changed very much</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Q37 Management are not interested in trying out new ideas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Risk Governance - Controls, Reporting, Goal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Denial</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Design processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>