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Barriers to Implementing PD Process Change in a British Manufacturing SME: A Case Study

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SUPERVISED BY: SIMON BARRANS

A thesis submitted to the University of Huddersfield in partial fulfilment of the requirements for the degree of Master of Science by Research

Abstract

The purpose of this thesis is to explore the hypothesis that there are barriers to the implementation of a formal new product development (NPD) process and associated tools in small to medium-sized enterprises (SMEs), and that these can be overcome by close partnership with a suitable knowledge base partner.

This thesis begins with a thorough review of existing literature relating to product development process change within SMEs. Following this, the experiences of a UK based manufacturing SME that makes use of a novel formalised process for product development are presented within a series of case studies. The Product Development (PD) process attempts to incorporate the recommendations of the literature. The case studies are based on projects that took place before and after the SME embarked upon a product development focused Knowledge Transfer Partnership.

The case studies have enabled conclusions to be drawn in relation to this hypothesis. Barriers identified within the literature review and experienced by the SME within project case studies are discussed, these include: Interference or a lack of strategy from top management; A lack of knowledge (and/or training) of the product design process and its tools; Complexity of tools and processes; A lack of resources or poor management of resources; Poor process flexibility; and prior development project failures.

New barriers are identified based upon the experiences logged within the case studies, these include: the desire (or perhaps need) within an SME to be agile and complete projects quickly or achieve a 'Quick Win', a bottleneck in the throughput of product development projects, the difficulties faced by SME's in accessing appropriate test equipment; a lack of communication (to inform company strategy) between product development team members and top management; and poor communication of information relating to a product from the product development team at the point of commercialisation.

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List of Acronyms

AUS	Associated Utility Supplies LTD
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
DNO	Distribution Network Operator
DOE	Design of Experiments
ENA	Electricity Network Association
ESI	Electrical Supply Industry
FEA	Finite Element Analysis
HOQ	House of Quality
KPI	Key Performance Indicator
KTP	Knowledge Transfer Partnership
MCI	Malleable Cast Iron
NPD	New Product Development
OLE	Overhead Line Equipment
OLEMI	Overhead Line Equipment Master Index
PA	(Network Rail) Product Acceptance
PD	Product Development
QFD	Quality Function Deployment
SME	Small or Medium Sized Enterprise
TRIZ	A Russian Acronym for The Theory of Inventive Problem Solving
VOC	Voice of the Customer

Publications Arising from this Research

L. Kangley, H., M. Barrans, S., & A. Newton, M. (2019). Making Improvements to Product Development within an SME (Vol. 7).

This paper was based on research carried out by the candidate, under the guidance of their supervisors. The candidate prepared the paper and the other authors made editorial contributions.

1 Introduction

The hypothesis of this research is that there are barriers to the implementation of a formal new product development (NPD) process and associated tools within small or medium-sized enterprises (SMEs), and that these can be overcome by close partnership with a suitable knowledge base partner. Other methods for overcoming these barriers will also be considered.

The objectives of this research are as follows:

1. To highlight barriers to the implementation of a formal new product development (NPD) process and associated tools in SME.
2. To determine how these barriers can be overcome, i.e. how change to a process for product development can be managed effectively in an SME; what role can a knowledge base play in this?
3. To assess the effectiveness of the product development tools highlighted in the literature for this SME.
4. To provide details of the cost implications that a product development process can have:
    - What is the cost in following the procedure: worked examples?
    - What was the cost (time and financial) in circumventing the procedure?
    - Is there a financial benefit in following a formal PD process– how does the financial benefit vary with potential gain (or some other measure) e.g. a plot of perceived commercial benefit vs time invested. A next step could be to look at perceived vs actual commercial benefit.
5. To determine what motivates and demotivates stakeholders to use a formalised process for PD?
    - Could the motivation to circumvent the PD process be altered once knowledge of the penalty of not following the PD procedure is more widely known?

The research methodology is to use case studies of multiple projects from a single UK based manufacturing SME to analyse the implementation and development of an evolving formal product development system over the course of a Knowledge Transfer Partnership. According to Zhan et al. (2018) 'a case study is considered an appropriate approach when answering research questions such as 'how' and 'why' things are done'.

Substantial portions of the remainder of this chapter are taken from Kangley (2019)

The company within the case study, Associated Utility Supplies LTD (AUS), is a well-established UK based SME, who have been developing, manufacturing and supplying bespoke products for the telecommunications, railway and electrical supply industries for over 20 years.

The company was founded in 1998 by its current Managing Director, who identified a gap within the Electrical Supply Industry (ESI) for a highly knowledgeable, reliable and trustworthy supplier of tools and safety critical equipment. This vision was formed whilst the founder was working within the Electrical Supply Industry, giving them a unique insight into what the industry really wanted. Soon after AUS was formed, it became clear that similar gaps existed within the Rail Electrification, Arboriculture and Telecoms sectors and a long-term strategy was formed in order to exploit these gaps.

Initially, AUS focused on supplying specialist, bought in, products into the industries. Over time, AUS took the decision to invest in its own manufacturing capability and secured the equipment, machinery

and personnel to do so; in 2015 31% of AUS's products were manufactured by AUS, by 2019, this had increased to 49%. The capability to create products to a design, paired with the desire to improve existing designs, resulted in AUS serendipitously becoming a leading innovator within the industries.

The industries that AUS are involved in are highly regulated. There are significant risks associated with activities carried out in these industries such as working at height, lifting components and working with electricity.

If a product is not approved, it will not be purchased by a utility company nor its contractors. The industries have mandatory product approvals processes in place to mitigate these risks and also to ensure lessons are learned from historical incidents. For example, a rail accident led to a train driver receiving a severe electric shock at Sutton Weaver, Cheshire 23 September 2014. The accident report (Rail Accident Investigation Branch, 2014) concluded that one underlying factor was that "Network Rail OLE inspections did not include detailed examination of the condition of the auxiliary wire strands within protective sleeves to identify wire strand breakage or fatigue precursor indications possibly present on the wire and/or the sleeve." The report goes on to make recommendations for improvements to maintenance regimes. It is now required for designers to take these modified maintenance regimes into consideration when designing equipment for these operations.

Utility companies will require evidence of conformance to standards and regulations, be it for a product or a process of design. For example, Design for Reliability is now a mandatory prerequisite for network rail product acceptance. This methodology, as detailed in a Network Rail (2018) standard (NR/L2/RSE/100/05) sets out to ensure all new products for the rail industry are designed with reliability in mind. Several product development tools, many of which are considered best practice, are mandated. Hence, for a company wishing to remain competitive in the rail industry and other regulated industries, it is necessary to become familiar with these best practice tools and to embed them in company systems.

In the twenty years that AUS have been developing products, a number of different approaches to product development have been used. Although a high-level structured process was never written, a variety of templates exist to guide users through a series of steps in an effort to ensure a level of traceability. This approach has resulted in a range of highly successful bespoke products that have allowed the SME to remain competitive.

More recently, the SME experienced a period of rapid growth. This growth has, in part, been stimulated by innovation and product development. At the time of writing AUS employ 60 full time employees. This is shown in Figure 1.1 in terms of turnover and number of full-time employees. Details of those employees who are involved in the KTP and product development can be found within section 4.3. The drop off in turnover into 2019 reflects the current phase that the Rail Industry is in; i.e. at the beginning of a control period.

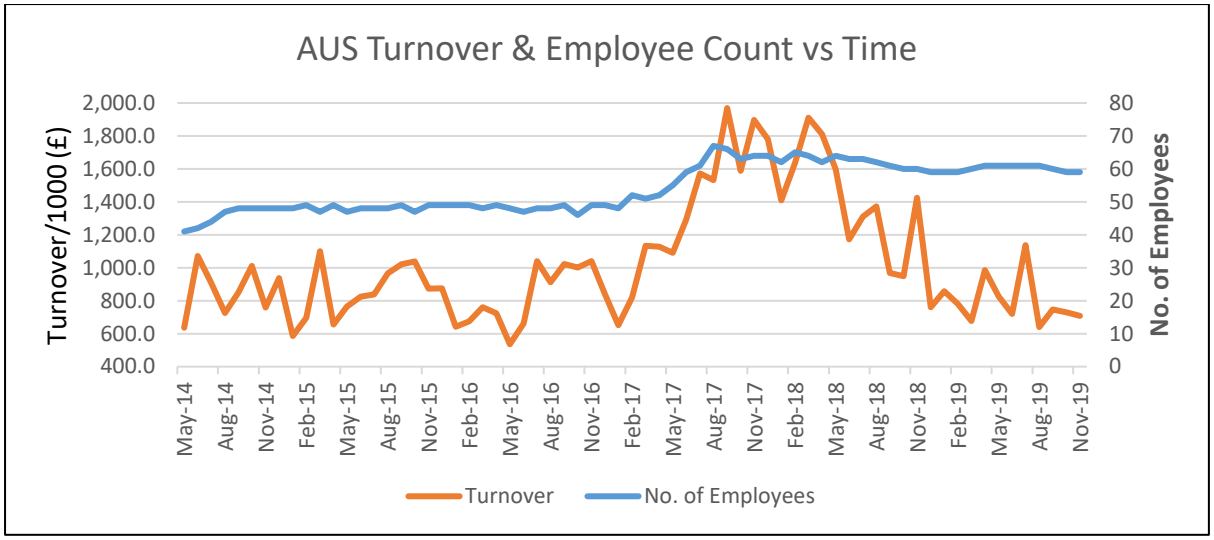


Figure 1.1 - AUS Turnover & Employee Count vs Time

In light of this, and as customer demand for more regulated and analytical product development became apparent (particularly within the Rail Electrification Industry), top management at the SME looked to gain support from local business support advisors who introduced the SME to a local university. The discussions that followed led to the formation of a three year Knowledge Transfer Partnership (KTP), which began in June 2017, with the following objective (Innovate UK, 2017): To develop and establish methodologies for innovative product design, analysis and multi-criteria optimisation, in a highly constrained design environment and to apply these to the design of novel products for rail electrification.

In the years that followed, the objective expanded in scope to include all of the industries that AUS are active in: To develop and establish methodologies for innovative product design, analysis and multi-criteria optimisation, in a highly constrained design environment and to apply these to the design of novel products for the rail electrification and electrical supply industries.

This thesis consists of a literature review, a review of product development at AUS with project case studies, a detailed analysis of the stages and tools of the formalised product development process implemented at AUS and finally a chapter that draws conclusions and opportunities for further work.

A variety of barriers to the implementation of PD process change within an SME are discovered and discussed.

2 Literature Review

This objective of this chapter is to look at the current state of the literature on product development processes within SMEs and the barriers that exist to effectively implement change to these processes and introduce new tools. Any gaps within the literature will be highlighted.

2.1 The Significance of SMEs

According to the Department for Business, Energy and Industrial strategy (BEIS, 2017), Small or Medium-sized enterprises (SMEs) represent 99.9% of companies in the UK, accounting for 60% of private sector employment and 51% of private sector turnover; almost a third of SME turnover is spread across three sectors: Construction (12%), Manufacturing (10%) and Professional, Scientific and Technical (10%). Since 2000 the number of SMEs has grown by 64%.

The European Commission (2017) defines an SME as having a staff headcount less than 250 and a turnover of less than 50m Euros. A small company is defined as having less than 50 staff and a turnover under 10m Euros.

As stated by Newton (2001), despite the chance of survival for many SMEs being low, especially in the early years, SMEs can be radical and adaptable. This means that SMEs are more likely to take the risk of investing in an innovative idea and disrupting a market. Comparatively, large businesses are much less likely to innovate due to the risk involved in innovation, their established market position and because of the complex and restrictive lines of communication that exist.

The findings of Newton are supported by research that looked at a sample of 500 South Yorkshire non-high-tech manufacturing SMEs. The research concluded that "to succeed in an intense competitive environment, non-hi-tech manufacturing SMEs must be proactive toward market opportunities, receptive to innovation and take the lead in new product innovation.'' (Laforet, 2008).

2.2 The Importance of Product Development to SMEs

For an SME, developing new and existing products is often essential for survival. It is common for an SME to find itself in an 'unstable' marketplace in which it must compete to survive and grow (Singh et al, 2008). Success can be achieved in product development by supplying a product or service, at the right time, that out-performs competitor products and meets the customer's needs. Indeed, for SMEs, effective product development provides greater returns when compared with other similar investments such as capital investment in machinery (Millward et al., 2006; Baker, 2018; Subrahmanya, 2010).

Within the UK, this phenomenon is backed by the Government via Innovate UK who, in 2016-2017 invested £561 million in cutting-edge UK firms (Innovate UK, 2016). The following statement demonstrates the return on investment Innovate UK has recorded, "Since 2007, Innovate UK has invested £1.8 billion in innovation, which has been more than matched by the private sector. This investment has returned between £11.5 billion and £13.1 billion to the economy. We have supported innovation in 7,600 organisations, creating around 55,000 new jobs." (Innovate UK, 2016)

2.3 Product Development within SMEs

To be able to offer new products to its customers, a company must have a means to develop them - a product development (PD) process; turning an idea or enquiry into something saleable. This process need not be a formalised process, and often it is not within an SME (Cooper, 2008). In support of Cooper, a study by De Waal (2016) looking at product development tool adoption in small, high-technology firms, collected data to show that 80 % of these firms did not have a formal process. It was

also observed that those firms that did have a formal process were more likely to adopt tools to assist product development. However, De Waal's study found that small high-tech firms tend to adopt fewer, less complex, tools than large firms.

Berends et al. (2013) also found that few small firms follow a formal, planned or even linear process, instead having an Ad hoc and iterative approach with loose project planning, and a stepped approach toward tangible outcomes. This research noted that SMEs tend to focus on a small number of product innovation projects and prioritise existing business over innovation projects

It is largely agreed that there is no process that is perfect for all product development projects (Salerno, 2015; De Waal, 2016). Salerno (2015) looked at 132 product innovation projects in 72 diverse companies across a variety of sectors. In line with a disillusionment to a one size fits all approach seen in the literature, their research categorised product development processes into 8 distinct categories, each suited to an initial uncertainty level and company characteristics. These categories are as follows:

1. A traditional approach: (AUS Style process) 53%; praised for its ability to enable incremental innovation, cautioned for the associated risk of inhibiting radical innovation, particularly those related to a market that is forming, as opposed to a mature or a non-existent market.
2. Anticipating sales, tailor made product. 6.1%
3. Anticipating sales: customer provided spec. 5.3%
4. Initiated by a call for innovation with funding (public/private) available. 12.9%
5. With a stoppage: 5, waiting for market (6.8%), 6, the technology (3) or 7, both (1.5%))
8. Parallel activities – initial prototype to market & development to improve/produce variations continues: 11.4%

Similarly, Lehnen (2016) looked at traditional approaches to product development that combined traditional project management tools with Cooper's stage gate model and concluded that these approaches are too rigid to successfully deliver high uncertainty projects.

Nicholas et al. (2011) reason that NPD practitioners in both SMEs and large companies have converging opinions regarding NPD best practice in that there may be core NPD practices applicable to all circumstances, meaning that " a core model of NPD excellence may be possible with further optional practices designed to accommodate companies with different circumstances and situations". However, inherent differences in these enterprises result in cultural and behavioural differences in how these best practices are delivered. Crucial factors include top level management involvement in NPD in SMEs but limited visibility of management in large enterprises, greater individual employee creativeness and general innovativeness in SMEs and rapid responsiveness to environmental changes in SMEs with a slow response in large companies.

Laforet (2008); as discussed in section 2.1, recognises that SMEs must innovate to survive. Factors that affect innovation are determined to be size, strategy and market orientation. In support of Nicholas et al. (2011), Laforet (2008) highlights weaknesses that may exist within large companies; specifically, poor flexibility and organizational structures that hinder sustained innovation.

Despite this, Laforet (2008) makes an additional distinction within the SME size bracket, hypothesising that medium sized companies (labelled as prospectors) are more innovative than small companies stating that "A small firm would have more difficulty in finding the financial support for technical work, human resource, plant and equipment, marketing and promotions when compared to medium-sized firms.".

Berends et al (2013) reasons that SMEs have the following strengths that align with Nicholas (2011): Flexibility, lack bureaucracy, efficient internal communication, and rapid response to technical and market changes. Berends also states the benefit of a process that is managed by a quick decision-making owner director and strong customer relationships.

2.4 What Makes a Good Product Development Process for an SME?

2.4.1 Customer Integration

SMEs who optimise development activities to improve customer integration are most effective (Leithold, 2016; Berends, 2013; Leithold, 2015). Lehnen (2016) put forward a process that gives lead users a significant role. Lead users are those who face future needs before others do. This approach is approved by De Waal (2016) who scored the lead user approach highly amongst a variety of functional product development tool. The opposite of a lead user is a trailing user – a user who is resistant to change and may be seen to place a high barrier on innovation or could be considered to be a 'dead weight' on innovation. Dealing with a trailing user can be challenging for an SME and developing products for this kind of user places particular demands on the innovator.

Within the industries that AUS supply into, one anecdotal example of this resulted from a Network Rail presentation on Design for Reliability during an event that was looking to attract new suppliers into the industry. The Managing Director of AUS, Simon Gibson (2018) stated 'The rigid process presented on the day only served to frighten prospective innovative suppliers from joining the rail industry" suggesting that Network Rail may be a trailing user.

Brunswicker and Vanhaverbeke (2015) found that engaging with external knowledge sources, such as a direct or indirect customer, offers performance benefits to SMEs. These are principally in the success of launching an innovation and the appropriation of financial value from new products and services.

2.4.2 Flexibility and Agility

Cooper (2008) suggests that the future of successful NPD lies within a flexible NPD process – a scalable version of the Stage-Gate process that can adapt according to the risk of a specific project; not a one-size fits all approach to NPD. This notion is supported by, Lehnen et al. (2016) who specify that product development projects that utilise methodologies such as PRINCE 2 and PMBOK alongside Cooper's stage-gate are too rigid to successfully deliver high uncertainty projects. However, the use of agile project management techniques, which are built on flexibility and leanness, can quickly respond to changing customer or market demands and have a higher chance of success.

Owens (2007) highlights the importance of a fast, high quality NPD Process. Owens recognised a need in SMEs to accelerate the process due to external pressure, such as an urgent requirement being communicated by a valued customer. This need for a flexible and agile process is further supported by other authors (Leithhold, 2016; Berends, 2013).

Salerno's (2015) research attempted to categorise innovation processes based on the initial uncertainty level and company environment. Categorising processes in this way highlights why processes must be flexible.

2.4.3 A Formal, Gated Process

According to *Leithold* (2016), a formalised NPD process is key to successful product development, but this is often lacking in SMEs (Berends, 2013; De Waal, 2016).

Many frameworks exist for building a formal process. One referred to repeatedly within the literature is the Stage-Gate process, described by Cooper (2008) as a blueprint for managing the new product

development (NPD) process to improve effectiveness and efficiency. Yet, it appears that this blueprint is written with large companies in mind, with Cooper often referring to large organisations in anecdotal evidence of the success of the Stage-Gate process. However, Cooper goes on to advise that the Stage-Gate process along with other tools (e.g. design for six-sigma, Lean, VA/VE, tollgate etc.) can be highly effective for any enterprise.

Stage-gate, as explored by Cooper (2002, 2008, 2014, 2016) is an approach to product development that involves breaking a process into stages with sign-off 'gates' to pass through. Several authors do recommend the use of stage-gate as best practice (*Leithold*, 2015; Sommer, 2015). *Leithold* (2015) praised the stage-gate system, writing that leaner versions of stage-gate were the most successful in smaller organisations. Their analysis shows that 'users with no reported innovation system estimated their innovation activities to be the least successful'.

In line with the requirement for a formalised process, De Waal (2016) states "Overemphasis on institutional process can have a chilling effect on creativity. The key to success is finding the right balance between formality and improvisation".

More recently, Leithold (2016) has acknowledged that stage-gate is not the answer to everything. This notion is supported by Salerno (2015) who put forward a strong argument for the idea that 'Not all innovation projects fit in the traditional linear process from-idea-to-launch.' and went on to state that much of the research around the 'idea to launch' stage gate model focused primarily on large enterprises.

2.5 Specialist Tools

The literature on product development has attempted to determine the usual characteristics and tools of a successful product development process. A study (De Waal, 2016) that looked at tool adoption in hi-tech SMEs scored the following 'functional' tools highly:

- Finance: sales forecast.
- Manufacturing: CAM and process flow diagram.
- Management tools: Project management, marketing plan.
- Marketing (Lower success to highest): VOC, lead user, beta testing, limited roll out, needs analysis, in-market testing, concept testing.
- Strategy: competitor analysis, IP protection, scenario planning.
- Engineering and design (high to low success rate): design mock-up, cad, alpha prototype, collaborative PD, beta prototype, rapid prototype, CAE, DOE, QFD, value analysis/engineering, gamma prototype, design for x, design for six sigma.

This paper noted that small PD teams benefit less from team management and communication tools. The following 'support' tools also scored well:

- Decision making: checklists, stage gates.
- Learning/reviewing: design review meeting, bench-marking.
- Team support: design review and workflow.
- Risk management: FMEA, Risk assessment matrix.
- Information management: change control and knowledge management.
- Creativity and problem solving: brainstorming, focus group, product lifecycle, road mapping, morphological analysis, delphi method and TRIZ.

Another Study (Miles, 2018), a survey-based study that collected data on the views of industry on tools (over 50% of respondent were large companies) for product development, collated the following data - "More than half of all respondents indicate that they seldom or never use the following NPD Tools":

- 3P - 93%
- A3 Reporting and Management - 87%
- Design for Environment (DFE) - 55%
- Design for Service (DFS) - 52%
- Pugh (Decision) Matrix - 59%
- Quality Function Deployment (QFD; aka House of Quality) - 65%
- Reusability Assessment - 74%
- Robust Designs/Taguchi methods - 74%
- Set-Based Concurrent Engineering (SBCE) - 78%
- Theory of Inventive Problem Solving (TIPS or TRIZ) - 84%
- Trade-Off Curves - 81%
- Value Engineering (VAVE) - 66%
- Visual Management - 77%

"More than half of all respondents indicate that they frequently or always used the following NPD tools":

- Competitive Benchmarking - 71%
- Design Failure Mode Effect Analysis (DFMEA) - 53%
- Design for Manufacture (DFM) - 56%
- Geometric Dimensioning & Tolerancing (GD&T) - 55%
- Modelling with Computer Aided Design tools (CAD) - 88%
- Rapid prototyping and/or 3D Printing - 60%
- Simulation tools and/or Finite Element Analysis (FEA) - 53%
- Voice of the Customer (VOC) - 62%

Table 2.1 highlights the tools that were rated positively by both De Waal (2016) and Miles (2018).

Positively Rated	**De Waal Only**	**Miles Only**	**Both**
Finance	Sales forecasting		
Management	Project management, marketing plan		
Marketing	Concept/in market testing,		VOC
Strategy	Competitive Benchmarking, IP, s		Competitive Benchmarking
Engineering and design	Design mock-up, alpha & beta prototype, collaborative PD, DOE, QFD	Geometric Dimensioning & Tolerancing	DFMEA, DFM, CAD, 3D Printing, FEA

Table 2.1- A comparison of PD tools positively rated

Tools that are repeatedly mentioned within the literature, and are pertinent to this research due to application within the case study, include:

2.5.1 The House of Quality

The Quality Function Deployment (QFD) tool, 'The House of Quality' (HOQ), which is used to transfer customer needs into an engineering specification with a focus on quality control, is mentioned throughout the literature as a valuable tool at the front end of a product development process (Chan, 2002; Yoji, 2008; Jaiswal, 2012; Leithhold, 2016; Ramirez, 2017; De Waal, 2016). This tool is an enabler of customer driven product development and ensures that the needs of the customer are met (Terninko, 1997).

Despite the wide adoption of the HOQ in product development processes, there are critics of the tool. Within Miles' (2018) survey, that primarily focused on manufacturing companies, QFD was reported as being difficult to implement despite a high level of expertise amongst tool users.

2.5.2 TRIZ – A Russian Acronym for The Theory of Inventive Problem Solving

TRIZ is a systematic approach for understanding and solving problems which allows clear thinking and the generation of innovative ideas (Oxford Creativity, 2019). Miles' (2018) study, which recommended the use of QFD and TRIZ together, rated Triz as one of the PD tools that is most difficult to sustain and implement. Triz was also rated negatively in De Waals (2016) study. Ilevbare (2013) acknowledges that the tool is generally regarded as a useful tool within the literature, but highlights a number of issues with the tool, "ranging from the complex nature of the methodology to underlying organisational and cultural issues which hinder its understanding and application".

Despite the findings of Miles (2018) and De Waal (2016), several examples of the successful utilisation of Triz exist within the literature (Vongvit, 2018; Ilevbare, 2013; Chechurina, 2016; Yeh, Huang and Yu, 2011). For instance, Vongvit (2018), used TRIZ (combined with QFD) to design a 5-axis CNC machine; concluding that the proposed approach was capable of delivering a product that meets customer needs.

2.5.3 Computational Design Analysis (Simulation) and Optimisation Tools

Millward (2006) suggested that the adoption of simple design tools will aid SME NPD performance. Computational design tools, used to model and understand real phenomenon via mathematical formulas, have advanced significantly in recent years meaning that these tools are readily available at an affordable cost. Alongside this, training courses are available which are designed to provide any capable engineer, or employee with technical knowledge or experience, with enough knowledge to make use of the tools within a matter of days, safely and effectively. (NAFEMS, 2018)

Currently, it appears that no research has looked at why the PD systems that SMEs implement are missing powerful, affordable, computational software; and specifically, how an SME can adopt such software and utilise it to efficiently develop products that meet the needs and wants of their customers.

Expanding on the over-arching hypothesis of this research, it is further proposed that British manufacturing SMEs are not utilising now cheaply available Computational Design Analysis (Simulation) and Optimisation tools, despite the democratisation movement (NAFEMS, 2018), as part of new product development (or redevelopment), but they should be. This could be down to several factors including lack of knowledge, training, expertise and research around the problems that SMEs are solving - constrained (standards, regulations), multi-criteria (customers wants/need) problems.

Easily accessible, simple, computational optimisation packages can be used to determine the optimal geometry of a mechanical component relative to a desired goal and defined criteria. This tool can offer benefits such as mass reduction and therefore potential environmental, dynamic and manual handling benefits as well as stress reduction and so improved fatigue life. Current research tends to be focused

either on constrained, single criteria optimisation or on unconstrained multi-criteria optimisation. Numerical optimisation using 'low level constraints' is common practice, for example Emmendoerfer et al. (2016) talk about optimisation with stress as the sole (low level) constraint. Here a specific product is optimised whilst ensuring the product will not fail.

2.6 Common Causes of Failure for SME PD Projects

Owens (2007) found that the following factors delay the NPD process: Poor definition of product requirements, technological uncertainty, senior management interference, lack of resources and poor project management. Owens highlights the 'ten most difficult to accomplish activities' within the research. The top three are assessing market potential, market testing and finalising the product design.

Wait (2011) supports this notion, finding that SME Product Innovation Processes (PIP) often have particular issues with the front end of the PIP and that a suitable solution to this barrier is an explicit company strategy that drives it. Looking at a single manufacturing SME, Wait found that the company strategy was held tacitly by the owner manager "only communicated emergently through his day-to-day decisions" creating a significant barrier to the PIP.

Another paper that looked at PIP in small firms by Berends et al. (2013) defined the following SME product development barriers: Limited financial resource, limited resources, inability to absorb innovation failures, lack of an appropriate skills portfolio, organisational constraints and marketing expertise. Reiterating the findings of Wait (2011), this paper highlighted issues with the front end of the PIP; small firms rely on their own customer knowledge rather than early market research.

Owens (2007) goes on to group the high impact areas of NPD into four main areas: 'Senior management support; early integration into functional NPD; availability of NPD resources and their management; and an organisational environment that supports teamwork.'

Millward et al. (2005) found that three major factors in SMEs impinge on successful NPD, these include: the influence of a dominant owner/manager (in line with Owens), a focus on finance and time ahead of other crucial factors and, in line with Owens, a failure to understand the importance of product design. These three factors are intertwined; top level management are keen to see results quickly with as little financial input as possible. When this is combined with a lack of knowledge of the product design process and pressure is put on practitioners to focus on designing, inevitably, the customer's needs and wants will be missed. For example, design documentation including market research reports, product design specifications, risk analysis (both technical and business) and verification or validation reports may be missing. This will often result in a product that will only provide a partial solution. Hence, further time and cost implications will be incurred.

All three of the case studies within the research carried out by Millward et al. showed a lack of emphasis on, and knowledge of, the product design stage. Millward et al. conclude that to improve NPD activities, SME management structures must become more strategic and willing to delegate design activities. This will facilitate an environment that is more receptive to change. Furthermore, a systematic approach to design, including formal training and the adoption of uncomplicated design tools, will aid NPD activities.

2.7 Barriers to the Implementation of Change to PD Processes in SMEs

For an SME, a formalised process or 'risk minimisation strategy', such as the Stage-Gate process, can be a daunting or imperceptible prospect. McIntyre (2009) states that, whether down to constraints on resources, lack of knowledge, or a combination of factors, SMEs are more likely to use a straightforward path, one that may seem to offer the least resistance, to develop a product. For

instance: a solution is put forward, manufacturing commences, and a trial and error cycle of testing takes place in the market in the hope that sales will take off. This is the natural, error prone, SME product development process. Wait (2011), referring to Product Innovation Processes (PIP), supports McIntyre by stating that "these processes are complex, and SMEs are known to encounter issues.". This aligns with the findings of Miles (2018) as discussed in section 2.5; tools that were perceived as complex received low levels of use by the product development personnel involved in the study.

De Waal et al (2016), supports McIntyre, but puts forward evidence to show that the natural process can be improved upon with the introduction of supporting tools, adding that SMEs are more likely to embrace low complexity functional product development tools such as those that support manufacturing, engineering, marketing and strategy. This suggests that one barrier to formalising a product development process within an SME is incorporating complicated PD tools.

Laforet (2008) emphasises some weaknesses within SMEs, including "a lack of flexibility, due to their company hierarchical structure, a partially closed culture, a lack of continuous improvement and an organizational structure that hinders sustained innovation.''

Leithhold (2016) advises that companies wishing to maximise NPD output should strive to complete activities simultaneously where possible. This results in a reduced development time and so products reach the market in the shortest time possible; thus, customer value is increased. In order to achieve this, an inherent level of flexibility must be maintained.

Millward et al (2006) conducted a study that analysed 20 highly successful Knowledge transfer partnerships, concluding with four issues that characterise design challenges within SMEs: the impact of the owner-manager, the resource constrained environment, the need for an effective design process and promoting a company vision for design and change. This aligns well with all of the findings of Laforet (2008) and Leithold (2006).

2.8 Conclusions

Aspects of a good PD process as recommended by the literature without reservations include: customer Integration; agility, computational design analysis; and optimisation. Indeed, a lack of these aspects could present a barrier to successful PD. According to the literature, the following elements can have a positive impact on a PD process where a carefully thought-out process of implementation is used and caution applied in the case of an SME: a gated process and specialist tools relevant to the Industry, e.g.: QFD.

The literature suggests that the following should be avoided in a PD process and could therefore create barriers to the implementation of a formalised or improved NPD Process in SMEs: poor definition of product requirement (A low-quality front-end process); interference or a lack of strategy from top management; technological uncertainty; a lack of resources or poor management of resources; poor project management; perceived risk with development activities; prior development project failures; relying on customer knowledge rather than market research; a lack of knowledge (and/or training) of the product design process and its tools; an environment that is not receptive to change; complexity of tools and processes; poor process flexibility; a partially closed culture; a lack of continuous improvement; and an organizational structure that hinders sustained innovation.

Within the literature, a few gaps exist. A major gap is research that looks at SMEs exclusively, this gap is highlighted within Cooper's (2015) paper on stage gates. It appears that the stage gate blueprint is written with large companies in mind, with Cooper often referring to large organisations in anecdotal evidence of the success of the Stage-Gate process. Furthermore, there is a lack of research into the take up of computational design analysis tools for product development by SMEs.

3 Product Development at AUS LTD

3.1 Case Study 0 – The Patented AUS Link Box Protection Blanket

Since AUS was founded in 1998, their legacy system for product development has produced a variety of highly successful bespoke products that have allowed the SME to remain competitive. More recently, the SME has gone through a period of rapid growth. This growth has, in part, been stimulated by innovation and product development.

3.1.1 The Product

One AUS product can be attributed to a 45% increase in turnover over a 12-month period; the link box protection blanket. In 2012 the Electricity Networks Association (ENA), the national body representing the regional Distribution Network Operators (DNO's) were charged with forming a Working Group to investigate an urgent matter of public safety. An alarming number of catastrophic explosive failures of electricity link boxes, as shown in Figures 3.1 – 3.3, generally located in pavements and public highways, were being identified. While there has yet to be a fatality as a result of these failures, there have been numerous near misses, several injuries and numerous instances of damage to vehicles and property. The pressure was increased as this was brought to the attention of the Health & Safety Executive (HSE) who immediately applied direct pressure to various DNO's to improve the situation.

Figure 3.1 - Link Box failure in Pimlico, London (BBC, 2015)

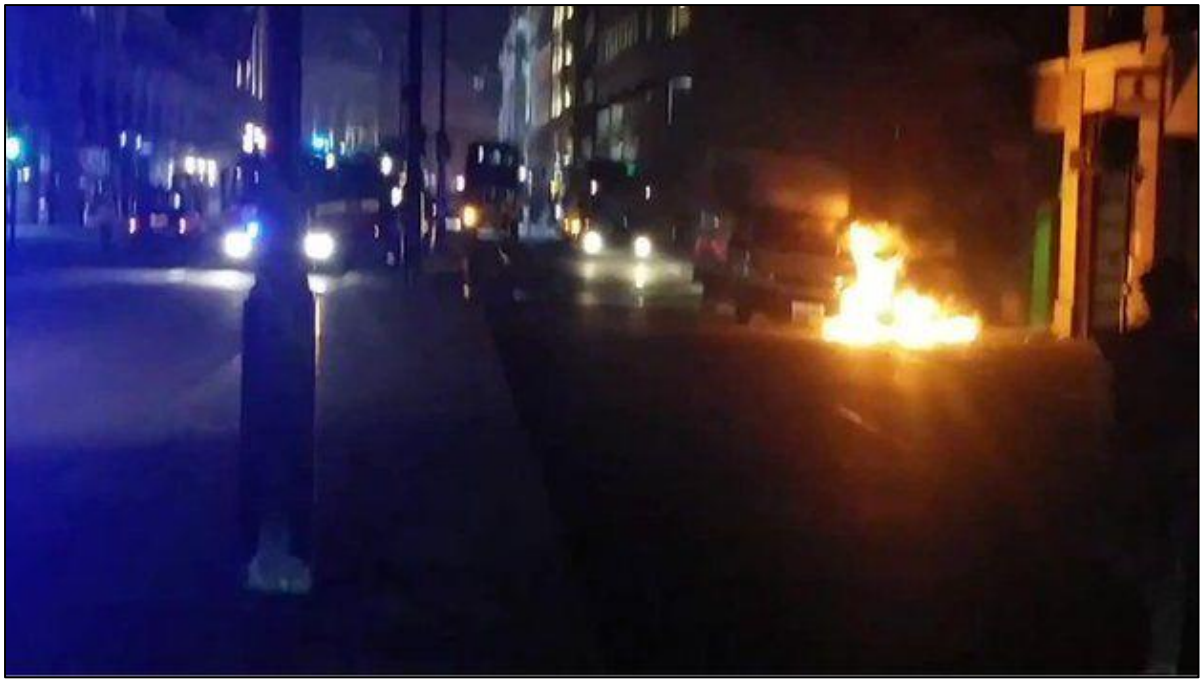


Figure 3.2 - Link box failure in Piccadilly Circus, London (BBC, 2015)

Figure 3.3 - Link Box Failure in Birmingham City Centre (BBC, 2019)

This is national problem, but London, with its exceptionally high density, heavily loaded underground cable network, was especially affected. UK Power Networks (UKPN), a lead user (Lehnen, 2016) of the failing link boxes and DNO for London and the south-east of England were put under extreme pressure by the HSE and the Media to react and come up with a means of increasing public safety.

AUS Ltd were awarded a contract to the value of approaching £8 million and started full scale delivery around May 2017. This involved significant upscaling of the production facility in Liverpool with the manufacture process reaching 2,000 blankets a week, and deliveries leaving AUS at 4,000 every two weeks. Physically, this represented around 70-80 pallets being dispatched every fortnight to one of

twenty different UKPN delivery locations. This was maintained until June 2018, and manufacture has rationalised back to around 1,000 per week.

The award of this contract in the AUS Ltd financial year 2017-18, following several years of innovation and product development, resulted in a 45% increase in the company turnover within a one-year period.

The results and benefits of this product innovation were immediately clear. Within the UKPN area alone there have been in excess of 80 disruptive failures of electricity link boxes where a blanket has been in place. The resulting effects have been negligible – no big arc flash explosions as seen in Figures 3.1 – 3.3. Instead the explosion is suppressed, and the pavement remains undamaged.

Further evidence of the success of this project is that other DNO areas are also now adopting the product - Scottish & Southern Energy (SSE), Scottish Power Energy Networks (SPEN), Electricity North West (ENW), Western Power Distribution (WPD) and Northern Ireland Electricity (NIE) have all deployed the link box protection blankets.

3.1.2 The PD Process

In 2012, when the link box failure issue was identified, UKPN at that time were already using an existing exclusive AUS patented Cable Damage Blanket product approved by them in 2001. This product was initially developed to protect the public and third parties from possible electrical arc flash issues when distribution cables are accidentally damaged by highways excavation contractors. When the pavement link box failures increased in frequency through 2013/14 UKPN contacted the Sales Director at AUS Ltd to see if AUS could assist in the onwards development of the blanket product to mitigate against the effect of disruptive failures and improve public safety.

Numerous site visits were made to fully understand the customer requirements and the specific challenges associated with the sites; which were largely in high profile locations in London such as Covent Garden and along Oxford Street. Prototype versions of the blankets were produced, and the concepts tested in a controlled environment in a Budapest test laboratory. Results appeared to be very positive.

From 2014 field trials started in London, with blankets installed through summer and winter cycles of temperature and network loading range, and this further proved the benefit of the innovation in a site environment. Through this period minor design improvements were made as understanding of the issues developed.

Further problems were identified where the fibreglass filled blanket could not physically be installed in some sites, and other sites with high water table levels required a “waterproof” blanket.

A Kevlar filled blanket was developed. AUS Ltd returned to Budapest accompanied by UKPN in August 2016 to re-prove the fibreglass blanket, and successfully test the Kevlar version.

Field trials and site visits further developed over the next few months until a policy decision was made in January 2017 that UKPN would undertake a programme to install a blanket in every link box on their network. They estimated this to be around 130,000 sites.

3.1.3 Process review

In Summary, this product which is the result of incremental lead-user assisted development to an existing and IP protected AUS product, led to a significant increase in turnover for AUS. This type of product development is discussed in the literature by Lehnen (2016), and this case study clearly supports the notion that this approach to product development can be highly successful.

Despite the success of the product, some failings of the product came to light in the initial years of use. For example: installation issues due to a wide range of box dimensions, failure to appreciate that it needed to be waterproof, unsuitability in some older link box locations and a lack of suitable equipment to install the blanket. It is probable that these requirements would not have been missed if a more formal approach to capturing the VOC and transferring this need to an engineering specification, such as QFD's HOQ, had been used at the front end of the process. If all of the product requirements had been captured from the outset, the need for a repeat visit to the electrical test house in Budapest could have been avoided – this cost saving would have been in excess of £10,000 and the product could have been in the market at least a year earlier if it had been right first time.

3.2 A Need for Change: Going into Partnership with a Knowledge base

As discussed within the Chapter 1; as a result of the rapid growth experienced by AUS around 2017, and as the need to develop more rigorous processes was recognised by top management at AUS, the KTP project between the University of Huddersfield and AUS was defined.

The KTP team consisted of Harvey Kangley (Author), who at the outset of the KTP had recently graduated with a first class honours in Mechanical Engineering (KTP Associate, Product Development Engineer), Professor Simon Barrans (KTP Academic Supervisor, University of Huddersfield), Mark Newton (KTP Industry Supervisor, General Manager, AUS) and Simon Gibson (KTP Chair, Founder and Managing Director, AUS). The KTP project was managed by the associate with the support of the other team members. Progress and plans were discussed in monthly KTP team meetings. In addition to this, quarterly meetings involving a KTP Advisor and the KTP team were used for a higher-level summary of progress and planning.

From the outset of the KTP there was strong support from top management at AUS to formalise a process for product development so little resistance to change existed. Despite this, any formal system would require a carefully thought-out implementation Plan. Top management at AUS advised that there was a high likelihood that any process could be defeated by stakeholders if it was perceived that a quick win could be achieved. Process development and implementation methods were carefully captured within the KTP's project and implementation plan.

3.3 Legacy AUS Product Development System

Substantial portions of this section are taken from Kangley (2019)

At the start of the KTP, a review of the existing product development process and its associated documentation took place. Over the twenty years that AUS had been developing products, several different approaches to product development had been used. Although a high-level structured process was never written, at this review point in the KTP, a variety of templates were in place to guide users through a series of steps to ensure a level of traceability. It seemed that the major purpose of this was to meet the requirements of ISO 9001 for the design and development of new products.

The existing documentation, copies of which can be found in Appendix A4, included:

- A Costing Log - to record any costs associated with PD
- A Design and Development Form - used for capturing an initial idea or customer enquiry.
- A Design and Development Log - a list of projects and project owners with columns for milestone completion dates
- A Design and Development Review Form - a stage sign off form for reviewing, verifying and validating progress and Test reports - although no standardised template.

This documentation acted as a means of ensuring traceability. However, other design and development activities had been carried out by AUS where this documentation had not been used and the process of design and development was determined by the project members involved at the time. Furthermore, development file storage was not standardised – not only in terms of location but also file naming and version control. When asked to describe the PD process, senior management cited the use of simple sketch drawings followed by the fabrication of an over engineered product that was tested to failure – an iterative process; often involving multiple prototypes and unnecessary costs. This process mirrored the processes described in the literature – a route through PD in SMEs that offers the least resistance (McIntyre, 2009). During the process review period it was clear that the existing design and development review form was not embedded nor a value-adding activity.

Up to the start of the KTP, product development was generally spearheaded by directors. Due to restrictions on their time the use of these templates was uncommon and an ad hoc approach to product development was the preference.

3.4 Conclusions

The case study presented within this chapter, whilst being of a highly successful product, indicated losses in time (estimated to be in excess of 12 months) and money (in excess of £10,000) due to the team responsible for the development of the product not effectively capturing the voice of the customer.

The PD process that existed at the outset of the KTP project was rudimentary, not structured and rarely followed.

4 A New Process for Product Development at AUS

4.1 The Methodological Approach to Formalising a PD process

Within the initial stages of the KTP, the decision was taken to approach process improvements using a case study methodology. This approach was essentially to propose a PD process and a number of associated tools and to trial them within the company using live projects. The formalised process was introduced and the tools either embedded or abandoned based on the outcome of those trials.

This case study method of investigation and change management, despite potentially creating an element of risk to the projects as process practitioners learn how to use the tools during projects, has been shown to be a valid method of process development. The methodology has been discussed extensively within the literature, with many researchers agreeing on the advantages and disadvantages associated with this methodology (Zainal (2007); Harrison (2017); Zhan (2018)).

Zainal (2007) highlights advantages including: data being collected within the context of its use; the ability to collect both quantitative and qualitative data, where qualitative accounts provide opportunities to understand the complexities of real-life situations which cannot always be captured via quantitative data. Zhan (2018) and Harrison (2017) support this, with Harrison stating that case study designs can address a wide range of questions that ask the why, what, and how of an issue, enabling researchers to explore, explain, describe, evaluate, and theorize about complex issues in context.

Some of the disadvantages agreed upon within the literature (Zainal (2007); Zhan (2018)) include a lack of rigour or robustness where biases from qualitative data can negatively influence research findings and conclusions; case studies providing very little basis for scientific generalisation where a small number of subjects are used; case studies producing a large amount of data which can be easily miss-managed; and reliance on single case exploration, again making generalisation problematic.

In the context of this research, the case study methodology presents the opportunity to look in detail at a specific subject - a UK based manufacturing SME. Whilst this presents risks to the rigour of the research, it enables the collection of qualitative data which provides opportunity for the exploration and interpretation of the social aspects associated with product develop within SME's. In the case of AUS, multidisciplinary teams collaboratively utilise the product development process and as a result, the human aspects are crucial to explore. Whilst this approach may limit the opportunity to make scientific generalisation, it will add knowledge to this field of research by exploring the use of a formalised product development process and its tools within the context of a British manufacturing SME.

For this research, both quantitative and qualitative data will be collected, explored and, where possible, generalisations will be made. Quantitative data will focus on the effectiveness of the PD process (e.g. output of successful products) and its tools as well as the time and cost associated with utilising the process. Qualitative data on the perceived ease vs benefit of utilising the formalised process and its tools will be collected via discussions with process practitioners and the KTP team during monthly KTP team meetings. As a means of systematically analysing this data, a table summarising the findings has been collated within chapter 9.

4.2 The Creation of a Formalised Process

Substantial portions of this section are taken from Kangley (2019)

Based on the best practice described in the literature, the merits of the tools discovered, KTP team meeting discussions, and the requirements laid out by Industry standards, tools that appeared to fit in with AUS as a business were selected. As detailed in 4.1, live projects were used alongside a continuous improvement approach to maximising the benefit of the process. Similar approaches have been successfully documented within the literature, Smeds et al (2003) discusses the use of games to simulate R&D processes whilst using real R&D projects. The AUS/University of Huddersfield KTP utilised a similar approach, however the 'game' element was replaced by discussion and analysis.

Within the context of an SME, there is no room for vast arrays of experimentation with various product development methodologies or tools (see sections 2.3 and 2.4.2); PD practitioners must be focused on the careful selection of methodologies and tools based upon the merits of the tool and the SME in question. At AUS, due to strong support from top management throughout the development of the process, methodologies and tools were selected for trial rapidly. Due to the use of real-world case studies, any ineffective aspects of the process became apparent rapidly and were abandoned.

The tools chosen included 'stage-gate' (see section 2.4.3), 'QFD's HOQ' (see section 2.5.1) and the creative problem-solving tool known as TRIZ (see section 2.5.2) and computer aided design tools (see section 2.5.3) were implemented. The HOQ methodology was initially trialled as a means of transferring the voice of the customer into engineering and design characteristics - In addition to being generally regarded as best practice, HOQ is also recommended by Network Rail's Design for Reliability standard NR/L2/RSE/0005 (SAI Global, 2019). Network Rail are keen to see innovative suppliers embed design for reliability into their quality management systems, as half of AUS's business is for the rail industry, this is further justification for using HOQ.

Following the initial review, the file storage system was also standardised.

The newly titled 'initial idea/enquiry form' (see Appendix B1) was reworked and designed to become an integral part of QFD at AUS. The form was designed to capture the VOC and ensured deliberate questions were asked, ones often missed historically, that were critical to ensuring customer satisfaction; and that enough information was captured to judge whether a project is worth pursuing from a commercial standpoint. For instance: "What is the customer timescale? Please give specific dates.", "Expected sales volume?" and "Please describe the business case that justifies the development of the product".

Alongside this, an overall process flow, as outlined in Figure 3.4, was developed in a stage-gate style; end of stage project review meetings were implemented in which resource requirements were weighed up against the potential commercial benefits. Initially, adding mandatory stage gates seemed to negate the desire to ensure a flexible process (see section 2.4.2 for the importance of a flexible process). It soon became apparent, however, that the gated approach resulted in useful discussions – and crucially, process users could be flexible within the defined process. See Appendix A1 for the full process & the interactions between stages.

At the end of Stage 1 – in which an initial idea is captured, development projects are reviewed ahead of approval, a design specification created, and concepts created – a concept selection meeting is scheduled to ensure that time is not wasted developing ideas that are not in-keeping with the product's design specification. A description of each end of stage 'gate' can be found in Figure 3.4. The full process flow (see Appendix A1), a more detailed version of Figure 3.4), which is a controlled document within the AUS quality management system (a system that must reflect actual company process under AUS's ISO 9001:2015 accreditation), reflects the need for flexibility within product

development; feedback loops exist to acknowledge the fact that the process is not always sequential; and that some products are not commercially or technically viable to develop.

Also, within the first stage, the process user is given the opportunity to make use of TRIZ – 'the tool for inventive problem solving' – TRIZ was determined to be the best fit for the process but is not mandated; another attempt to ensure flexibility.

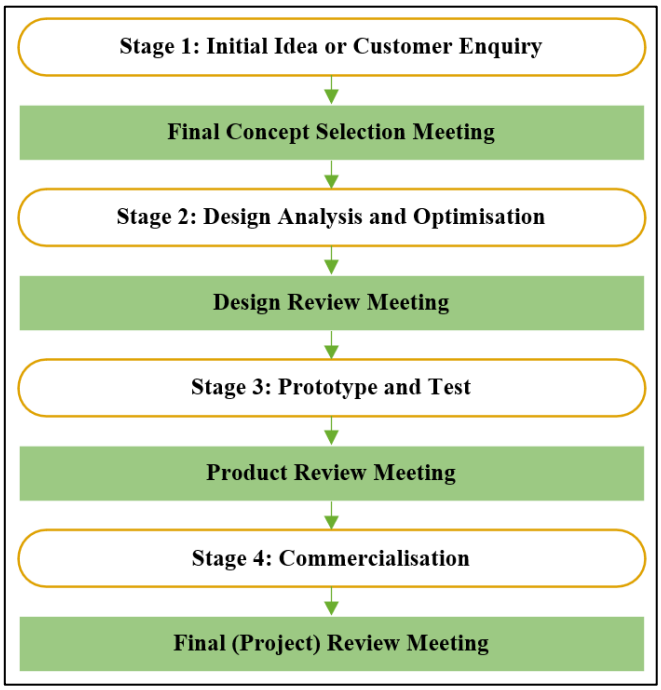


Figure 4.1 - An outline of the AUS PD Process

Once past Stage 1, when a final concept (or multiple) has been selected, and approved by a company Director, the process ensures attention is paid to design analysis. In line with the conclusions of the literature review (sections 2.5.3 & 2.8), and to implement the successful use of the tool, a methodology and process for computational design analysis and optimisation has been developed to assist this stage. At this point, the team must decide, based on costs vs benefits, whether the use of computational design is necessary, or whether a simple hand calculation will suffice. The intention behind this stage is to ensure that the design is right first time and optimised for function. The product's design specification, as agreed upon in the first stage, is used as a reference point in the end of stage meeting to ensure the analysed, optimised and detailed design is still in line with the original vision.

At Stage 3, a prototype is made according to the detailed design and testing is carried out in accordance with the requirements detailed in the initial design specification. Another end of stage meeting takes place when tests are successful, and a feedback loop takes the user back to the design analysis stage is the event of failed testing.

Stage 4, the final stage titled 'Commercialisation', emphasizes interaction with the customer during field testing, followed by dialogue with the customer to see how the customer rates the final product. The final stage is closed out with a review of the product development process to highlight any kaizen (continuous improvement) opportunities.

A stage sign-off document and a project summary document are used to ensure traceability, the templates for these documents can be found within Appendix A2 and Appendix A3 respectively.

4.3 The Product Development Team

The case studies presented, within chapters 5 – 8 of this thesis, document projects in which the AUS product development team utilised the formalised product development process. The team was made up of:

The KTP team (section 3.2), with Harvey Kangley (Author) acting as product development lead. As the author of this thesis and the person responsible for the success of the product development projects presented within the case studies of this thesis, it could be argued that a conflict of interest exists. However, this fact also places the author in the ideal position to deliver the research objectives; which have been carefully selected to combat any potential conflicting interests. The Author and the KTP team were responsible for the successful introduction of the process and its tools, as such it is recognised that these team members may have been biased towards process implementation without room for continuous improvement, regardless of process/tool effectiveness. To combat this, Key Performance Indicators were established to provide an objective means of reviewing the effectiveness of the process, its tools and outputs.

Mechanical engineering placement students Rhys Martindale, Ciera Greensill (replacing Rhys) and Greg Jones (2 month summer placement) were brought in to the product development team to increase PD project throughput and provide a degree of impartiality in the evaluation of the PD process; as they had not previously been exposed to systems within the company. These placement students were the team members most closely involved with the operation of the new tools being used.

It was also necessary to include other people in the process of developing the PD process as this process had to integrate with other company systems. It was recognised that these people may have been resistant to change and therefore biased against the introduction to new tools. However, as an objective of the research was to find ways of overcoming the barriers to the introduction of new tools and processes in SME's, it was essential that their reaction to these was gauged. These team members include:

Alan Stringer, Manufacturing Engineering Manager; Craig Lees, Manufacturing Planner; Sales Directors: Rick Tucker (Rail Sales Director) and Richard Brown (ESI Sales Director); and Technical Sales/Accounts Managers: 4 members within the ESI team and 4 members within the Rail team.

4.4 Conclusions

This research utilises the case study methodology, with a focus on a single subject and multiple product development project cases.

As a result of the KTP project (section 3.2), a new flexible but formal and gated PD process was defined, based on the findings of the literature review. This process focuses on the use of specialist, relevant and advanced PD tools. These tools allow the voice of the customer to be captured and transferred into an engineering design specification. Creative problem solving and computational design analysis and optimisation techniques are also introduced to AUS LTD within the new process to ensure solutions are fully explored and optimised A documented four stage process provides the roadmap for process users, who are further supported by standardised templates and documentation.

The process is utilised by AUS's product development team.

5 Stage 1: Initial Idea through Concept Selection

The objective of this chapter is to outline the first stage of the AUS product development process, which exists to turn ideas or customer enquiries into concepts, and then look in detail at product development projects at AUS that made, or attempted to make, use of this formalised process over the course of the KTP. The focus of discussion around the case studies will be the barriers and challenges faced, the impact of those and the action taken.

5.1 Stage 1: The Process

Based upon the findings detailed within the literature, PD tools with an appropriate level of sophistication were selected and added to a formal process for PD at AUS. The segment of the process presented in Figure 4.1 shows stage one of the AUS PD process.

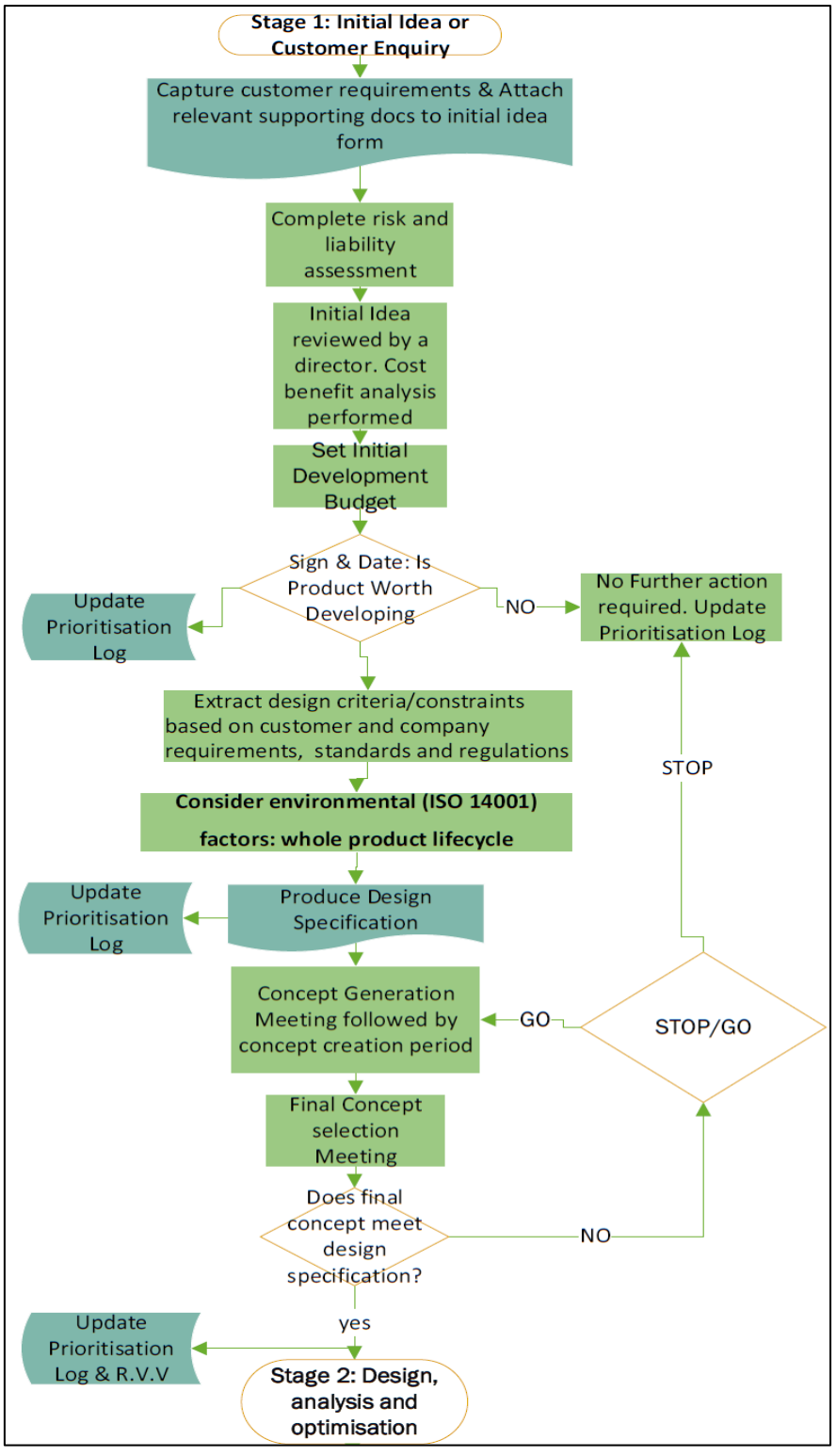


Figure 5.1 - Stage One of the AUS Product Development Process

This process can be initiated by internal or external customers. The typical route to the process via internal customers involves a desire to improve an aspect of an existing product; this can also be driven by external customer feedback and quality investigations. There is an additional 'gate-keeper' process for existing products, titled 'Engineering Change Request Process.' – see section 5.1.2. External customer routes to the process are generally via customer facing staff, namely Sales Managers, who operate within regional areas.

All steps within stage one up to "Sign and date: is product worth developing?" are captured within one of two documents titled "Engineering Change Request Form" and "Initial Idea/Enquiry form"; for existing and new products respectively. These documents (see Appendix B1) serve as process 'gate-keepers' and ensure that only projects with an appropriate level of commercial potential, are taken forward. This is an aspect of the AUS PD process that is not widely discussed in the literature but is fundamental to successful product development within this SME.

Without a commercial review taking place to filter out projects, the development team's time could be wasted on projects that offer little return. The perceived benefit of developing new products would then be affected, potentially creating a barrier to the implementation of change to a PD process.

Once approval is given to a project, the next step is to hold a 'problem definition meeting' to extract engineering and design criteria based on the information presented in the initial idea form, the company's experience, relevant standards and regulations e.g. ISO 14001. And the purpose of this meeting is to produce a design specification; the template for which can be seen in Appendix B2.

At AUS, sales managers typically have a number of years of hands on industrial experience so have a good grasp of the customer 'needs'. Despite this, the temptation of a quick sale can lead to the wants of the customer being perceived as the optimum solution from the outset. In line with recommended industry best practice (specifically, within Network Rail's Design for Reliability standard (Network Rail, 2018), the Quality function deployment tool 'House of Quality' (HOQ) is utilised to create an (ideally unbiased) design specification. The problem definition meeting is designed to facilitate generation of a robust product design specification as a group exercise and has the following agenda:

1. Post-it-note/brainstorming method to identify customer needs or benefits ('Customers buy benefits').
2. Group customer requirements together and carefully define.
3. Populate the first HOQ column with the defined customer needs.
4. Complete HOQ product planning process as a team. The output is a list of measurable engineering characteristics/design requirements or 'what must be achieved to satisfy the customers need'.
5. Collect performance measures via planning matrix: Weight importance & review competitor products: Involve customers where possible.
6. Identify contradiction(s) & TRIZ design principles using the TRIZ technical correlation matrix.

Typically, the problem definition meeting Involves a sales team member (who has captured the VOC), a manufacturing team member and a member of the product development team. This multidisciplinary approach is designed to create an innovative team dynamic where project team members often look at a problem in a unique way.

Within the problem definition meeting, a period of a time to generate concepts is agreed upon and the next development team meeting scheduled. This meeting is used to select a final concept or concepts which are taken forward into stage 2 – 'Design Analysis and Optimisation'. The creative problem-solving tool TRIZ is recommended to assist this stage; see point six in the problem definition meeting agenda. Using the proceedings from the problem definition meeting, a product design specification that also highlights contradictions & design principles is created and agreed upon.

The prioritisation log (referenced in the left column in Figure 4.1) is a tool, in the form of a spreadsheet, used by AUS to manage product development priorities and allocate resource. This is updated at various intervals throughout the process to communicate the status of active projects to the AUS management team. The R.V.V (Review, Verify and Validate), referenced alongside the prioritisation log, is synonymous with the end of stage sign off sheet.

5.2 Project Case Study 1 (S1): Rod Light

5.2.1 Overview

Linesmen build and maintain the electrical systems and infrastructure which generate and transport electricity. A key item in any linesman's toolbox (or vehicle) are glass fibre operating rods, these rods are shown in Figure 4.2 and in use in Figures 4.3 and 4.4. These are electrically insulated to 75 kV/ft. Rod sets come with various end adapters for performing a range of tasks, adapters are secured to the rods via the connection shown in the right-hand image in Figure 4.2.

Figure 5.2 - AUS Insulated Intermediate and Top (right) Operating Rods

Linesmen often use operating rods from the ground, this removes the need to climb a pole and hence the risk of working at height. These rods can reach in excess of 30 feet (4ft per rod). Maintenance is carried out at all hours and in all conditions (often storms), this means that they can face some challenging circumstances when it comes to visibility. As illustrated by Figures 4.3 and 4.4, the places in which the linesmen use the rods aren't always accessible by vehicle.

Figure 5.4 – AUS rod ice removal (Keenor, 2019)

Figure 5.3 - AUS rod with 'Silky' Saw adapter

Current solutions to the visibility challenge include attaching a torch to the rod with tape, having a second person operating a torch on the ground, or standing a torch on the floor so it illuminates the working area. These solutions are either unreliable or require two people.

At present, the preferred concept is a light emitting section of 'rod'. Alternatively, an external rod attachment would be considered. However, there is a risk associated with this, in that any additional width to the rods may get caught during operation. Rods are also used by other professionals such as arborists; in this case, an external light may catch on branches.

5.2.2 Design Specification Generation

For this project, the following documentation (as shown in a series of Figures 4.5 – 4.9) was generated. The format of this documentation reflects the templates used at the time of the project and does not reflect the template detailed in Appendix B1, which is the most recent iteration of the form.

AUS

Initial Idea/Enquiry Form 8.0041.5

Date:	1/8/18
Name:	Rhys Matindale

Project Title: Rod Light

Development No:

Customer: AUS (Internal Project)	**E-Mail: N/A**
Contact: N/A	**Tel: N/A**

1. **Description:**

A light for insulated operating rods

2. **Who will be liable for this product?** ***If AUS have designed a product then AUS are liable. If AUS manufacture to a technical drawing, acting as a subcontractor, the liability lies elsewhere and it can be assumed the design meets relevant standards and regulations. If a technical drawing is provided skip sections 3-5.***

AUS

3. **If AUS are liable, are there any Risk implications for the end user in the following areas: Electrical, Lifting Equipment, Working at height, Other?**

Electrical, Lifting (standard rod operations).

4. **List standards and regulations specified by the customer:**

N/A

5. **Performance Criteria:**
E.g. Expected Loading, Environmental conditions, etc. Please provide mitigation (Design requirements) for risks stated above.

Must not affect the electrical or mechanical properties of the rod, be bright, be fixed onto or part of the rod.

6. **Customer Timescale:** ***Please give specific dates***

17/8/18, concept selection meeting.

7. **Describe the business case that justifies proceeding with this product:**

Expected sales volume:_____

Target Price:_____

8. **Director Approval:**
State the conditions of approval including Development Budget, critical dates, etc.

Budget_____

Name: **Sign:** **Date:**

Please attach Sketch/Drawing/Photo (Attach additional drawings/Specifications/Photographs as applicable)

Figure 5.5 – The Rod Light Project's Initial Idea form (Martindale, R, 2018)

Figure 4.5 shows the rod light project initial idea form, the details within sections 7 and 8 of the form have been withheld. This form reflects a lack of captured requirements at the outset of this project.

Despite the lack of requirements captured within the initial idea form, Figures 4.6, 4.7 and 4.8, depict a detailed use of the QFD HOQ tool as completed during the Problem Definition Meeting.

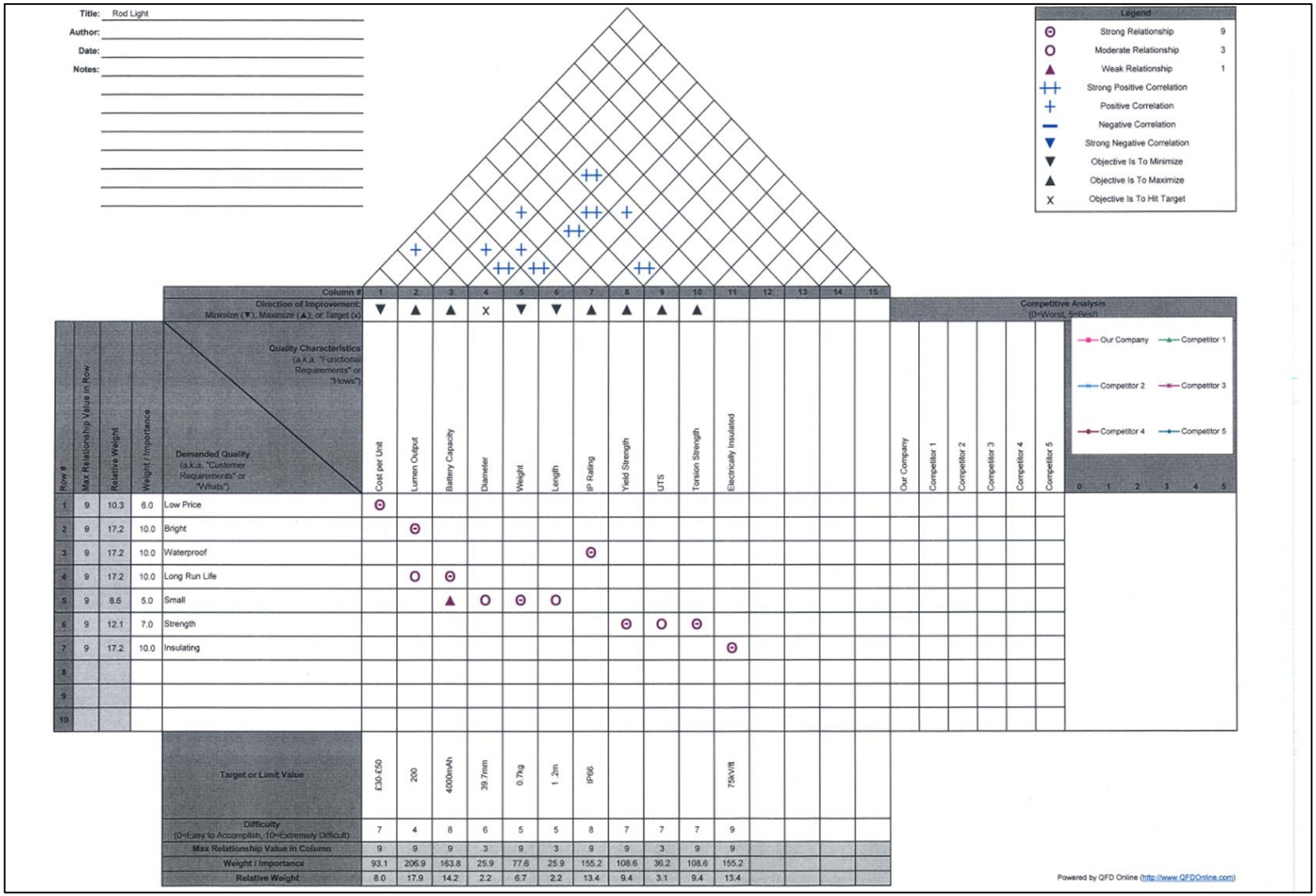


Figure 5.6 - HOQ 1, Rod Light (Martindale, R, 2018)

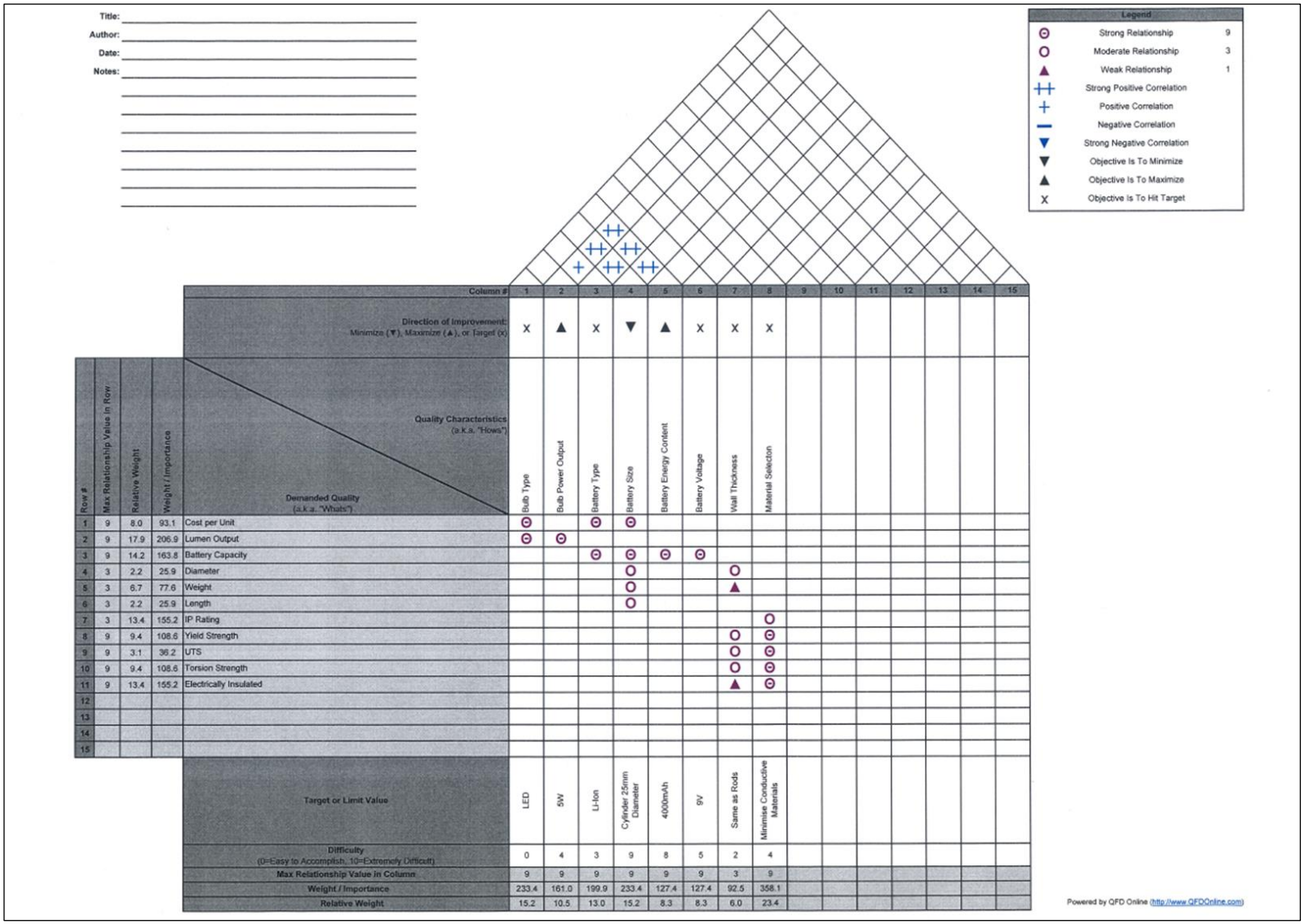


Figure 5.7 - HOQ 2, Rod Light (Martindale, R, 2018)

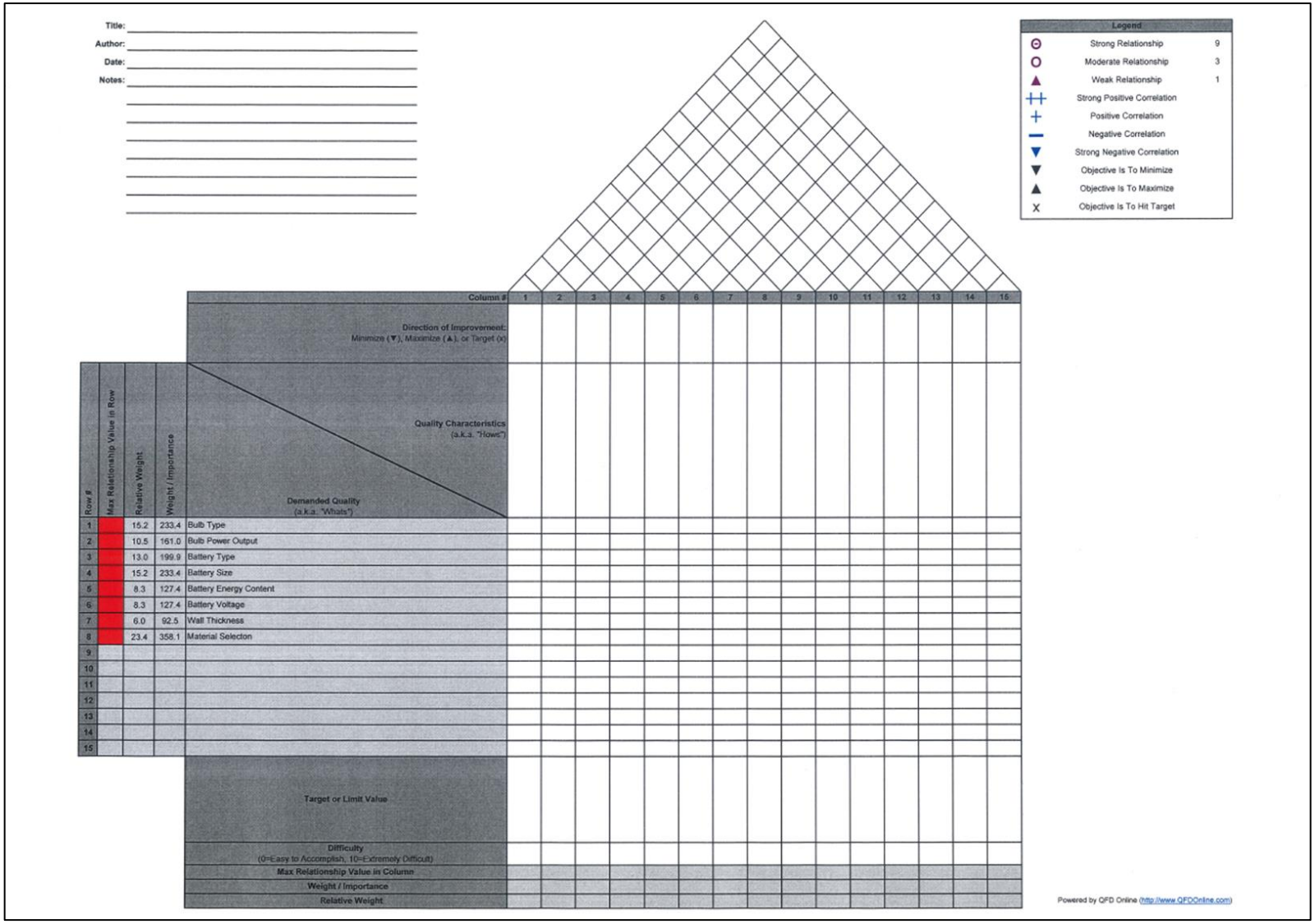


Figure 5.8 - HOQ 3, Rod Light (Martindale, R, 2018)

Figure 6, showing the first house, was used to convert customer requirements into engineering characteristics; in line with the process detailed within section 4.1, all aspects of the tool were utilised at this stage except for the competitor analysis. In this instance, the process user went a step further than the process mandates and completed the second phase of the HOQ and defined some specific quality characteristics. The user then combined the engineering and quality characteristics into a product design specification as shown in Figure 4.9.

Product Design Specification

- Operates in all Weather
- Lights Immediate Area
- Doesn't Affect Electrical Properties of Rod
- Doesn't Affect Mechanical Properties of Rod

- Long Operating Time
- Rechargeable
- No Bigger Than One Rod
- Cost <£50

Contradictions

- Battery Capacity/Battery Size & Weight
- Bulb Power Output/Bulb Energy Usage
- Bulb Power Output/Battery Capacity

Figure 5.9 – Rod Light Product Design Specification & contradictions (Martindale, R, 2018)

5.2.3 Concept Generation and Selection

Based upon the design specification detailed in Figure 4.9, three concepts were generated. Despite contradictions being captured within this specification, the process user did not document the use of TRIZ design principles. At the time of this project, the decision was taken by the process user to list the advantages and disadvantages associated with each concept; these were discussed alongside illustrations of each concept and the preferred concept selected during a concept selection meeting attended by the product development team and top management.

5.2.3.1 Concept 1

Concept 1 is device which illuminates the work area using LED strips. The device secures on to the top of a rod set, the device would provide the top rod connection for any adapters required.

Pros:

- Illuminates top area
- Battery contained in core
- 3 LED strips
- Facing outward
- Positioned at top of rod

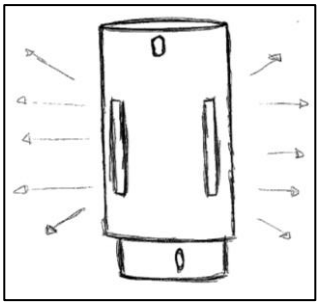


Figure 5.10 - Rod Light Concept 1 (Martindale, R, 2018)

Cons:

- Undergoes same stresses as rod
- Could affect electrical properties by replacing a section of the rod
- Single purpose/industry (Unless adapted)
- Need light shielding from ground
- Needs adapting to fix to rod

5.2.3.2 Concept 2

Concept two acts a miniature section of the rod set. The section houses a light source at the base with a reflective mirror acting to disperse the light at the top.

Pros:

- Single or Multiple Bulb
- Mirror used to reflect light outwards
- Simple design
- Battery in bottom

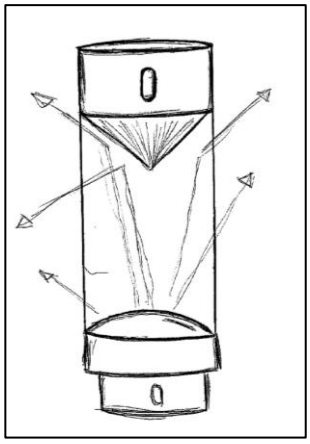


Figure 5.11 - Rod Light Concept 2 (Martindale, R, 2018)

Cons:

- Undergoes same stresses as rod
- Could affect electrical properties of the rod
- Single purpose/industry (Unless adapted)
- Need light shielding from ground
- Needs adapting to fix to rod

5.2.3.3 Concept 3

This concept is a light device that can be attached to the outside of a rod in any position as required. LEDs on one side of the device provide a source of light.

Pros:

- Small
- Can be strapped to any point of the rod
- Can have other uses (attached to any tube)
- No rod attachments
- Low cost
- Doesn't affect rod properties

Cons:

- Could slip/fall
- Restricted battery size
- Powerful LED required

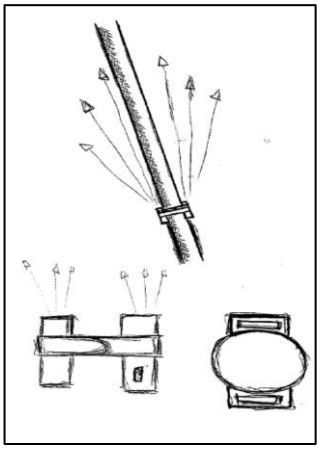


Figure 5.12 - Rod Light Concept 3 (Martindale, R, 2018)

Concept 2 was the concept selected to be taken into stage 2 – after this decision was made, other product development priorities presented themselves and this project was put on hold.

5.2.4 Case Study Review

This project was used as a means of embedding Stage 1 of the AUS PD process (and associated tools) and training a new member of the AUS PD team; a mechanical engineering placement student. The Rod Light project was championed by the placement student. Having spent around a week becoming familiar with the process and learning about the tools and their significance, the process was followed stringently. The student was challenged to complete the Rod-light project, and at the same time to demonstrate use of QFD tools to produce a product specification (e.g. House of Quality). A thorough use of QFD's HOQ ensured that all customer needs were highlighted, and a detailed design specification created. These initial steps highlighted contradictions within the specification. The process and its tools served their purpose and feasible concepts were generated.

According to the literature, potential barriers to the use of specialist tools within a PD process include a lack of knowledge or training on how to use the tool and tool complexity. This case study supports the notion that with training, specifically a 'training by doing' approach, PD practitioners can increase the likelihood of successful PD tool adoption in SMEs. Furthermore, whilst QFD's HOQ could be described as a complex tool, this case study has shown that a carefully detailed guide on how to use the tool can be used to overcome the perceived complexity barrier.

Whilst it was envisaged that there was a market for this product, this project had a history of stalling at AUS after numerous attempts outside of a formal process. Potentially as a result of this, the project had a low priority associated with it and therefore other projects took priority – this notion is supported by the literature in that prior project failures can present a barrier to successful product development.

The following points should also be noted. The process was not followed by a multidisciplinary team and as a result and given the lack of industrial experience of the student, manufacturability of the concepts presented may be poor. Furthermore, the preferred concept (the florescent tube – see concept 2) was previously selected by AUS senior management in an earlier iteration of this project. Despite this, when concepts, that were arguably more straightforward to deliver and made use of recent advances in technology, were offered, the old concept was reselected; perhaps this was the result of bias within the selection. In hindsight, a more objective approach to concept selection could have been beneficial in this case; this type of approach may also help to reduce the potentially

negative impact of senior management interference on the product development process as discussed within the literature review.

5.3 Project Case Study 2 (S1): Long Portable Earths

5.3.1 Overview

The rail electrification industry expressed a requirement for a long portable earthing system with an improved level of safety.

Long portable earths act as a secondary defence to protect operators (linesmen) from OLE (overhead line equipment) that is unelectrified/isolated. Certain scenarios, such as induced voltages, fault currents and accidental power-ups can potentially lead to the OLE becoming live whilst the operator is in the process of maintaining/repairing or replacing OLE. The portable earths, placed either side of the work area, will stop any current reaching the operator by directing it to earth. The (line side) clamp (A in Figure 13) is connected to the potentially live wire and the Earth/'G' clamp (B in Figure 4.13) to an earthing point, such as a piece of bonded steelwork or rail, at the other end. The two clamps are connected by a flexible aluminium cable and crimped aluminium lugs.

When installing the traditional system, if the line side clamp (A) is installed to the line before the 'G-Clamp' (B) there is a risk of fatality by electrocution. The correct and safe process is to install the G-clamp' first and then the line side clamp using insulated operating rods. The long portable earth redesign project was initiated formally following the traditional system being condemned by the HSE/Network Rail following a fatal incident in 1998 (Network Rail, 2019).

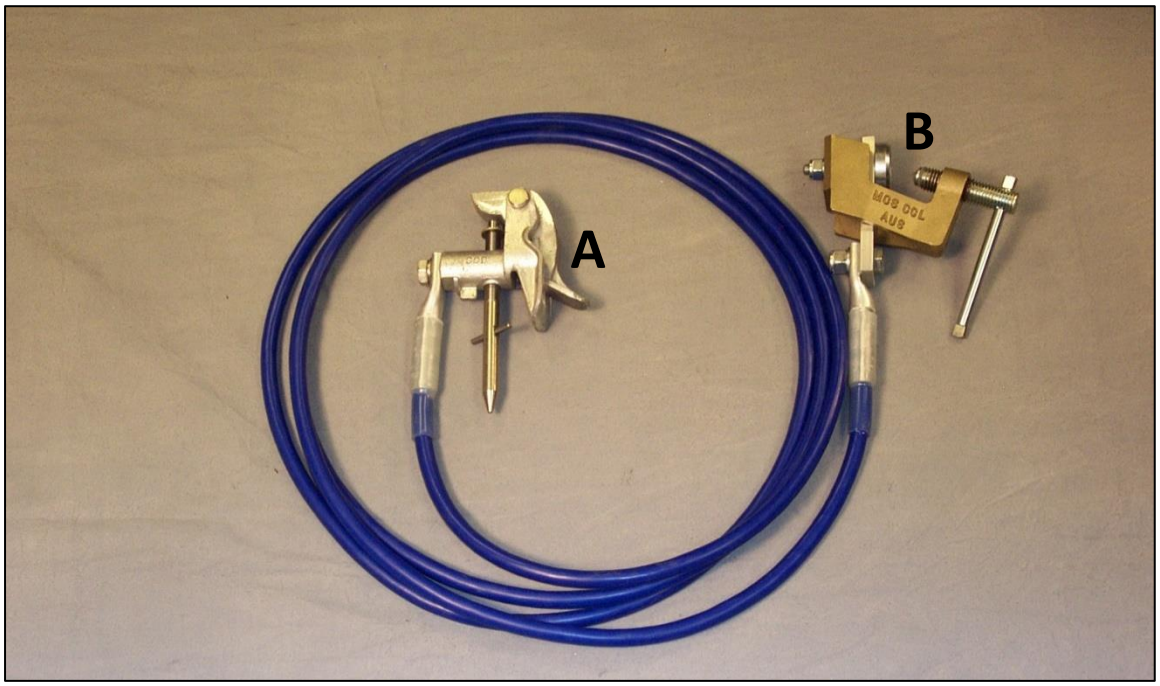


Figure 5.13 – A Traditional Long Blue Earth

AUS set out to offer a product to market with reduced risk for operators. Ideally, the improved system would ensure that the line side clamp could not physically be installed before the G-clamp.

5.3.2 Design Specification Creation

The Initial Idea form for this project can be seen in Figure 4.14.

The QFD HOQ tool was used for this project using the templates shown in Figures 4.6 and 4.7, however all steps other than those detailed below were missed. This was a result of the process user attempting

to shortcut the process and accelerate the project which was given a high priority. In the first 'house' the column titled "Demanded Quality" was populated with the following statements of customer requirements:

- Ensures correct and safe removal of earths from overhead lines
- Rugged construction and good corrosion resistance
- Tamper-proof, e.g. multiple key combinations
- Suitable for attachment onto corroded rails, steel framework or earthing points
- Suitable for fitting to all common types of running and conductor rails
- Ensures that electrocution is impossible during installation/removal

These statements of demanded quality were converted into the following engineering characteristics:

- Ensures correct and safe removal of earths from overhead lines as per mandatory process
- No temptation for user to use an alternative tool or shortcut the process
- Ensures that electrocution is impossible during installation/removal
- Rugged construction and good corrosion resistance
- Suitable for corroded rails, steel framework or earthing points
- Suitable for fitting to all common types of running and conductor rails
- Quick and easy to install/fit – trains may still be running

AUS

Initial Idea/Enquiry Form 8.0041.5

Date:	10/10/18
Name:	H.Kangley

Project Title: Long blue earth: G-CLAMP Product Change

Development No:62

Customer: AUS RAIL	**E-Mail:**
Contact: BAZ/RICK	**Tel:**

1. **Description:**

G-CLAMP: Design change to ensure the correct installation process is followed.

2. **Who will be liable for this product?** ***If AUS have designed a product then AUS are liable. If AUS manufacture to a technical drawing, acting as a subcontractor, the liability lies elsewhere and it can be assumed the design meets relevant standards and regulations. If a technical drawing is provided skip sections 3-5.***

AUS

3. **If AUS are liable, are there any Risk implications for the end user in the following areas:**
Electrical, Lifting Equipment, Working at height, Other?

Electrical

4. **List standards and regulations specified by the customer:**

Network rail: safety notice

5. **Performance Criteria:**
E.g. Expected Loading, Environmental conditions, etc. Please provide mitigation (Design requirements) for risks stated above.

All weather conditions, stored in damp conditions.
With current guidelines: The design change must ensure that the conductor clamp cannot be fitted without the G clamp installation complete.
Route cause of change requirement: if the conductor clamp is connected and someone contacts the G-clamp they could be electrocuted.

6. **Customer Timescale:** ***Please give specific dates***

ASAP

7. **Describe the business case that justifies proceeding with this product:**

Network rail safety bulleting outlawing old design, all contractors + network rail must replace their clamp/earth.

Expected sales volume: 100-1000

Target Price: In line with competitor product (see P&B)

8. **Director Approval:**
State the conditions of approval including Development Budget, critical dates, etc.

Budget_____

Name: **Sign:** **Date:**

Please attach Sketch/Drawing/Photo (Attach additional drawings/Specifications/Photographs as applicable)

Figure 5.14 - Long Portable Earth Initial Idea Form (Sensitive data removed)

The engineering characteristics listed within the design specification were used as the basis for the product design specification, and from these requirements and some supporting documentation (images of the existing solution and a video of the existing process) concepts were created by members of the development team during a 'concept generation period'.

To initiate the period of concept generation, in line with the AUS process, a concept generation meeting was held. Within this meeting the product design specification and supporting documents were presented alongside perceived contradictions and the associated TRIZ design principles. The **contradictions** and associated TRIZ design principles (numbered below each contradiction) were as follows:

The product ensures correct and safe removal of earths from overhead lines as per mandatory process AND is quick and easy to install/fit. The TRIZ features deemed to match this potential contradiction in requirements were 36 – Design complexity and 33 – Ease of operation.
The 'Known Solutions' or 'Design Principles' matching this contradiction are as follows:
9. Prior Counteraction: e.g. Lead apron during X-Rays. Discussion point: *Could we Insulate the device?*
26. Copying – replace expensive objects with simpler inexpensive ones
27. Cheap short-living objects – e.g. paper cups instead of durable glass in hotel
24. See below

Tamper proof AND good manufacturability. The TRIZ features deemed to best fit this potential contradiction in requirements were 31 – Object-generated harmful and 32 – Ease of Manufacture.
The 'Known Solutions' or 'Design Principles' matching this contradiction are as follows:
2. Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object. E.g. Locate a noisy compressor outside the building. Discussion point: *Would it be beneficial for the G-clamp to be separate from the rest of the earth?*
24. Intermediary – e.g. oven glove for hot dishes. Plectrum for guitar. Discussion point: *Could we introduce some insulated tooling for each earth or an insulated handle?*

5.3.3 Concept Generation and Selection

Following a period of concept generation, in which all team members were tasked with creating a minimum of two concepts each, a concept selection meeting was held and concepts were presented by team members but no concept selected; the consensus was that with more time and development of ideas, improved concepts were achievable. In this instance, a feedback loop exists that guides process users back towards another period of concept generation. This process was followed, and during the second concept selection meeting, a highly innovative final concept selected.

Concept one, shown in Figure 4.15, uses a locking cam (see arrow in Figure 4.15) as the means of unlocking the earth clamp – this tool would serve both as the jaw of the line side clamp and the removal tool. The tool would be removable via a reusable pin. Concept two, is similar to the first concept, however the tip of the 'bayonet fitting', as labelled in Figure 4.16, would serve as the earth clamp removal key. Concept three makes use of a removable clamp spindle, as shown in Figure 4.17, that also acts as an earth clamp removal tool. The fourth concept (Figure 4.18) separates the earth side clamp from the rest of the earth via a socket connection. The earth side clamp could only be removed via a hex head worm screw (similar to an adjustable spanner mechanism) that is hidden within the socket connection.

Other considerations were deliberated as shown in Figure 4.19, as well as an innovation magnetic approach to connecting earths to steelwork (Figure 4.20). Further details of the concepts presented in the concept selection meetings, alongside the pros and cons of each are listed within figure 4.15-4.20:

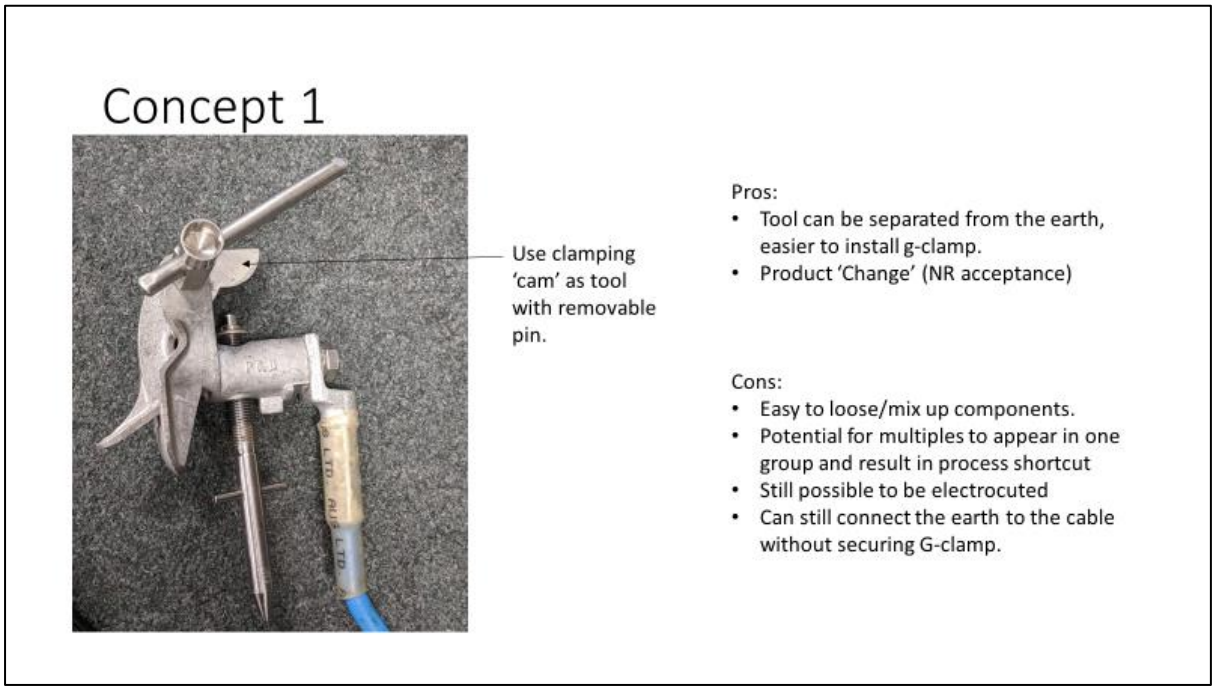


Figure 5.15 – Long Portable Earth Concept 1

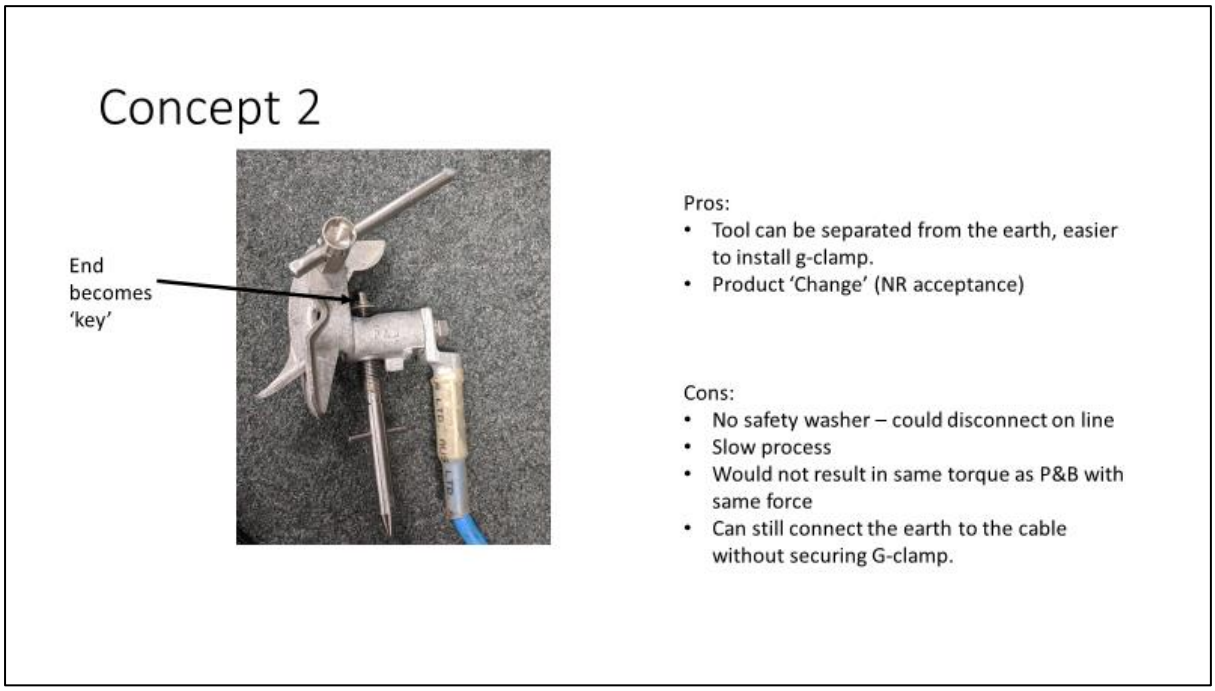


Figure 5.16 – Long Portable Earth Concept 2

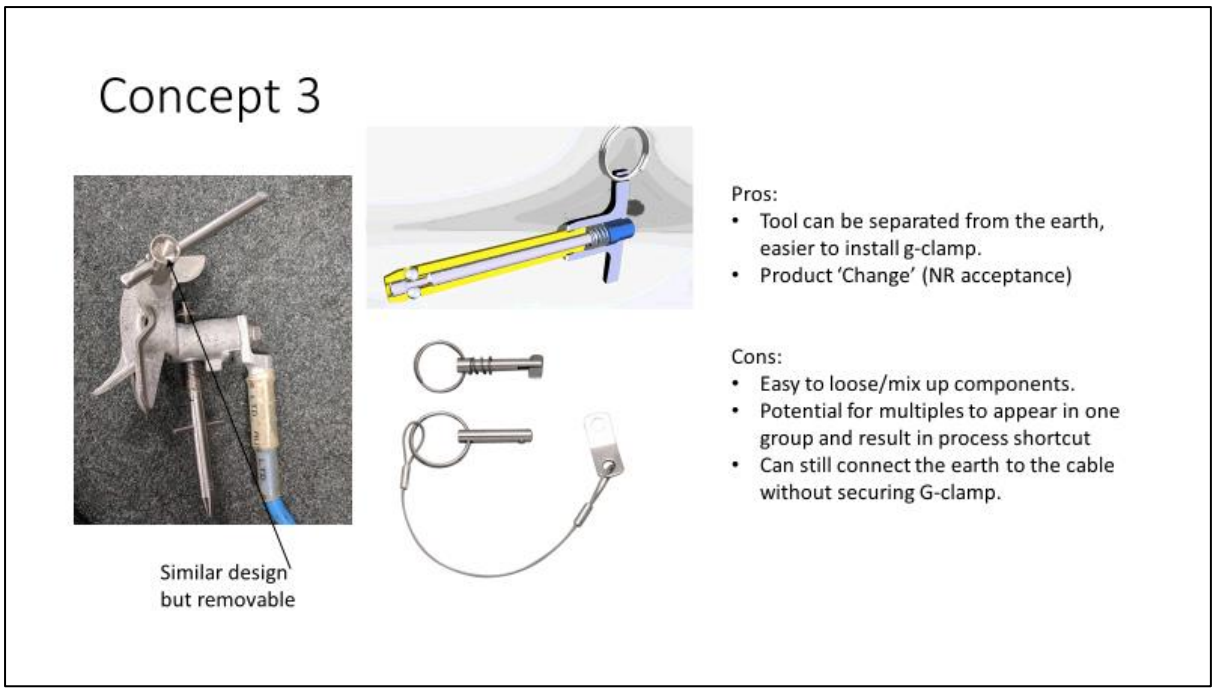


Figure 5.17 – Long Portable Earth Concept 3

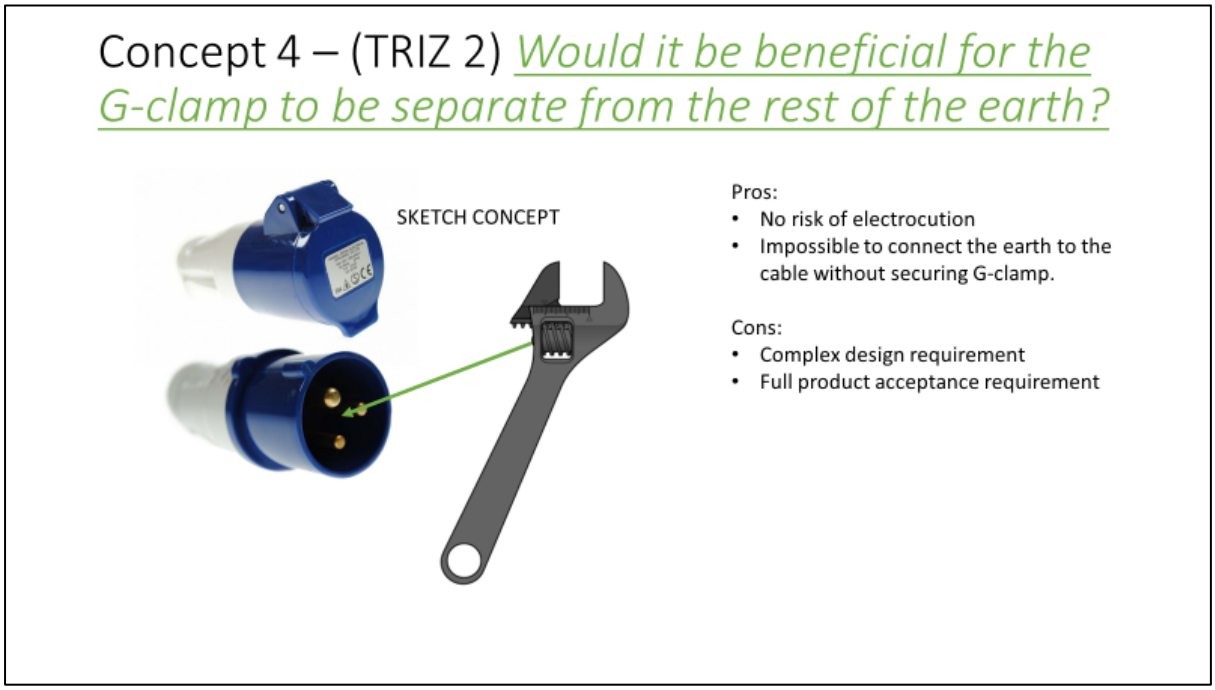


Figure 5.18 – Long Portable Earth Concept 4

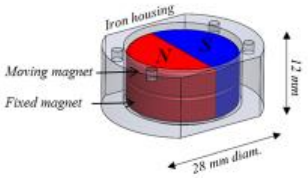
Other considerations/ideas

- Colour coding parts to reinforce process steps
- If a key system is used > 20 combinations or even a unique design for every system….
- Could we Insulate the unnecessarily exposed parts of the device? (TRIZ 9) e.g. Plastic coating.
- Could we introduce some insulated tooling for each or an insulated handle? (TRIZ 24)

Figure 5.19 – Long Portable Earth 'Other Considerations'

Magnetic Clamp/Base

- On/Off magnet used to either close a clamp onto section, or flat base would sit directly onto surface
- Magnet works by rotating one magnet either another magnet, or in between two blocks or Iron, separated by aluminium
- Only needs to be rotated by 90 degrees
- Key on line clamp used to turn magnet on/off
- Further research needed into how a current running through the earth would effect magnet



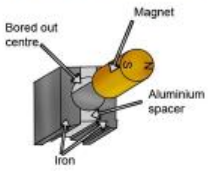


Figure 5.2019 - Long Portable Earth Concept 5

The chosen concept, as shown in Figure 4.21 comprises a locking Earth Clamp that can only be unlocked with a key which is tethered to the line side clamp. This key is only removable once the earth clamp has been secured in position onto an item with an appropriate thickness. This concept was created during the concept selection meeting and makes use of the second TRIZ design principle, 'Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object. E.g. Locate a noisy compressor outside the building'. The initial discussion point associated to this principle was '*Would it be beneficial for the G-clamp to be separate from the rest of the earth?',* but during the selection meeting the idea of separating a key from the earth clamp was conceived. At the time of writing, this project is in the detailed design stage.

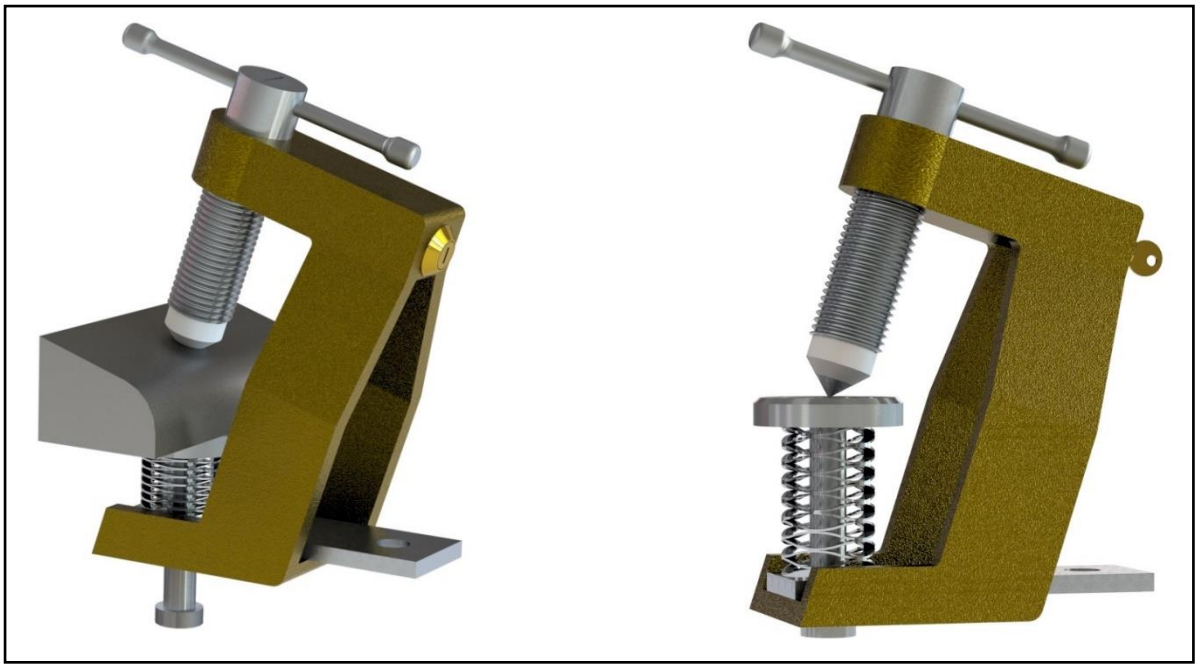


Figure 5.20 – Selected Long Portable Earth Concept

5.3.4 Case Study Review

In retrospect, the QFD HOQ tool was not used to its full potential. It could be argued that the demanded quality statements were initially too in depth and prohibited further exploration and definition of true customer needs. On the other hand, it would have been possible to expand this house of quality further. Details which were arguably not critical for conceptual idea generation but critical for the detailed design could have been defined; e.g. how much of the earth needs to be insulated, the electrical capacity of the earth and the mechanical capacity of the assembly. Indeed, another 'house' could have been used to turn requirements such as 'suitable for fitting to all common types of running and conductor rails' into actual design constraint values. However, for this project, those details were initially missed.

Whilst aspects within the HOQ template were missed to accelerate the project, the tool still proved to be of use in defining the engineering characteristics of the product. This case study, and the desire to find the shortest path through the process, is pertinent to this research. Based on this case study, it can be argued that the need, within an SME, to be agile and complete projects (and get a product to market) quickly can be a barrier to implementing product development process change. This is well aligned with the findings of the literature review, in that complex tools can present a barrier to product development process change and success.

At the point of concept selection, it was clear to all team members & top management that the HOQ and TRIZ tools were beneficial to this project. The Managing Director, Simon Gibson (2019) commented that previous attempts to innovate within this field, outside of a formal process, had been unsuccessful and hence the tools and process have had a positive impact on product development and innovation at AUS.

This positive feedback from the team demonstrates the benefit of group exercises on the product development tool implementation process.

5.4 Stage 1: Conclusions & Future Development

The main achievement detailed within this chapter is the introduction of a formal gated process for product development with advanced tools for problem definition and creative problem solving. The case studies within this chapter have been used to look at the positive and negative aspects associated with the introduction of change within the PD process.

The first major conclusion that can be drawn from the case studies is that the desire and perhaps need within an SME to be agile and complete projects quickly can present a barrier to the implementation of change within the PD process. This is especially true, as discussed within the literature, for complex PD tools.

A potential means to overcoming the complex tool barrier is also presented – engaging a diverse project team in a live project as a means of implementing a complex tool that is accompanied by a thorough guide on how to best use the tool; this method is supported by the literature's perception that a lack of knowledge of, or training on, a specialist tool can present a barrier to the successful implementation of the tool.

Despite the negative perception of the QFD HOQ tool within the industry, as identified by the literature, these case studies suggest that this tool can have a positive impact on a formal process for product development.

In line with the literature, case study 1 supports the notion that prior project failures can present a barrier to successful product development and so a barrier to the implementation of PD process change; previous attempts at the rod light project had resulted in tainted views of what an ideal solution should look like.

Another point discussed in relation to case study 1 and the findings of the literature review was the implementation barrier presented by the impact of top management interference on the PD process. A potential means of overcoming this barrier is put forward in the case of concept selection – the use of an objective and so unbiased concept selection tool. Future research into the use of this type of tool within an SME would be pertinent.

The cost associated with this stage is equal to the cost of staff time in attending the development meetings. However, the cost of not following this stage of the process could be very substantial: it could result in a product that is fit for purpose never being developed and an entire future income stream not being acquired. Furthermore, if this stage is skipped a product that is not fit for purpose could be developed and a whole project up to the point of realisation could be wasted.

As the volume of new ideas and enquiries from internal and external stakeholders increased over the duration of the KTP, a bottleneck began to emerge. The bottleneck resulted in a barrier to the delivery of successful product development projects and so also became a potential barrier to the implementation of the formal process. It was determined that this bottleneck was caused by limited human resource. In order to combat this, AUS looked to increase the human resource available by allocating more time for production team members to spend on product development.

An improvement was also made within the stage 1 of the process – a benefit vs difficulty matrix was introduced to ensure that the development team's time was being spent in the best way; i.e. prioritising projects with the highest matrix score. This matrix, which at the time of writing has only recently been introduced within section 8 of the initial idea form, is shown in Figure 4.22.

Going forward AUS intend to track actual timings for activities within their PD process and continuously improve their understanding of the relationship between types of projects and the minimum costs that are likely to be incurred by undertaking the project.

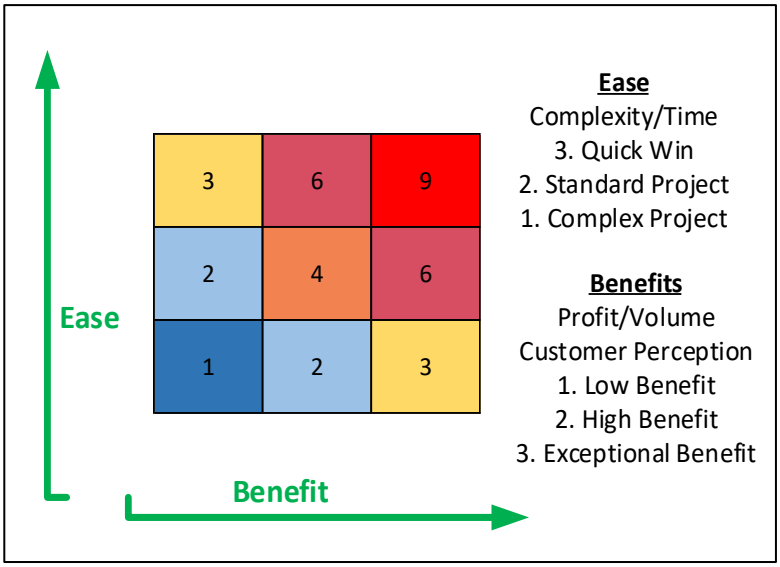


Figure 5.21 - Ease vs Benefit Matrix

6 Stage 2: Design Analysis and Optimisation

The aim of this chapter is to provide detail of the second stage of the AUS PD process; the purpose of this stage is to turn the conceptual design selected in stage one into a detailed design suitable for prototype production. Following this, case studies where this process has been applied over the course of the KTP. As with the previous chapter, the focus of discussion around the case studies will be the barriers and challenges faced, the impact of those and the action taken.

6.1 Stage 2: The Process

Given the objective of the KTP between AUS and the university, and the conclusions of the literature review (section 2.8), the decision was made to create a stage that was exclusively for design analysis and optimisation.

Two sub processes exist within this stage: the design analysis and optimisation process and the drawing check and approval process. These subprocesses are detailed in sections 5.1.1 and 5.1.2 respectively

There are two routes through the design analysis and optimisation process, as depicted in Figure 5.1. The first route involves design analysis and optimisation by hand calculation, and the second, computational design analysis and optimisation. The route is decided at the outset of the stage based on a cost/benefit assessment and the complexity and background of the project (Kangley, 2019). The computational design analysis and optimisation route is detailed in section 5.1.1. Both routes through the design analysis and optimisation process aim to produce a detailed design of the concept selected in stage 1, that is based on engineering design principles and theory, and is fit for prototype production.

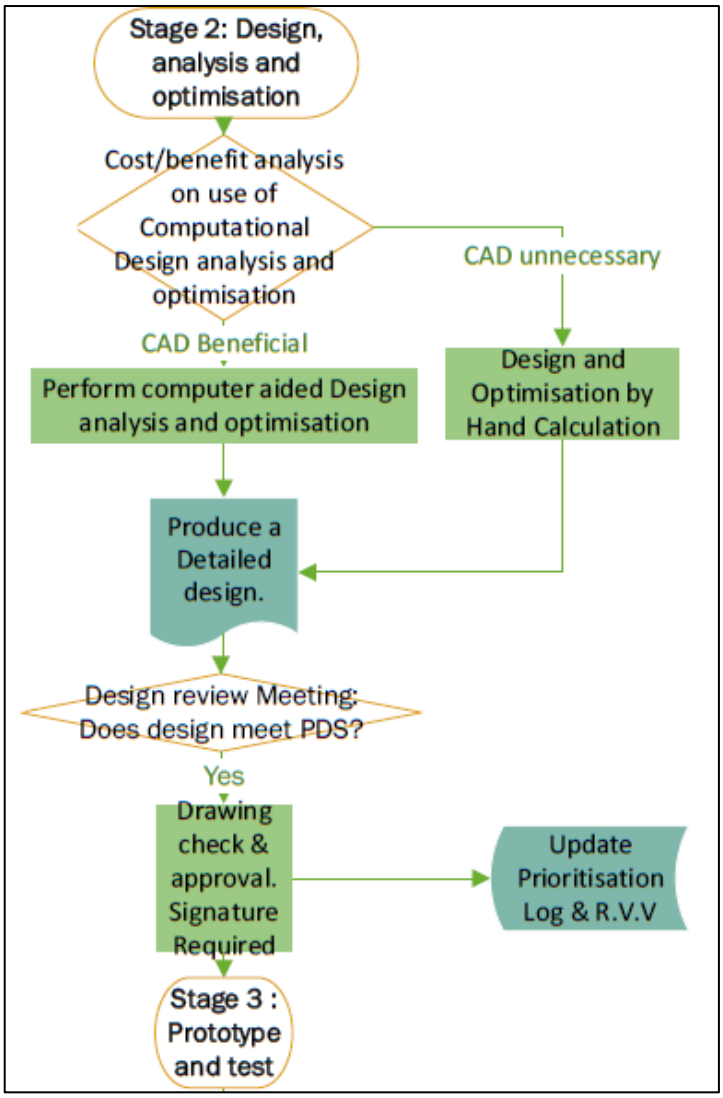


Figure 6.1 - Stage Two of the AUS Product Development Process

Once a design has been finalised, a detailed design is created. From there, the drawing is checked and then drawing approval is decided (by top management) during a design review meeting; in which the design is assessed against the product design specification agreed upon in stage 1. If the product's design requirements have been met, drawing approval is given and the stage is completed.

6.1.1 The Computational Design Analysis and Optimisation Sub-Process

The sub-process depicted in Figure 5.2 exists to ensure a consistent approach to computational design analysis and optimisation at AUS; if the process is followed correctly, any user should complete the process with the same results.

The sub-process is based on guidance taken from literature provided by the creator of the software used by AUS – SolidWorks. (Dassault Systemes, 2017, 2018)

The sub-process begins with a representative 3D CAD model of the concept selected in stage one, from here a calculation is made by hand that is equivalent to (or as near as possible) to the analysis to be performed. Next, the process should consider model simplification – the simpler the model the faster the computational analysis. Once decided, the analysis type can be selected and material properties, connections, fixtures and external loading specified. At this point, model discretisation, or mesh creation, can commence, followed by 'running' the analysis and a convergence study.

The convergence study and the steps that follow – mesh quality checks (with a mesh improvement feedback loop) and general analysis quality checks alongside comparison against the hand calculation made at the outset of the process – all exist to ensure high quality, repeatable, results are obtained. Once the results are obtained and processed, an additional analysis with any

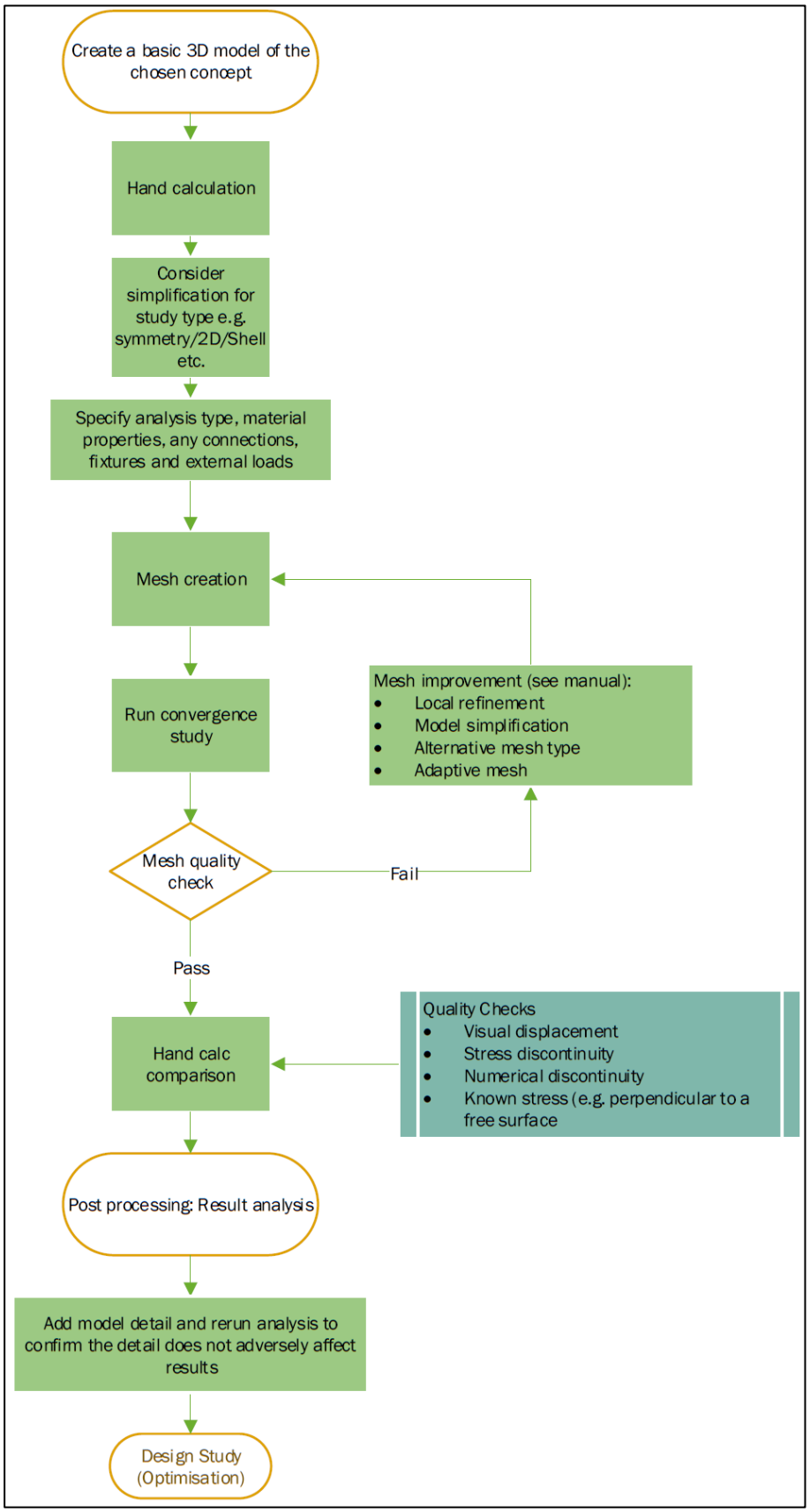


Figure 6.2 - The Computational Design Analysis and Optimisation Sub-process

omitted, but potentially crucial, detail added back in to ensure the detail does not adversely affect the result.

The final step of this process is to carry out optimisation; this is known as a design study within SolidWorks Simulation Professional. This step could warrant its own subprocess but, at the time of writing, this training is typically delivered to AUS PD team members in a learning by doing approach once they are comfortable with the design analysis process.

The AUS design analysis handbook (Figure 5.3) exists for process users who are new to computational design analysis, optimisation, and the second stage of the AUS PD process. The guidance document provides details of best practice design analysis techniques and advice on where to find further learning resources on the specific design analysis tool used by AUS SolidWorks Simulation Professional. The major resource used to aid the development of this handbook was the training manuals (Dassault Systemes, 2017, 2018) discussed in section 5.1.1.

This Handbook is made available to process users to improve knowledge of the specific advanced tool used within one pathway of this stage, and ultimately to assist with the implementation of design analysis and optimisation tools at AUS.

Computational Design Analysis & Optimisation

The Design Analysis (Simulation) Process within SolidWorks Simulation.

- Create a study
- Apply material
- Apply fixtures
- Apply loads
- Mesh creation (discretisation)
- Running the study
- Result analysis

Design Analysis & Optimisation Report – Typically, this report should provide evidence of the process followed and the results of the analysis completed. Where appropriate, use SolidWorks to produce a report.

More information and guidance:

- Simulation Guidance tool in SolidWorks
- SolidWorks Help Centre: http://help.solidworks.com/2018/english/SolidWorks/SWHelp_List.html?id=5c9de6517243423299dfe0d5f22016ef#Pg0
- Simulation Manual: Hard Copy & Online PDF available

Figure 6.3 – The AUS 'Design Analysis and Optimisation Handbook'

6.1.2 The Engineering Change Request and Drawing Approval Process

The process detailed within Figure 5.4 consists of multiple process; the engineering change request process (as discussed within section 4.1) and the drawing approval process.

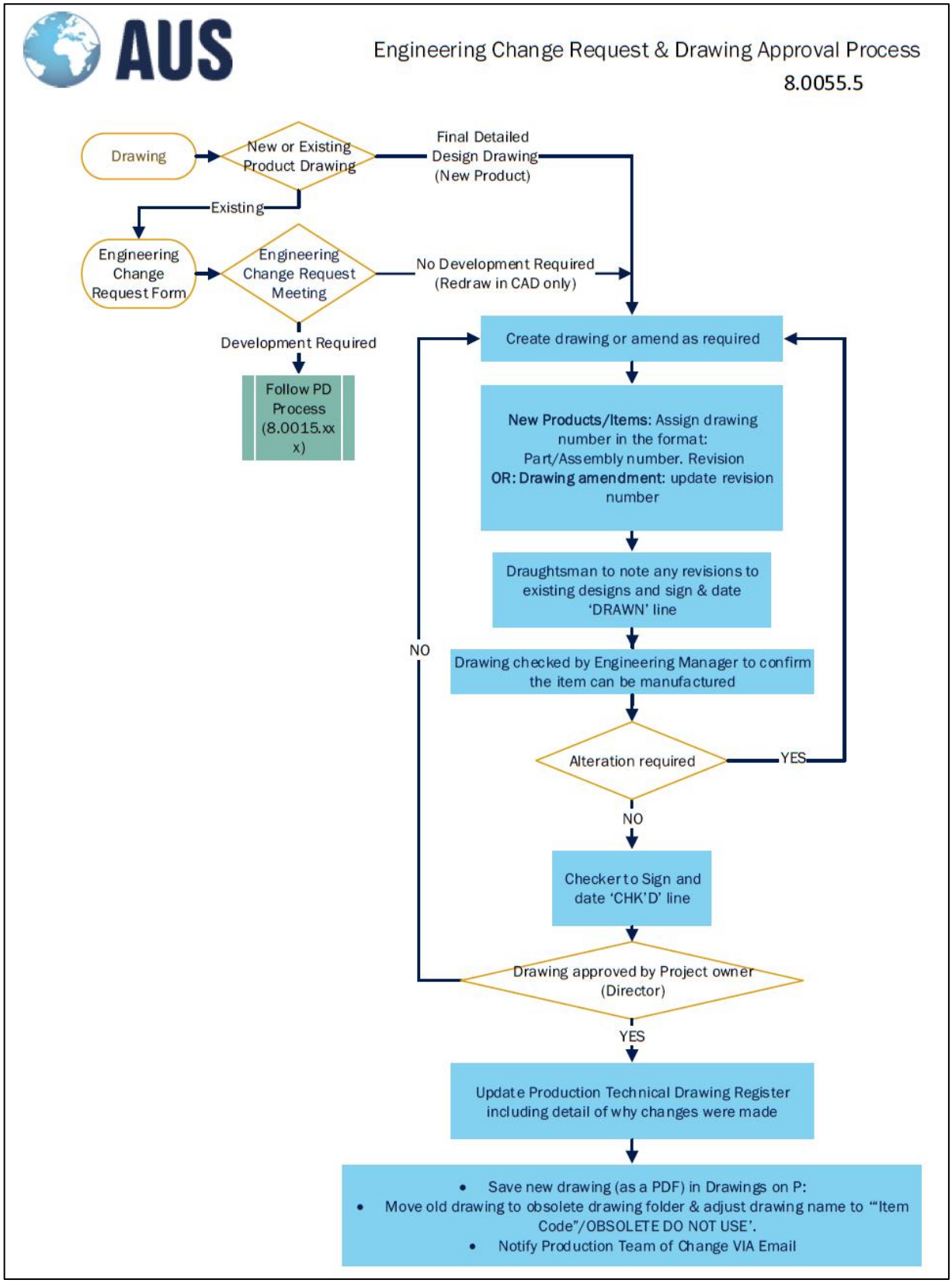


Figure 6.4 – The AUS Engineering Change Request & Drawing Approval Process

The drawing approval process exists to maintain a level of traceability in the product development process. The process ensures that any changes to existing products are noted on the drawing. The drawing check step and alteration feedback loop exist to ensure that drawings contain all the required information for the product to be manufactured. At AUS drawings are approved, once checked, by the project owner who must be a Director. This step happens concurrently with the final stage gate meeting of the second stage of the AUS PD process in which the design is evaluated against the design specification agreed upon within stage one.

It could be argued that the need for a director to be approve every product detailed design drawing could fall under the senior management interference barrier highlighted within the literature review. Perhaps providing product development team members the authority to approve drawings & move projects past a stage gate could improve the efficiency of the process.

The final steps of the drawing approval process serve to maintain traceability and complete the administrative tasks associated with creation or revision of a drawing update that ensure the latest drawing revision is referred to during (prototype) production.

6.2 Project Case Study 3 (S2): Strut Rig

6.2.1 Overview

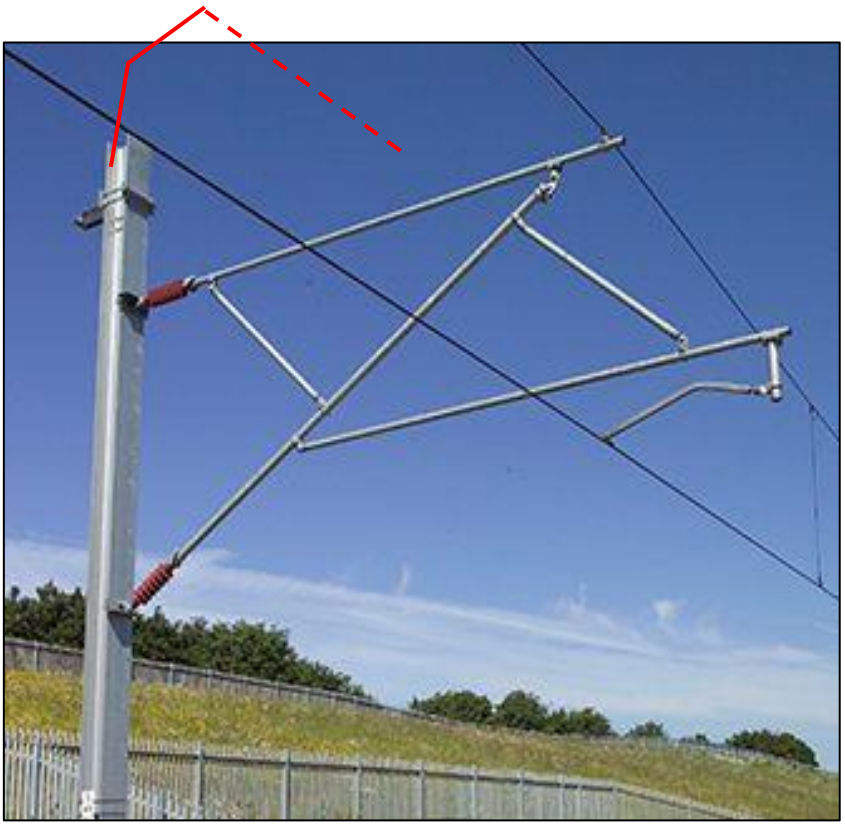


Figure 6.5 – An OLEMI style Cantilever (RAIL OLE, Pinterest)

This case study looks at an existing product development project for an item known as a strut rig (existing Part Number is RAIL-5001), this project took place in the early stages of the KTP whilst the PD process was still in an early form; there was no engineering change request process nor the cost vs ease decision matrix. A strut rig is a piece of equipment used by linesmen within the rail electrification industry, it is a bespoke, low usage, piece of lifting equipment used whilst working at height. The rig, as illustrated by the red sketch lines in Figure 5.5, is wedged into the top of a universal column (UC)

and supports the top horizontal beam of the cantilever via a sling (red dotted line) that is in series with a pull-lift, as other supporting cantilever components are maintained/replaced. Figure 5.6 shows the production drawing used previously for the standard strut rig; hand sketched technical drawings such as this were typical for products developed prior to the KTP.

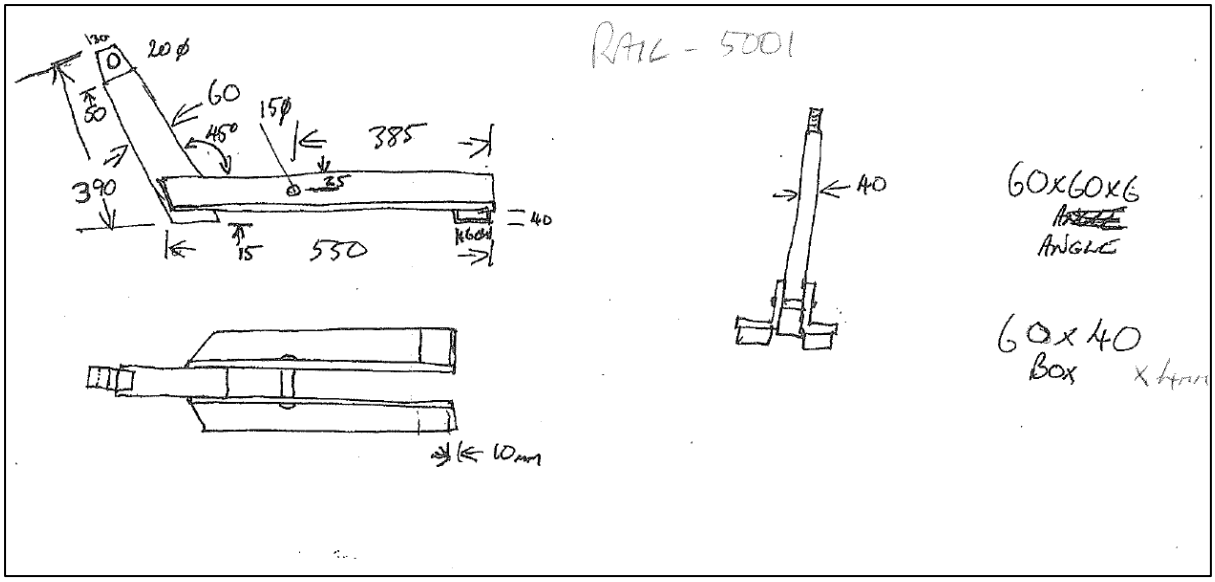


Figure 6.6 – A hand sketched technical drawing for RAIL-5001

Following a request from a highly valued customer, efforts were made by senior management to react quickly to the customer's (seemingly simple) request to slightly modify the existing product. The decision was made, due to the assumed trivial nature of the design change, to bypass the formal PD process and go straight to the production of the small batch (8 items) based on a simple customer provided sketch. Following manufacture, the product was tested to ensure that it could sustain the required working load. Unfortunately, the test result was a failure and the whole batch became scrap. The cost of the scrapped batch accounted for approximately 80% of development costs to that point. Due to the commitment made to the customer, development continued.

Upon closer inspection, it became apparent that the change was not trivial but in fact detrimental to the design of the product; further computational analysis work was required.

6.2.2 Computational Design Analysis and Optimisation

This section provides details of the computational design analysis and optimisation work carried out, in accordance with the process detailed in 5.1.1, that looked at the extended version (P/N: RAIL 5176) of the AUS (Rail-5001) Strut Rig. Through the definition of optimisation design variables, constraints and criteria, as per customer requirements, the optimum design of the extended Strut Rig was determined for the minimised mass of the product. For reference, the original RAIL-1576 post powder coating has a mass of 12.4KG.

In accordance with the third step of the process detailed within Figure 5.2, steps were taken to simplify the model. Due to the geometry of the model, beam elements were used to provide the most efficient means of analysis. Given the simplicity of beam elements, no further simplifications (e.g. symmetry or length reductions) were required. Some features of the design, that were incompatible with beam elements, were omitted for the design study.

The Material specified for the standard strut rig is s275 structural steel.

In use, the strut rig is wedged into the end of a universal column. The interaction between the Strut Rig and the universal column was simulated by constraining displacement in all three directions at the two points next to A and in the horizontal direction at points B within Figure 5.7. It would have been inefficient to model the column, so fixtures were used to constrain the model and replicate in use conditions.

In order to give a worst-case loading condition, the direction of load was positioned perpendicularly to the line of action of the moment; this moment was taken about the point of contact between strut rig and the end face of the universal column. This is illustrated in Figure 5.8. A working load limit of 250kg was requested by the customer. Based on a The Lifting Equipment Engineers Association's (LEEA) recommended factor of Safety of 5, the test load will be 1250 Kg.

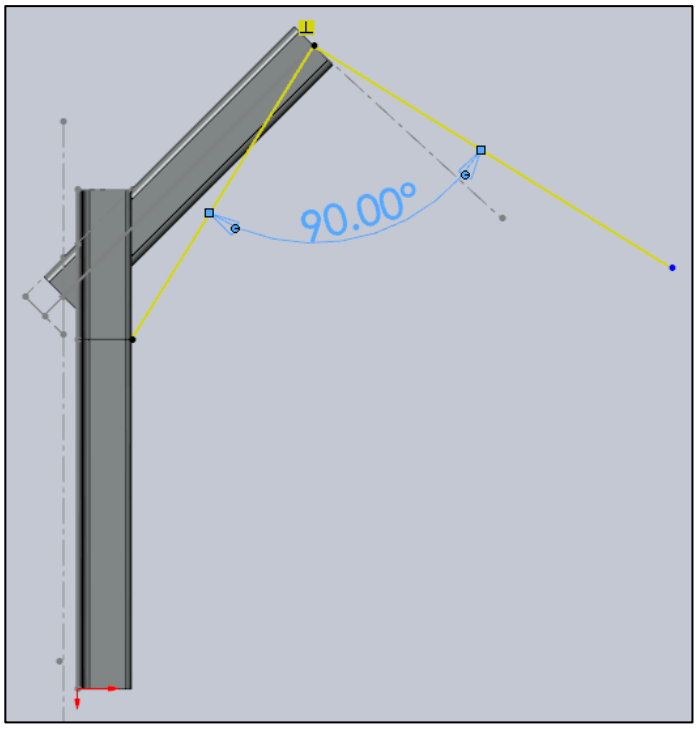


Figure 6.7 - Loading Schematic

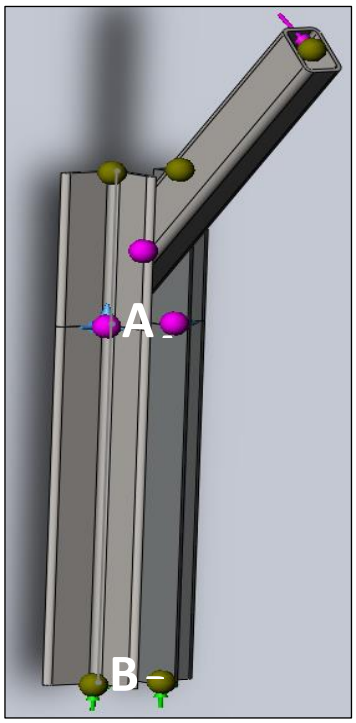


Figure 6.8 - Analysis Boundary Conditions

6.2.2.1 Analysis of Original design

Figure 5.9 shows the stress results for original design. The maximum stress is 792 Mpa, this value is 2.9 times above yield stress of the material. The analysis was rerun with increased cross-sectional areas, this reduced the maximum stress to 5.947 Mpa; a 25% improvement. However, this value was still 2.16 times above the yield strength of the material. Further improvements were required.

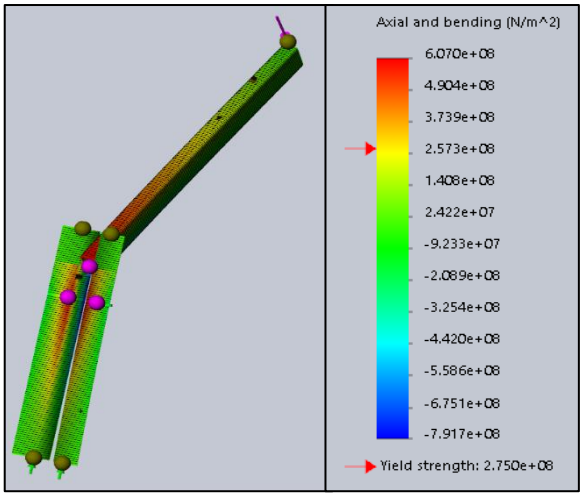


Figure 6.9 - Analysis of original design

6.2.2.2 The Design Study

During physical testing, the angle sections deformed suggesting that they are the weakest link, this was seen again in the FEA. Hence, the next logical step is to consider beams with an improved

second moment of area. This design study looks at rectangular and box section within the design space. Ideally, the optimised design would make use of standard material profiles.

The setup of this design study reflected these requirements and the parameters in Table 6.1

Design parameters	
Constraints	• Maximum external dimensions of parallel beams = 60*60 mm • Length of cantilever 885mm • Maximum stress < Yield strength of chosen material
Variables	• Section shape within space • Supporting material outside universal column
criteria	• Minimise mass

Table 6.1 – Design Parameters

This design study compared 399 (19/418 simulations failed) scenarios, with the goal to minimize overall mass within the yield strength of the material.

The optimum design, as seen in Figure 5.10, reduced stress to 308.3Mpa. Whilst this did not satisfy the problem defined, given a material with a yield stress above this value, this design is feasible. However, this 'optimum' design gives a mass of over 20kg; almost twice the mass of the redesign.

A next step could be to source a lighter material such as an aluminium alloy e.g. 6082t6. A like for like costing comparison of 50*50* 3 box section showed that the Al was 2.4 times the cost; the density of the al (2700 Kg/m^3) is approximately a third of the density of s275 steel (7850 Kg/m^3). Further investigation into material sizes is required.

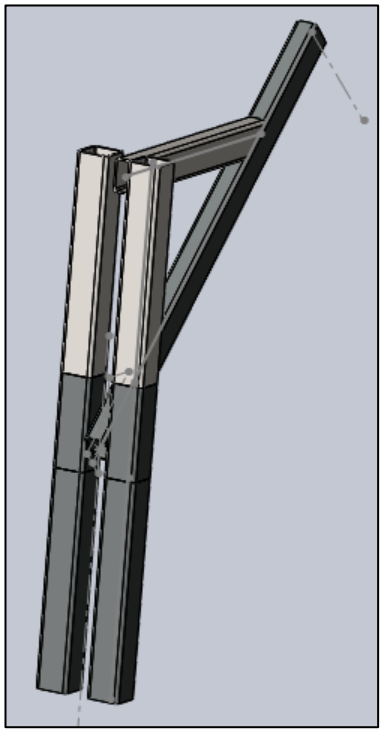


Figure 6.10 - Optimal Design

6.2.3 Case Study Review

Inescapably, the initial error in project management had a negative financial impact for AUS. Despite the efforts made that were motivated by a desire from top management to achieve a 'quick win' and please the customer, eventually the development costs exceeded the commercial benefit for both AUS and the customer and the project was stopped. Again, the conclusions of the literature review regarding top management interference are supported by this case study.

In this case, once used, the second stage of the process was highly effective in determining an optimum design and communicating development options to the project team. Despite this, this project resulted in wasted time in the region of 3 days and, including that time, financial losses in the region of £1500. The portion of this cost that represents the process being followed accounts for approximately £100.

This case study is an excellent example of why the process exists, and undoubtedly helped to embed the formalised process. This is contrary to the conclusions of the literature review that project failings can result in a barrier to the implementation of a formal process. The KTP further assisted the

embedding of this stage of the process by providing a platform for team members to reflect upon and discuss lessons learned during projects, as well as providing access to expertise and knowledge of the tools utilised within this stage of the process.

Following this project, all future projects would pass through the formalised PD process stages as intended. This made it clear that too much flexibility in the PD process can in fact have a negative impact on the process, which again conflicts with recommendations of the literature review. This example allowed the KTP team to find the correct balance between flexibility and formality in the development process for AUS.

6.3 Project Case Study 4 (S2) Tongue Compression End Fittings

6.3.1 Overview

Network Rail, the company who own and are responsible for the maintenance of most of the rail infrastructure within the UK, approached AUS with a request for a solution to an issue with a historic, widely used, electrification component, that had resulted is multiple extremely costly failures.

The component(s) in question, as shown within Figures 5.11 and 5.13, are known as a Tongue Compression End Fittings. The fittings are crimped into two sizes of tube and used in conjunction with clevis assemblies as a means of connecting the tubes.

Figure 6.11 – Tongue Compression Fitting to Clevis Connection

These connected tubes are assembled to create cantilevers from the Overhead Line Equipment Master Index (OLEMI) range, an example of a cantilever of this style is given in Figure 5.12. The existing fittings and clevis are both manufactured from Malleable Cast Iron (MCI) and were designed in the 1960's.

Figure 6.12 – A Typical OLEMI Cantilever

AUS set out to design and manufacture a range of fittings that resolve the issues experienced by Network Rail. These issues were caused by water trapped within cantilever tubes, which can freeze resulting in tube failure and/or the fitting being forced out from the tube.

To ensure no water could be trapped within the cantilever tubes, a drain hole design was put forward by AUS. This design was validated using computation design analysis techniques. This analysis enabled AUS to optimise the design of the fittings and reduce component mass. AUS have considered two materials for the new fitting: aluminium (6082 T6) and (galvanised) structural steel (S275JR).

6.3.2 Computational Design Analysis and Optimisation

It quickly became apparent within this project that due to the nature of a crimped connection, AUS's Design Analysis and Optimisation capabilities, namely linear Finite Element Analysis (FEA), were not sufficient. Fortunately, as a result of the KTP, AUS were able to carry out the non-linear FEA with the assistance of the University of Huddersfield.

The non-linear analysis was used to assess the tube to fitting crimped connection and optimise wall thickness to reduce mass. The result of this work was the fittings shown within Figure 5.13.

Figure 6.13 – The First Iteration of the AUS Tongue Compression End Fittings with Drain Hole alongside the original versions

These fittings, which now offered a reduced weight and a drain hole, were tested according to the appropriate specification, see section 6.2.3 and Appendix C4.1, and met the requirements of Network Rail. According to Network Rails Product Acceptance (PA) process, all PA applications must be sponsored by a Network Rail Employee. Unfortunately, the contact who had requested the development work was unable to act as sponsor. As a result, AUS liaised with Network Rail's asset management team and met to discuss the PA application. This brought to light a new customer requirement that had been missed at the outset of the project. This was a result of the first stage of the process being missed due to the perceived complexity level of the project and a desire to meet the customer request as quickly as possible.

The requirement missed was a perceived issue with grease blockage of the drain holes. The new sponsor requested that the hole size was maximised within the loading requirement. To address this AUS investigated the feasibility of machining holes at an angle. Whilst this increased the complexity of the manufacturing process, an angled hole would eradicate any flat areas for grease to collect in. Following another round of FEA and optimisation at AUS, it was determined that the design show in Figure 5.14 was achievable.

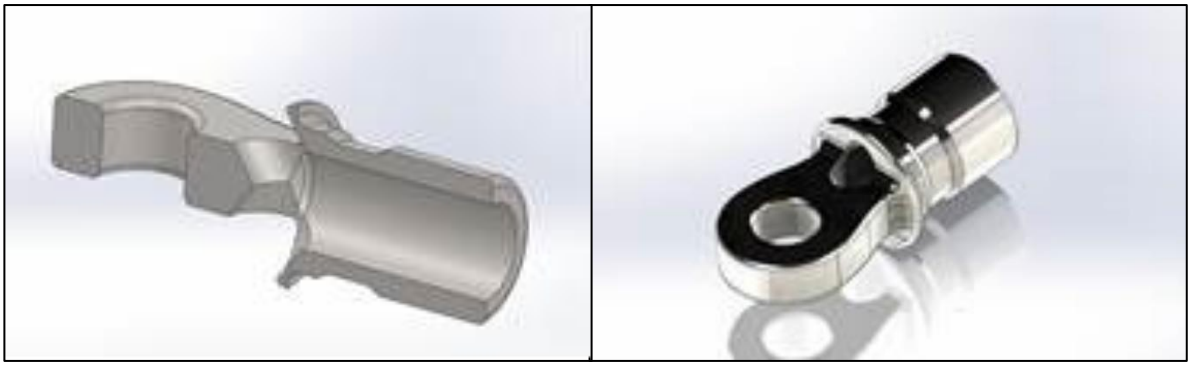


Figure 6.14 - The Final Iteration of the AUS Tongue Compression End Fitting with Drain Holes

6.3.3 Case Study Review

The case study demonstrates the use and importance of the second stage of the product development process at AUS. This stage served its purpose well and each iteration of the process delivered optimal products given the criteria presented. This study shows that the AUS product development can be used to deliver solutions in a timely manner, but as with any process, it is only as good as the information provided to it.

The main issue faced within the case, and the reason that multiple iterations of the stage were required, were caused by a customer requirement that was missed within the first stage of the process. However, it would be extremely difficult to create a formal product development process suitable for an SME that eradicates any risk of human error, such as a missed product requirement. This barrier was highlighted within section 2.7 of the literature review.

In this case, it could be argued that the customer, who instigated the project, was responsible for the delays created by the requirement for larger drain holes and a barrier to the thorough use of the formal process. Although, if these requirements had been missed completely and the product rushed to market, additional costs may have been incurred if blockage issues had occurred following component installation. The motivation of the customer, that resulted in an inadequate use of the (first stage of the) process, was to solve their seemingly simple issue as quickly as possible, and this motivation was shared by AUS who missed some steps within the first stage.

The cost associated with reiterating this stage (and stage 3) was in the region of £2000. Comparatively, the cost associated with actually completing this stage thoroughly in the first instance would have been approximately £500. This shows that there is a strong commercial case for completing Stage 1 regardless of the perceived level of complexity.

6.4 Conclusions and Future Development

This chapter details the successful implementation of a formalised process for product development that incorporates a stage dedicated to computational design analysis and optimisation. The case studies show that the initial reaction (from stakeholders within AUS top management) to this stage was that, for a simple project, it could make more sense to act upon instinct instead of relying on the new process. However, when this approach failed and the formal process was used to rectify the situation and objectively provide options to the project team, the benefits of the process and its advanced tools were clear to the SME.

The second case study shows a successful project, that utilised this stage of the process as intended, and was highly commended by a valued customer and has since resulted in similar projects being passed to AUS by the customer. However, this case also highlighted the criticality of stage 1; this is the stage that all other are built upon. Within the literature (section 2.8), CAD, FEA or design analysis and optimisation is recommended for product development without reservation. These case studies support this recommendation.

The hypothesis made within section 2.5.3 that expands on the over-arching of this research, ‘that British manufacturing SMEs are not utilising now cheaply available Computational Design Analysis (Simulation) and Optimisation tools, despite the democratisation movement (NAFEMS, 2018), as part of product development, but they should be.’, is fully supported by the case studies presented in the chapter.

Within the strut rig case study, the total losses were estimated to be in the region of £1500, within this loss, the cost of testing a prototype (AUS completed prototype manufacture and testing In house) that didn’t work was approximately £500. The cost of carrying out FEA on the original design that

failed was approximately £100 – this figure accounts for AUS's KTP costs (which includes the KTP associates time, of which 4 hours were spent on this work), as well as the overhead cost for the software used, SolidWorks; this figure is in line with the costs of employing a graduate engineer with the required skills to carry out this work. The difference in the cost of carrying out FEA compared to physically testing samples illustrates the impact that computational analysis techniques can have on a project for an SME. The analysis then went on to show that even with larger sections, that design would not work. The additional cost of rerunning the analysis with the larger sections was trivial, whereas the cost of doing the physical test would have exceeded the cost of the original prototype test due to the use of more expensive materials. This provides further evidence to support the use of computational design analysis and optimisation within SMEs.

At present, no templates exist to ensure the minimum required amount of information is captured during a design analysis and optimisation project. It would be sensible for AUS to create templates for the consistent presentation of design analysis and optimisation projects and results.

7 Stage 3: Prototype and Test

7.1 The Process

The products that AUS develop often have a high level of risk associated with them; risks such as OLE tear down and train derailment, working at height, working with electricity and those risks associated with lifting equipment. As a result of this, for these products there are often test requirements.

As with Stage 2, two routes can be taken through the third stage of the AUS product development process. The first sees the manufacture of prototypes for direct use in a trial by AUS or a carefully selected, often lead user, customer within the next (and final) stage. The second route involves the manufacture of prototypes for testing followed by a trial.

Advanced tools such as those found within Six Sigma methodologies (Tjahjono, 2010) e.g. the Taguchi method (Karna, 2012), could be used within the testing procedure. However, no advanced tools have been utilised within stage 3. This decision was one made consciously by the KTP project team; the use of such tools was deemed to be too big a step for a company that was only just adopting a formal product development process. Furthermore, within the industries that AUS fall within, testing requirements within standards must be followed stringently. These test requirements may conflict with these tools.

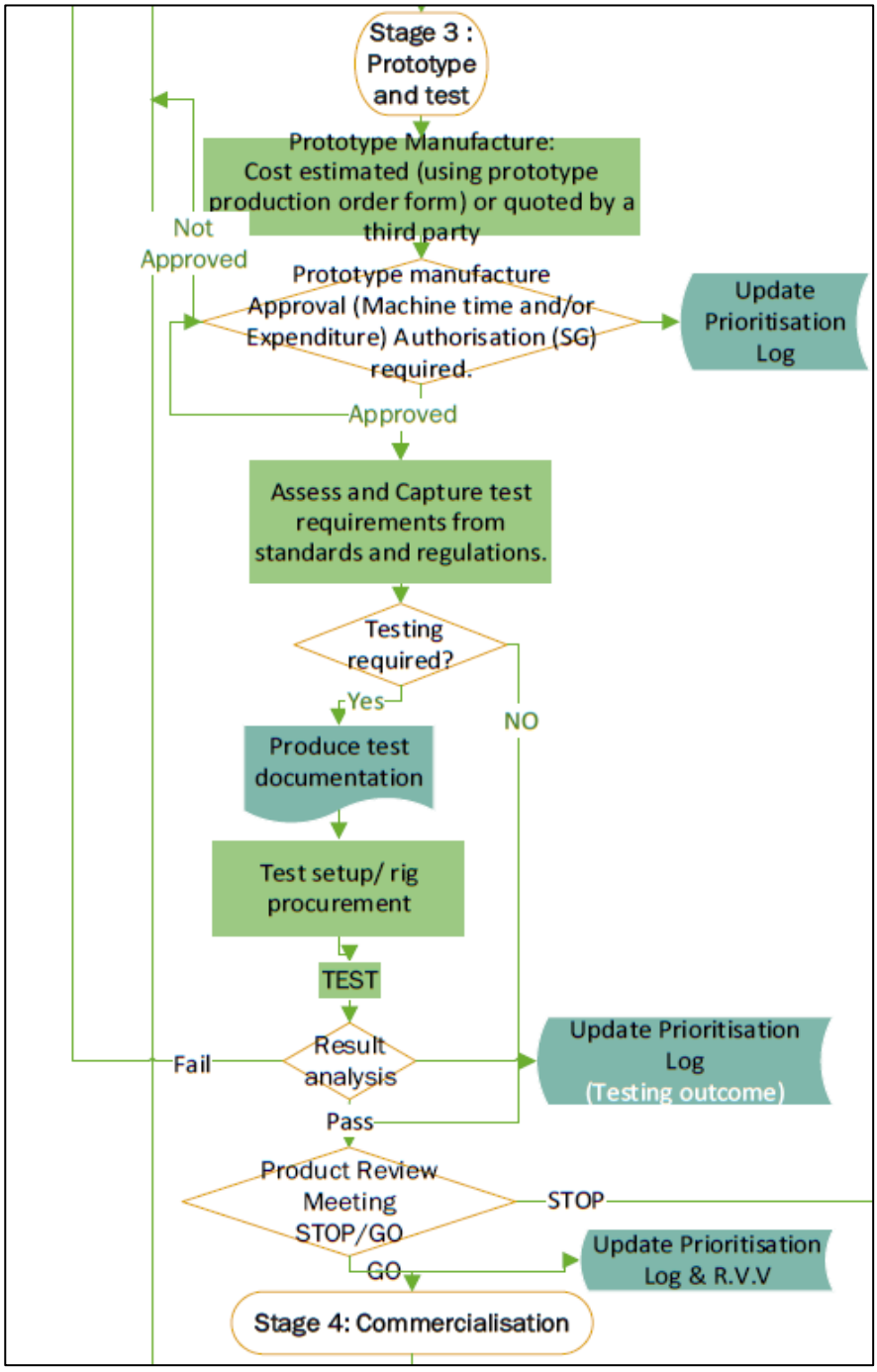


Figure 7.1 - Stage 3 of the AUS PD Process

The process shown in Figure 6.1 is the result of lessons learned over the course of multiple project iterations. Despite the lack of tools, various templates have been developed to ensure a consistent approach to prototype manufacture, trial and test. These include a prototype production order, a test proposal & procedure template and a test report template. These templates can be found within Appendix C1, C2 and C3 respectively.

The process begins with the prototype production order (PPO) form. This form, shown in Appendix C1, is used to capture the cost of prototype manufacture as provided via supplier quotes or estimates on internal expenditure. At the time of writing, the PPO requires approval from the managing director before prototype manufacture commences, this is primarily due to the lack of a formal budgeting process for product development projects.

Once prototype manufacture is approved, testing requirements, which should have been captured within the initial idea or engineering change request form within stage one of the PD process, are reassessed and (if required) test documentation produced. At this point this documentation is in the form of the test procedure and proposal document. At present, this document also requires approval from top management so is often presented alongside the PPO; where testing is required. Furthermore, any testing equipment (jigs and fixtures etc.) required is generally captured within the PPO. Once approved, testing is scheduled, carried out and results presented within a test report.

In line with the conclusions of the literature review (see section 2.4.2.), a high level of flexibility is required throughout this process for successful product development and for process change implementation to be successful. For example, it may be the case that a batch of prototype samples are manufactured and presented to the customer for approval before testing is scheduled, in which case a number of PPO's would be created. Moreover, if multiple concepts are selected at stage 1, or multiple optimum designs are discovered at stage 2, multiple prototypes may be manufactured and the preferred option selected during the test and/or trial phase.

7.2 Project Case Study 5 (Study 4 continued) (S3): Tongue Compression End Fittings

7.2.1 Overview

The overview for this project can be found in section 5.3.1.

7.2.2 Prototype and Test

As a result of the computational design analysis and optimisation carried out, as described in section 5.3.2, two rounds of testing occurred; one for each design iteration.

The test proposal and procedure document shown in Figure 6.2 was created and approved for this project, in line with the 'produce test documentation' step of Stage 3. As detailed within the objective, and in line with the stage 3 process, the relevant test requirements were assessed and captured from standards and regulations:

Tongue Compression End Fitting Test Proposal

Objective of Test

To test various tongue compression end fittings (and clevises) to destruction in accordance with 8.2.1.5 of 50119.

Sample size & specification

See Prototype Production order 85.

1 fitting crimped into a 300mm tube. To be drilled at the university.

Sample acquisition & Preparation

Manufactured in house by AUS to controlled drawings. Crimped using customer press, dies and process.

Description	Crimped Assembly Quantity
48.3 machined fittings (steel)	4
42.4 machined fitting (steel)	4
48.3 machined fittings (Al)	4
42.4 machined fitting (Al)	4
48.3 – 142-090-001	2
48.3 – 142-16-001, 142-17-001	2
42.4 – 142-17-001	2
Machined clevis – Aluminium	4
Potentially: Machined clevis – steel	4

Test Procedure:

1. Calibration of equipment – record date of last calibration or perform calibration with load cell.
2. Labelling/record the test equipment and specimens used with permanent marker or labels
3. Programme equipment to start, apply load/displacement and end in line with 50119:
    - Step 1: Apply 10N preload at a 10mm/min rate
    - Step 2: Apply a displacement at 25mm/minute
    - End Condition: 60mm displacement or 95% reduction from peak force
4. Carefully position samples to ensure repeatability – note set up
5. Photograph/video test set up
6. Capture load (N) vs displacement at a rate of 1 Hz
7. Video where possible + photograph and write a description for each specimen
8. Start test
9. Test will end according to point 3
10. Record results in excel if possible & save data after each test
11. Carefully store labelled test specimens
12. Repeat from step 4

Figure 7.2 - Tongue Compression End Fitting Test Proposal

The PPO shown in Figure 6.3, a document which is referred to within the initial step of the stage 3 process, was one of many used to capture costs and request approval the manufacture of the test samples, fixtures and fittings used for during this project:

Project Owner:

Customer:	Network Rail	**Development Number:**	87
Project Owner:	RT	**Document Date:**	19/11/2019
Due Date:	29/11/2019		

Item: Tongue Compression End Fittings
Quantity: 20

Components

Item Number	Description	Unit Cost	Quantity	Total Cost
	142/017 S275JR Galvanised	£29.97	5	£149.85
	142/017 6082T6	£26.89	5	£134.45
148-028-998	300mm X 42.4mm X 4mm galvanised steel tube **(bore to OLE specification and check tolerance)**	£5.75	10	£57.50
	Getting Tubes Crimped at SPL			
				£284.30

Operations

Description	Est. Time	Total Cost
Captured within the costings above		£0.00
		£0.00
	Total Cost Estimate	£284.30

Production Approval

Name: Date: Sign:

Figure 7.3 - Example PPO for Case Study 5

7.2.3 Tongue Compression End Fitting Testing

The tongue compression end fitting testing carried out in accordance with the process stage detailed within 8.1 is documented within the test report provided in Appendix C4.1. This testing, which occurred over two rounds at two locations, applied a tensile load to the crimped tube and fitting assemblies. In line with the Stage 3 process, the test setup and rig procurement occurred at the appropriate time. The test rig jigs were designed and manufactured by AUS using the drawing check and approval process and the PPO form. AUS did not have internal testing equipment capable of carrying out this test, so AUS made use of their KTP with the University of Huddersfield and looked to use the tensile test equipment at the University. The test set up can be seen in Figure 6.4.

Figure 7.4 - 50KN Tensile Test Machine

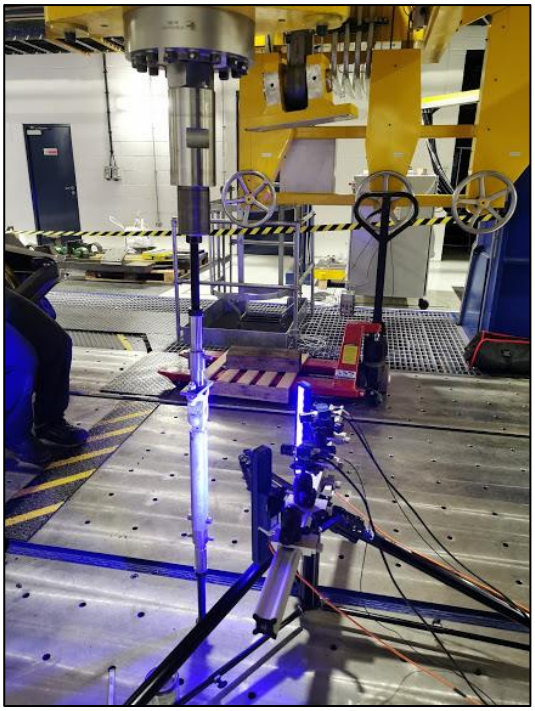


Figure 7.5 - 250KN Tensile Test Machine 'Harold'

This test rig was capable of applying a maximum load of 50KN, unfortunately this maximum proved to be insufficient as seen within the first round of test results within the test report. As a result of this, AUS arranged the use of the test rig seen within Figure 6.5. This rig could apply a 250KN load, which was sufficient to complete the testing.

The testing carried out for both design iterations provided the desired results and, following a product review meeting as per the stage 3 process, enabled AUS enter into the final stage of the PD process and the customer's Product Acceptance process. Sales of these products for a customer trial are anticipated in the near future.

7.2.4 Case Study Review

Case study 5 shows the successful application of the third stage of the AUS product development process. In this instance, all test requirements are provided by the standard specified by the customer. The standard does not, however, provide details on how best to interpret the test data. A potential improvement to the AUS process would be to provide guidance on best practice here.

In this instance, there were no stakeholders with motivation to bypass the stage. This highlights the relevance and critical nature of this stage to the project and PD process.

This case study shows the difficulties faced by SME's in accessing appropriate test equipment. This difficulty could present a barrier to successful product development; such a barrier can be overcome via a partnership with a knowledge base such as a university.

The cost associated in following this stage of the PD process was approximately £3000. However, without this stage, the product could not reach market.

There were challenges presented within this project in that the first test rig selected was not capable of fulfilling the test requirements. This difficulty could have potentially been overcome if test requirements had been more carefully considered within the initial steps of Stage 2. If these steps had been taken, and the correct rig selected from the outset and therefore only one set of test fittings

being manufactured, a saving in the region of £500 could have been achieved. This highlights the importance of stage 2 of the PD process.

7.3 Project Case Study 6 (S3) – Insulated Operating Rods

7.3.1 Overview

AUS supply insulated operating rods into the electrical supply industry. These rods, as discussed within case study 2 (the rod guide) provide linesmen with protection from up to 75KV whilst they maintain the power networks.

Within Rail and ESI, in recent years, there has been a push to avoid working at height and in close proximity to overhead powerlines. As a result of this, AUS's insulated operating rods have become a critical tool for arborists. Historically, arborists would dismantle a tree from the top down with (often powered) hand tools. AUS have recently recorded a sharp uptake in the use of insulated operating rods used in conjunction with a 'silky saw' and pruner adapters (as seen in Figure 6.6) to carry out this type of work. Alongside this increased utilisation of the equipment, AUS recorded an increased number in reports of insulated operating rod failures.

Figure 7.4 - Insulated Operating rod with 'Silky Saw' attachment as used by Arborists near live overhead lines

In response to this, AUS looked to offer a stronger rod to the arborist market. The Insulated operating rods are made from various composite tubes connected with adhesive. Whilst some progress was made in computationally analysing and optimising the design within stage 2, the decision was taken to move to third stage of the PD process and test multiple prototypes with various design alterations.

7.3.2 Prototype and Test

For this project, top management took charge of sample procurement and no prototype production order was raised. In accordance with the process detailed in Figure 6.1, tests requirements were assessed in line with the relevant standard and regulations; in this case the Electricity Network Association's (ENA) Technical Specification 43-81. It was deemed that the test requirements set out

within this specification for a flexure test would not yield the information required by AUS at this time, as a result AUS created their own test regime.

AUS set about designing this test methodology alongside the test fixtures, jigs and fittings required. The resulting test set up can be seen within Figure 6.7.

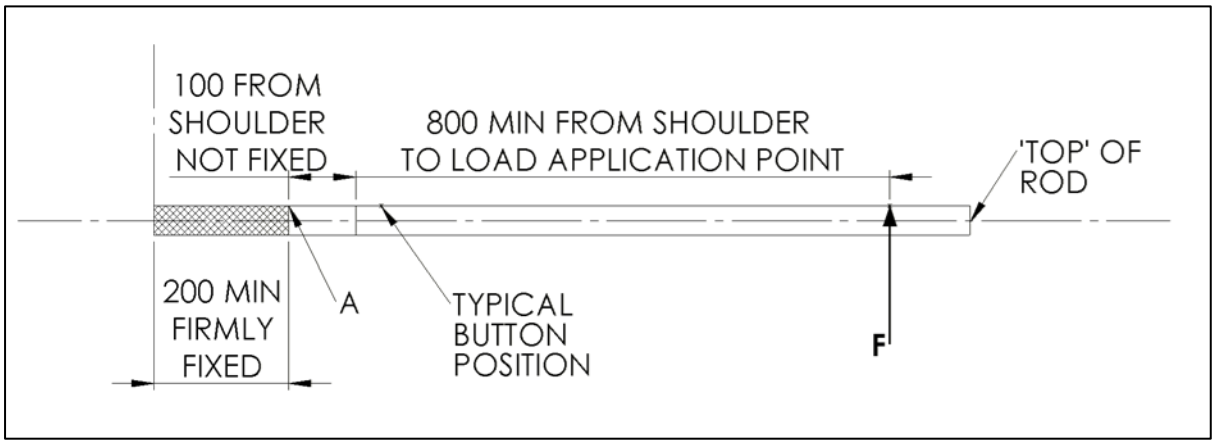


Figure 7.5 – Flexure Type Test for AUS Insulated operating rods.

A potential barrier was present here in the form of a lack of the equipment required to carry out his testing. Without the KTP, it would have been more costly for the SME to undertake these tests. Specifically, the lack of specialist equipment for capturing peak load. However, the KTP enabled AUS to make use of this equipment which was available at the university. This presented a cost saving of approximately £2000.

Testing was carried out, which looked at the effect of 5 design changes on AUS insulated operating rods (see Appendix C4.2 for full details), in line with the schematic in Figure 6.7. The following conclusions were drawn and presented during the end of stage 3 product review meeting:

The greatest improvement achieved resulted from the addition of two wraps (B samples) with the collar over the button area (D samples) not falling far behind. The introduction of pips is a relatively simple change and yield a healthy improvement on failure load.

The statistical analysis tool, Students T test, was used to objectively analyse the significance of the results based on sample batch size.

A discussion was had in which the commercial impact of each change was considered against the improvement in performance demonstrated in the test results. Following this, a decision was made by the project team and the preferred combination of changes was implemented into a new product, that is soon to launch, that will be specifically marketed as a tough rod set for arborists.

The cost associated with following this stage of the process for this project is approximately £1500.

7.3.3 Case Study Review

This study shows a successful use of the third stage of the AUS product development process. There was no resistance to the use of this stage within this project. The availability of costs at the start of the stage and presentation of objective results at the close enable decisions to be made with ease.

The improved test method devised by AUS has been accepted by the ENA within a new draft of the 43-81 specification which is soon to be released for comment within the technical working group. This shows that the formal process has had a positive impact on product development at AUS.

The use of Students T test was helpful in assessing the quality of the information presented; tools such as this could be a useful addition to the stage – as discussed within section 6.2.4.

7.4 Conclusions and Future Development

Both case studies demonstrate how the correct use of the prototype and test stage feeds into the AUS product development process when used as intended. In both cases, there was very little resistance to the implementation of change to this aspect of the process. This is most likely a result of the legislative requirements imposed upon AUS to carry out product testing. As a result of this, AUS had already embedded product prototyping and testing. The changes implemented in accordance with the formal process were in the form of the standardisation of planning and reporting these activities.

For stage 3, the cost of following this stage of the process can represent a significant portion of project costs (£3000 and £1500 for case study 5 and 6 respectively), but likewise, the cost of not following the process can be substantial. As with early steps within stage 2, the cost of spending the time to check the standards is fairly trivial compared to the process not being followed and testing (for example) not being carried out in accordance with standards and therefore invalid and a waste. Furthermore, if safety critical products are developed and sold without the mandatory steps being followed in accordance with the relevant standards and regulations, the potential cost resulting from component failure and litigation could dwarf any potential profits.

A potential improvement to this stage of the process, and in line with the advice detailed within section 2.8, would be to provide more control to product development teams members and therefore less reliance on top management for approval of test proposals, procedures and prototype production orders. This could be achieved by the allocation of a budget, that is controlled by the PD team, within stage one of the product development process. This improvement is not supported by the case studies and may also have a negative impact – the process of request approval provides a good opportunity for product development team members to communicate project progress to top management; this ensures visibility of company operations and can help to inform company strategy. A lack of strategy is from top management is presented as a barrier to the successful product development and could therefore present a barrier to the implementation of change to a PD process.

8 Stage 4: Commercialisation.

8.1 The Process

Of all the stages within the AUS product development process, AUS are most accustomed to Stage 4: Commercialisation. This stage is shown within Figure 7.1.

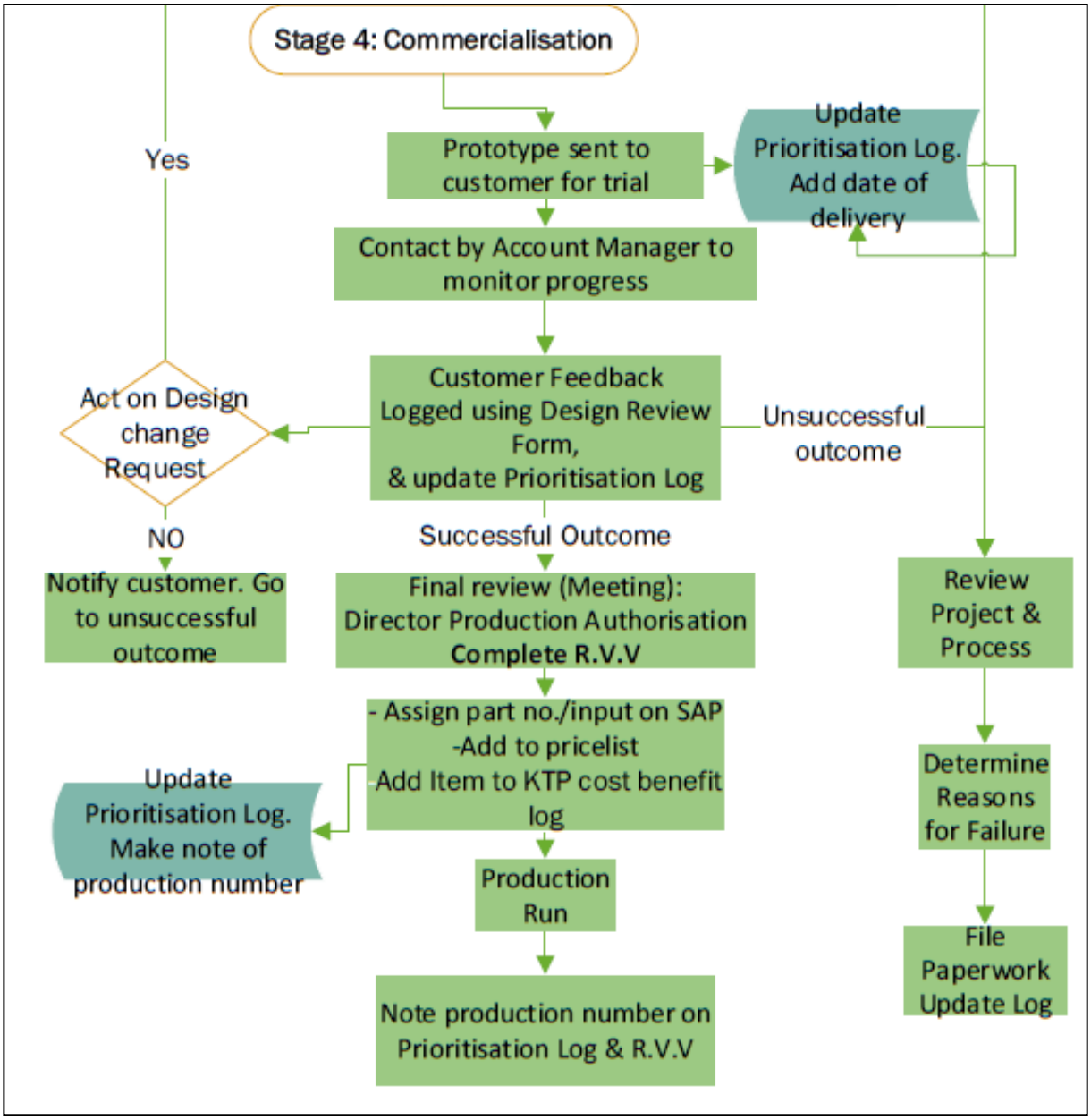


Figure 8.1 - Stage Four of the AUS PD Process

8.1.1 Existing Processes

Indeed, several processes that are separate to the product development process exist to assist the commercialisation of products new to AUS. Most of these processes are facilitated by the industry leading (Cocca, 2018) Business Management and Enterprise Resource Planning tool SAP. These include processes for new product set up, (internal and external) sales order processing, supply chain

management, procurement, customer management, stock management, material planning and production management. At present, the AUS PD process does not engage SAP in projects until sales are confirmed; for example, prototype production is managed via the prototype production orders (Appendix C1 and section 6.3.2). The rationale behind this is that this ensures that human resource is not wasted, and that SAP does not contain data that may not be of relevance if a development project is stopped or is unsuccessful.

Once the commercialisation stage has been reached, the aspects of the processes which exist within SAP are highly effective, as long as the correct information is entered into the system. However, new products developed internally typically have a higher level of complexity than bought in products, and barriers were faced by AUS whereby the correct information was not always available to the correct team members at the appropriate time. As a result of this, a formal commercialisation process primarily for new products was deemed to be necessary by the KTP project team. The Process is the fourth and final stage of the AUS PD process.

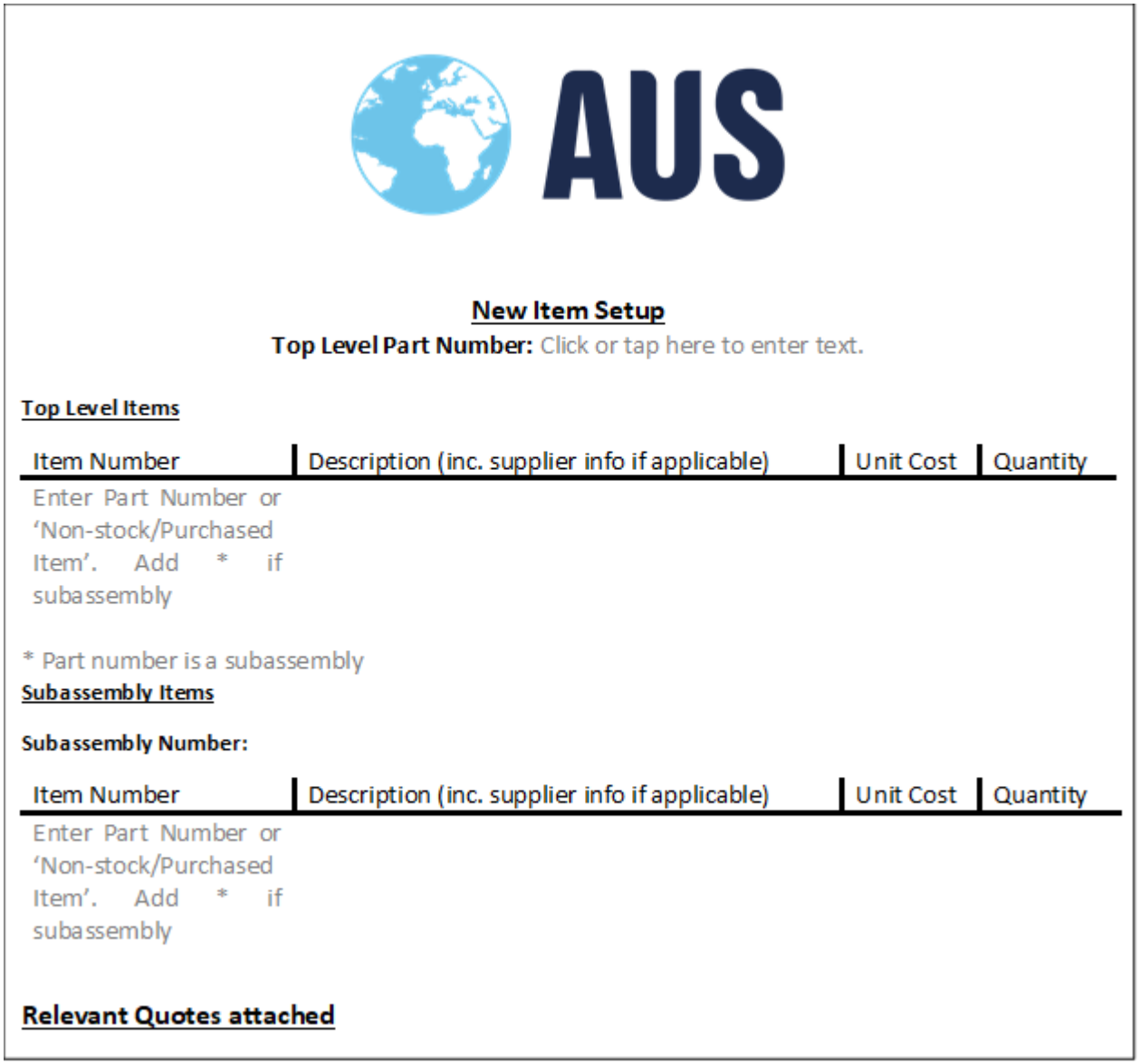
8.1.2 Additional and Modified Processes

The stage commences with a final trial of a production quality prototype, where possible and in line with recommended best practice within the literature (section 2.4.1) this trial is carried out by or involves the customer. Given a successful outcome and/or positive customer feedback following the trial, a final review meeting is used to reflect on the project and look for any potential improvement opportunities (within the PD process and surrounding processes), part numbers are assigned, the product and its bill of materials is created and any relevant information such as cost prices are logged within SAP. From here, final production drawings are updated with an allocated production number (and taken through the drawing check and approval process – section 5.1.2) and the project is brought to a close. Production commences as orders are received.

If a trial is unsuccessful, customer feedback will be considered and a 'STOP/GO' decision made: return to an earlier stage in the process or stop the project and consider reasons for failure; again in an effort to look for opportunities for process improvement and minimise losses.

The aspects of this process which are managed within SAP, as listed within section 7.1.1, remain as they are, however the process exists to ensure these steps are taken at the correct point within the project. This ensures that team member's time is utilised at the correct time – an example of poor utilisation of this time would be spending time setting up a new product and its bill of materials within SAP before orders have been confirmed; as there is a risk that the development project may not come to fruition.

Furthermore, as a result of the barriers faced in communicating information collected over the course of the project to the relevant team members at the right time, the template shown in Figure 7.2 was created. This form captures and communicates the product's bill of materials, part numbers and provides details of procurement information to the production, procurement and sales teams.



New Item Setup

Top Level Part Number: Click or tap here to enter text.

Top Level Items

Item Number	Description (inc. supplier info if applicable)	Unit Cost	Quantity
Enter Part Number or 'Non-stock/Purchased Item'. Add * if subassembly			

* Part number is a subassembly

Subassembly Items

Subassembly Number:

Item Number	Description (inc. supplier info if applicable)	Unit Cost	Quantity
Enter Part Number or 'Non-stock/Purchased Item'. Add * if subassembly			

Relevant Quotes attached

Figure 8.2 – The Stage 4 New Item Setup form

8.2 Case study 7 (S4) – Polymeric Insulator Paint Cover

One case that highlighted multiple opportunities for improvement was the development of paint protection blanket for polymeric insulators. This project was requested and fully funded by a customer. The customer had been successful in tendering for a contract to paint a number of electricity transmission towers on the condition that the top section of the polymeric insulators – the components that isolate the high voltage transmission cables from the tower – would be protected from any paint that may fall from the painter's brushes.

A number of concepts were created, and the customer requested that all of these were manufactured for a trial at a training centre. A photograph taken during this trial (using a ceramic insulator instead of a polymeric insulator) can be seen within Figure 7.3. The prototype production was arranged via a prototype production order. This PPO incorporated quotations received for the supply of the stitched assembly as this was outside of the manufacturing capabilities of AUS internally. Although AUS did supply some component pieces that would be stitched into the assembly. These quotations were requested and provided to the PD team via ema

Figure 8.3 - Polymeric Insulator Paint Cover Trial

The preferred concept was a combination of the prototypes trialled and the customer raised an order for 70 units. At this point, the process detailed within Figure 7.1 was followed. The required information for setting up item within SAP was held by the product development team. An attempt was made to pass on the information via an email to a sales administrator which contained a series of supplier discussion and quotations; this resulted in some confusion. As a result, the form shown in Figure 7.2 was created and the relevant information passed on.

8.3 Case study 8 (S4) – Wellington Link Bar

Another pertinent case is the development of a product called a wellington link bar. This project, which was fully funded by a customer, was associated with the electrical failures of underground link boxes discussed within section 3.1. Alongside the supply of pavement protection blankets, AUS were asked to investigate the root cause of the of many of the explosive failures resulting from faulty link boxes. AUS concluded that the component at the route of the failures was the link; specifically, the links within the box becoming loose over time as electrical and thermal load increases and falls through the network. The link and the solution developed by AUS is shown in Figure 7.4.

Figure 8.4 - AUS Wellington Link Bar

Figure 8.5 - Link Bar Trial

Once the link is installed and tightened to the correct torque setting, the plastic 'Wellington' link bar is installed which prevents rotation over time. Figure 7.5 shows a trial installation of three Link Bars.

AUS used their PD process to design this solution and made use of computational design techniques within the second stage. While early prototypes were produced “in house” using AUS’s CNC machines, once the design was finalised and approved by the customer, mass production (in batches of 10,000 units at a time) was achieved using the outsourced services of a local injection moulding company. AUS are currently supplying the product for the London and South East electricity Network and are currently looking to take this innovation to the wider UK market.

The prototype’s created during this project can be seen within Figure 7.6, the number of prototypes illustrate the importance of the feedback loop (following a customer trial) that exists between the final stage of the process & the detailed design stage.

This project began before the KTP started and the evolution in design shown within Figure 7.6 is a testament to the process and tools introduced during the KTP.

Figure 8.4 – Link Bar: Prototype Evolution

8.4 Conclusions

The major achievement detailed within this chapter is the identification of an opportunity to improve upon existing processes when used in conjunction with the AUS PD process. Processes relating to SAP required modification to ensure that appropriate information is available at the right time and as a result the New Item set up form (Figure 7.2) was created to assist this.

Case study 7 illustrates the importance of these new item setup code in maintaining an efficient use of the resources available to an SME. Case study 8 presents a successful project that required a high degree of flexibility and agility to adapt the product and meet customer needs.

This stage resulted in the least resistance to change of all the stages presented within this research. The ease of implementation in this instance is probably due to the fact that, out of necessity, experienced manufacturing staff were employed by AUS early on in the company’s formation and

therefore, the importance of elements such as Bills of Material and production drawing had already been embedded. This may be true for most manufacturing SMEs.

This stage could be further enhanced if project management and product development was embedded into the SAP system from the outset of projects. This would have multiple benefits: project time and costs could be easily allocated and logged, all information relating to a project could be stored in a central location and changes to this information tracked and the information required for new product setup could be collated throughout the project and made available to the relevant team members at the correct time automatically.

The cost associated with following this stage of the process is trivial, however, the cost of not following the process could be very substantial; ranging from delays in production to the loss of a customer.

As of January 2020, 25 new product development projects have reached this stage since the start of the KTP. The projects and resulting products have resulted in revenue exceeding £250,000.

9 PD Process Review, Conclusions & Further Work

9.1 The AUS Product Development Process: A Review

As the KTP reached its conclusion (June, 2020), team members were asked to provide an opinion on the KTP project and the resulting projects. These statements provide a qualitative account of the benefits that the introduction of a formalised process for product development has had for AUS:

Richard Brown (2020), Sales Director stated “We've certainly become more confident in our own (product development) ability now and can really call ourselves innovators.”.

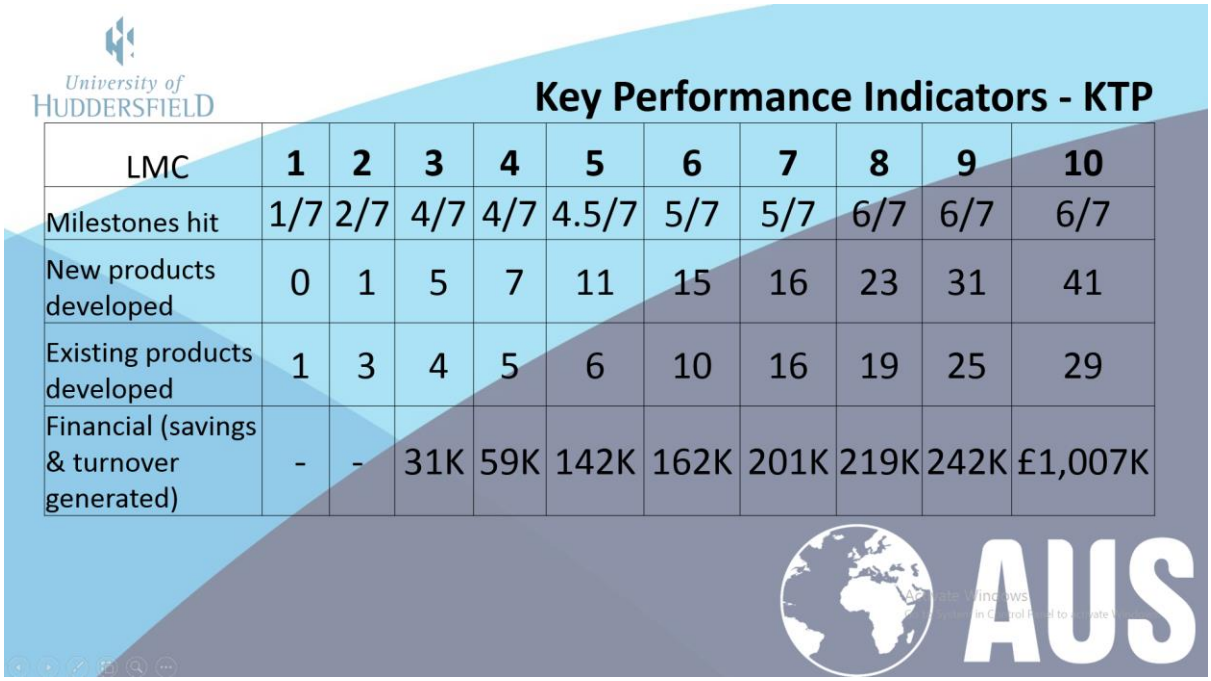
Simon Gibson, Founder and Managing Director at AUS said “In 2015, I thought we needed to move the product development side of AUS on, and following discussions with the University of Huddersfield, it was clear that we needed to look at a better design process. The KTP has led to a properly embedded design process, everyone understands what we need to put in to get the right result out. I'm particularly proud of the innovative nature of the new product development process.”.

Table 10.1 provides a summary of the quantitative data produced via this research which related to errors, these errors presented opportunities for insights to be gained. Within the cases presented, financial waste resulting from poor product development practices before the introduction of a formalised process exceeded the those after the introduction, this is a fair reflection of the situation at AUS.

Case Study	Stage	Waste Time	Financial waste (£)	Comments
0	N/A	Not recorded	10,000	An example of the potential consequences of not fully capturing customer requirements.
1	1	0	0	Time spent carefully capturing the ‘VOC’ and working towards an optimal concept selection against an approved design specification results in cost savings and the creation of turnover.
2	1	0	0	
3	2	3 days	1500	Temptation to shortcut crucial elements of a carefully structured design process will often result in losses that may significantly outweigh the cost of following the process.
4	2	Weeks	2000	Lower costs stages, when completed hastily can result in significant losses to a project during more complex and costly stages.
5 (4 continued)	3		500	As per row above
6	3	0	0	The lack of any waste shows that this case of process usage has been successful

Table 10.1 - Waste resulting from poor PD practice

Another insightful data set is the KTP’s key performance indicator log. This log, which is depicted within table 10.2, provides an overview of the performance of the AUS PD process as a function of time for the duration of the KTP.



LMC	1	2	3	4	5	6	7	8	9	10
Milestones hit	1/7	2/7	4/7	4/7	4.5/7	5/7	5/7	6/7	6/7	6/7
New products developed	0	1	5	7	11	15	16	23	31	41
Existing products developed	1	3	4	5	6	10	16	19	25	29
Financial (savings & turnover generated)	-	-	31K	59K	142K	162K	201K	219K	242K	£1,007K

Table 10.2 – KTP KPI's

For reference, the objectives, milestones and deliverables of the KTP can be found in Appendix D.

9.2 Conclusions and Further Work

As noted within chapter 4, the use of a case study research methodology results in various limitations. One of the disadvantages highlighted by both Zainal (2007) and Zhan (2018) was "a lack of rigour or robustness where biases from qualitative data can negatively influence research findings and conclusions". In the case of this research, the candidate was involved in all case studies presented. It is probable that some biases exist where opinions and qualitative data have been documented; the mitigation put in place to combat this is discussed within 4.3.

It may have been possible to mitigate this with a greater focus on the collection of data with more validity as to the effectiveness of the process changes for AUS. For instance, it would have been possible for the project team to capture accurate records of time spent on each activity involved with the staged PD process. Furthermore, it would have been useful to capture details of how much time was spent in creating the documentation to support the process and training team members on the process and its tools. This aligns well with another of the disadvantages highlighted, "case studies producing a large amount of data which can be easily miss-managed" (Zainal (2007); Zhan et al. (2018)).

Another highlighted disadvantage ((Zainal (2007); Zhan et al. (2018)) was "case studies providing very little basis for scientific generalisation where a small number of subjects are used". This thesis focuses on one subject, in AUS, which brings the validity of the findings into question. However, several case studies were analysed in which multidiscipline teams participated. In response to the potential disadvantage highlighted by Zainal and Zhan in "reliance on single case exploration, again making generalisation problematic.", this helps to mitigate the risks associated with a single subject. However, due to the nature of the case study methodology applied within this research, the conclusions of this research can only be generalised to SMEs with similar characteristics to those of AUS; these characteristics can be summarised as follows:

- A well-established UK based SME, with circa 20 years of trading

- Approximately 50 employees with a turnover around £10-20m
- A relatively small but diverse product development team
- Prior experience of developing, manufacturing, and supplying bespoke products
- Top management with a clear strategic vision for innovation and product development
- Highly regulated industries: Rail Industry, Electrical Supply Industry, Telecommunications, Electrical Arboriculture.

This research would be particularly generalisable to an SME, with similar characteristics to those listed above, that is engaged in a KTP with a focus on innovation and product development.

The hypothesis of this research is that there are barriers to the implementation of a formal new product development (NPD) process and associated tools in SMEs, and that these can be overcome by close partnership with a suitable knowledge base partner. This hypothesis has been supported via the identification of several barriers within the literature review and during case study reviews. The hypothesis that a close partnership with a knowledge base partner has been particularly supported within Chapter 6, in which the availability of expertise and equipment was instrumental in the successful delivery of the testing stage of two projects.

The hypothesis made within section 2.5.3 that expands on the over-arching hypothesis of this research, 'that British manufacturing SMEs are not utilising now cheaply available Computational Design Analysis (Simulation) and Optimisation tools, despite the democratisation movement (NAFEMS, 2018), as part of product development, but they should be.', is fully supported by the case studies presented within Chapter 5.

This thesis has conducted a thorough review of existing literature relating to product development process change within SMEs, a novel formalised process for product development within SMEs has been presented and the use of this process has been documented within a series of case studies. The case studies have enabled several conclusions to be drawn in relation to the initial objectives set out and the conclusions of the literature review.

The first objective of this research was to highlight barriers to the implementation of a formal new product development (NPD) process and associated tools in SMEs. Within the literature review, the following barriers were identified:

Poor definition of product requirement (A low-quality front-end process); interference or a lack of strategy from top management; technological uncertainty; a lack of resources or poor management of resources; poor project management; perceived risk with development activities; prior development project failures; relying on customer knowledge rather than market research; a lack of knowledge (and/or training) of the product design process and its tools; an environment that is not receptive to change; poor process flexibility; a partially closed culture; a lack of continuous improvement; and an organizational structure that hinders sustained innovation.

Out of all of the barriers identified within the literature, the following barriers were demonstrated or discussed within the case studies presented. In line with the second objective of this research, methods of overcoming the highlighted barriers are listed where solutions have been discovered:

- Interference or a lack of strategy from top management: This barrier was seen within case studies 3 and 4. A potential means of overcoming top management interference was put forward within chapter 4: "the use of an objective and so unbiased concept selection tool"
- A lack of knowledge (and/or training) of the product design process and its tools – as seen within case studies 1 and 2

- Complexity of tools and processes – as seen within case studies 1 and 2
- A lack of resources or poor management of resources – as seen within case study 1 and 2
- Poor process flexibility – as seen within case studies 2, 4, 7 and 8
- The barrier resulting from prior development project failures was highlighted within case study 1, however case study 3 showed that project failures can also provide useful learning opportunities and can therefore help to implement positive change.

The emergence of these barriers within the case studies supports their identification within the literature review.

The literature recommended, without reservations, that the following features should be included with a PD process: customer Integration, agility, computational design analysis and optimisation. All of these aspects were incorporated within the AUS PD process and all were shown to have been successfully implemented within the case studies.

According to the literature, the following elements can have a positive impact on a PD process where a carefully thought-out process of implementation is used and caution applied in the case of an SME: a gated process and specialist tools relevant to the Industry, e.g.: QFD. In the case of a gated process and the specialist HOQ tool QFD, the implementation plan, put together by the KTP project team, was shown to have ensured that these tools had a positive impact on PD activities.

Throughout the case studies a number of new barriers were identified. These barriers are listed alongside potential solutions to the barriers:

- The desire (or perhaps need) within an SME to be agile and complete projects quickly or, as described within Section 5.2.3, achieve a 'Quick Win'. This is especially true for the implementation of complex tools. A potential means of overcoming this barrier was put forward within section 4.4: "Engaging a diverse project team in a live project as a means of implementing a complex tool that is accompanied by a thorough guide on how to best use the tool.". Project failure as a result of an attempted 'Quick Win' is another means of overcoming this barrier, but implementation in this way should be avoided If possible.
- A bottleneck in the throughput of product development projects. A potential means of overcoming this barrier is presented within Figure 4.22.
- The difficulties faced by SME's in accessing appropriate test equipment. This difficulty could present a barrier to successful product development; such a barrier can be overcome via a partnership with a knowledge base such as a university.
- A lack of communication (to inform company strategy) between product development team members and top management. A means of overcoming this barrier is via the introduction of stage gates that require approval from top management throughout the PD process.
- Poor communication of information relating to a product, that has been gathered during the development process, from the development team to stakeholders involved with commercialising the product e.g. the procurement and sales team. A potential means of overcoming this barrier is put forward within figure 7.2.

The third objective was to assess the effectiveness of the product development tools highlighted in the literature for this SME. The tools discussed within the literature review and then implemented into the formal PD process at AUS include: QFD's HOQ, TRIZ and computational design analysis and optimisation. The effectiveness of the computational design analysis and optimisation tool has been clearly demonstrated within case studies 3 and 4. The HOQ and TRIZ tool both were presented by the

literature as being well established tools that had a perceived level of complexity associated with them within the industry. Case studies 1 and 2 provide evidence that these tools can be effective for successful product development within SMEs.

The fourth objective looked to provide details of the cost implications that a product development process can have on an SME. The cost implications associated with each stage have been discussed with the case studies.

The cost associated with stage 1 is equal to the cost of staff time in attending the development meetings. However, the cost of not following this stage of the process can be very substantial: it could result in a product that is fit for purpose never being developed and an entire future income stream not being acquired. Furthermore, if this stage is skipped a product that is not fit for purpose could be developed and a whole project up to the point of realisation could be wasted. This theme is seen throughout the process, the costs associated with skipping or not following the final three stages of the process were all shown to exceed the cost of following the process correctly – this is clearly crucial for the successful implementation of a formal process for product development.

The final research objective was to determine what motivates and demotivates stakeholders to use a formalised process for PD and to assess whether the motivation to circumvent the PD process could be altered once knowledge of the penalty of not following the PD procedure was more widely known. Based upon the case studies, motives to bypass the process include the desire to achieve a quick win and quickly satisfy a customer request, a perceived lack of complexity in the problem presented. The barriers presented can all act to demotivate stakeholders and result in a reluctance to use the formal process.

Within the literature review, research gaps were highlighted. The first gap was research that specifically looked at SMEs, this gap was highlighted within Cooper's (2015) paper on stage gates. This thesis looked exclusively at AUS, a British manufacturing SME, and therefore helps to close the gap within the literature; the findings of this research can be generalised to SMEs with similar characteristics to those of AUS. Furthermore, the lack of research into the take up of computational design analysis tools for product development by SMEs was highlighted within the literature review. Chapter 5 addresses this and the benefit and resulting take up of computational analysis and optimisation tools are presented and discussed. Based upon the case studies within Chapter 5, the benefits of this tool for SMEs akin to AUS are clear.

There are many opportunities to expand upon this research. For instance, future research could look to carry out a more analytical approach to case study reviews within manufacturing SMEs as well as the recording of and reporting on the action taken. Based upon the recommendations made throughout this thesis within the case study review sections, the PD process at AUS could be further developed to include:

- The use of an objective and so unbiased concept selection tool within an SME
- At present, no templates exist to ensure the minimum required amount of information is captured during a design analysis and optimisation project. It would be sensible for AUS to create templates for the consistent presentation of design analysis and optimisation projects and results.
- A potential improvement to stage 3 of the process, and in line with the advice detailed within section 2.8, would be to provide more control to product development teams members and therefore less reliance on top management for approval of test proposals, procedures and

prototype production orders. This could be achieved by the allocation of a budget, that is controlled by the PD team, within stage one of the product development process. This improvement is not supported by the case studies and may also have a negative impact – the process of request approval provides a good opportunity for product development team members to communicate project progress to top management; this ensures visibility of company operations and can help to inform company strategy. A lack of strategy is from top management is presented as a barrier to the successful product development and could therefore present a barrier to the implementation of change to a PD process.

- Stage 4 could be further enhanced if project management and product development was embedded into the SAP system from the outset of projects. This would have multiple benefits: project time and costs could be easily allocated and logged, all information relating to a project could be stored in a central location and changes to this information tracked and the information required for new product setup could be collated throughout the project and made available to the relevant team members at the correct time automatically.

A number of barriers were identified within the literature, but not demonstrated or discussed within the case studies, these include:

Technological uncertainty; poor project management; perceived risk with development activities; relying on customer knowledge rather than market research; an environment that is not receptive to change; a partially closed culture; a lack of continuous improvement; and an organizational structure that hinders sustained innovation.

The lack of demonstration or discussion of these barriers within the case studies does not mean that these are not potential barriers for SMEs. A sensible next step for research that expands upon this research, and for the implementation of the PD process at AUS would be to specifically target these barriers and consider the impact that these factors may be having on the implementation of PD process change within SMEs.

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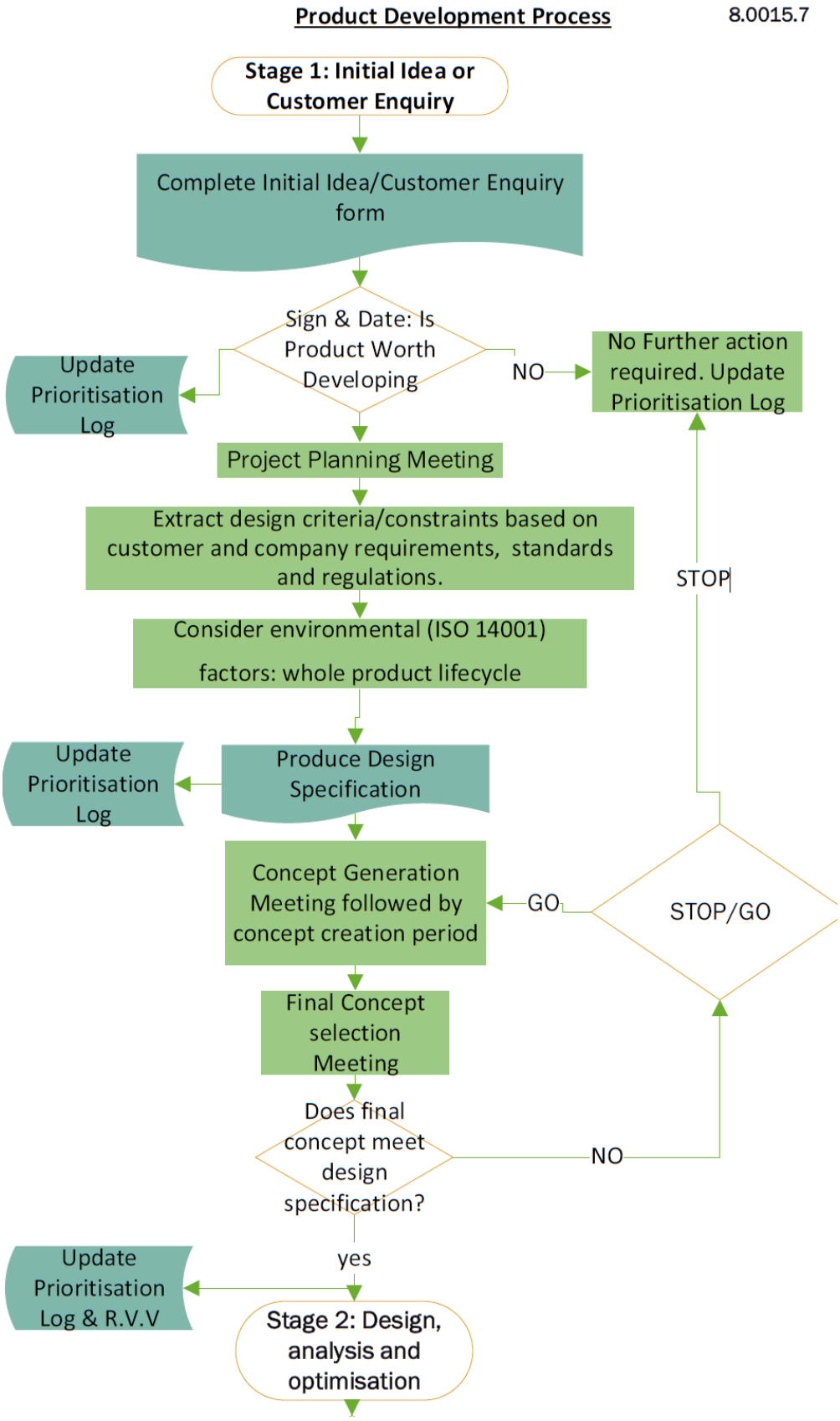
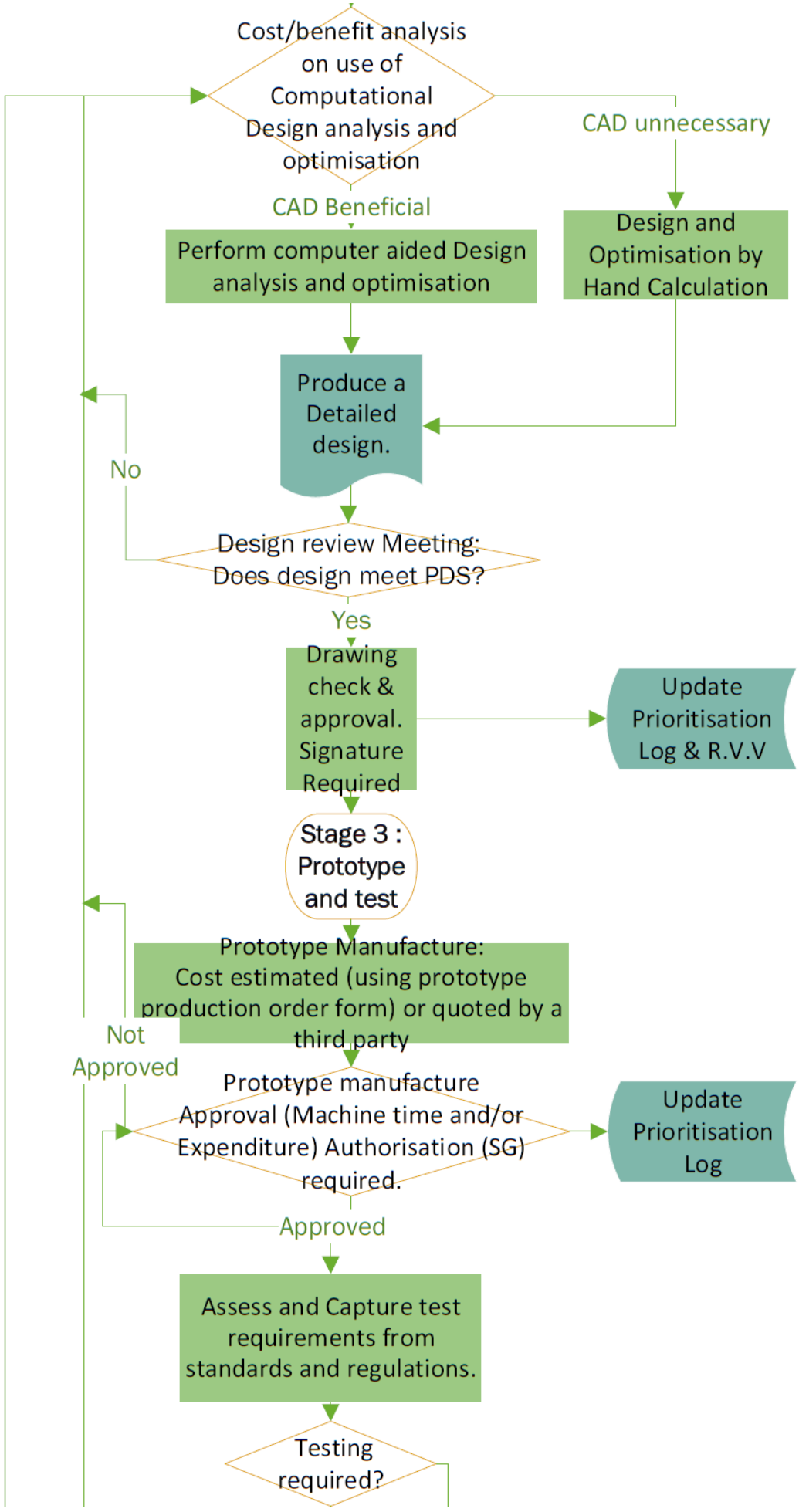
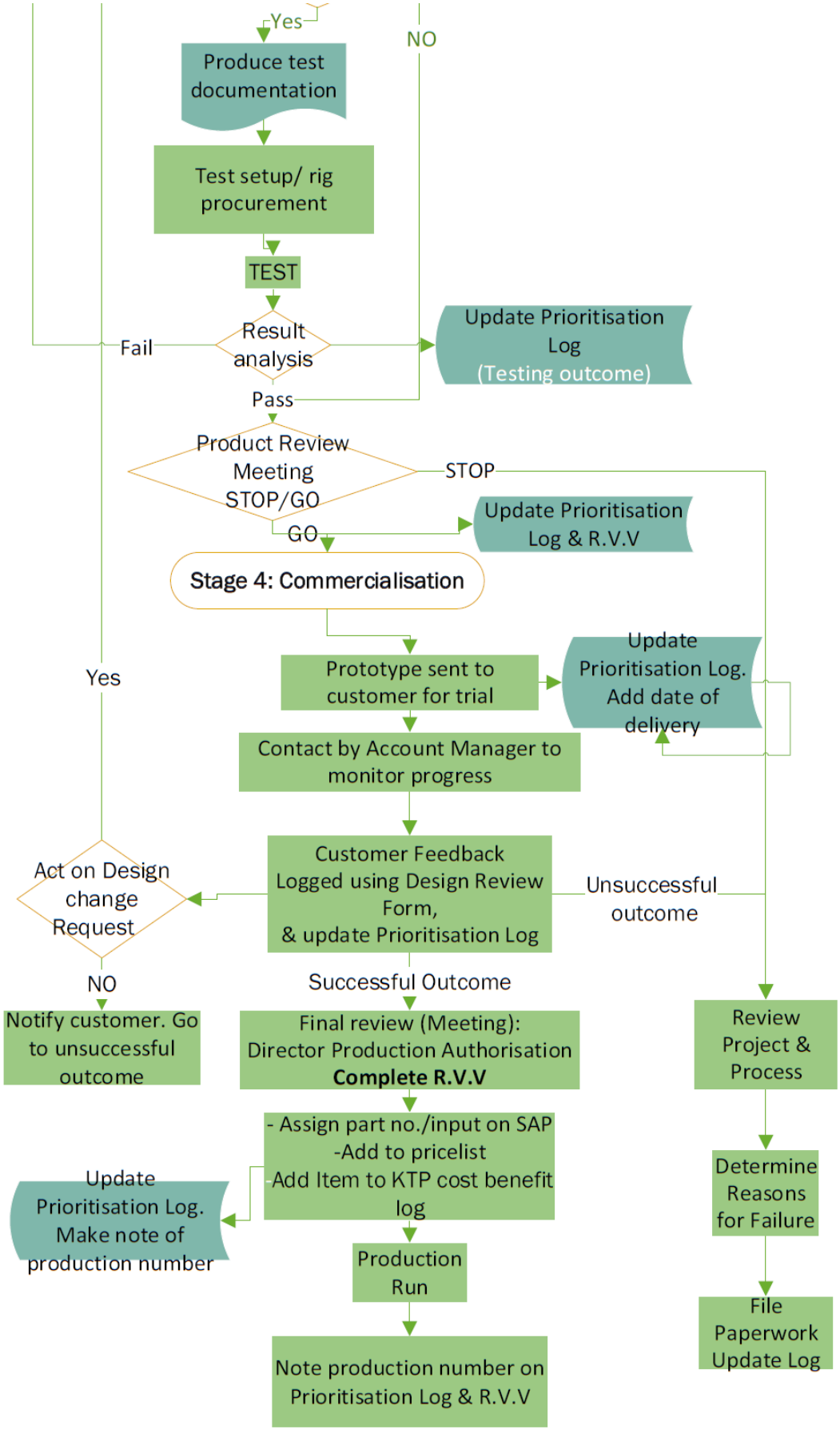
Appendix A

A1. The AUS Product Development Process




Cost/benefit analysis on use of Computational Design analysis and optimisation
CAD unnecessary
CAD Beneficial
Perform computer aided Design analysis and optimisation
Design and Optimisation by Hand Calculation
Produce a Detailed design.
No
Design review Meeting: Does design meet PDS?
Yes
Drawing check & approval. Signature Required
Update Prioritisation Log & R.V.V
Stage 3 : Prototype and test
Prototype Manufacture: Cost estimated (using prototype production order form) or quoted by a third party
Not Approved
Prototype manufacture Approval (Machine time and/or Expenditure) Authorisation (SG) required.
Update Prioritisation Log
Approved
Assess and Capture test requirements from standards and regulations.
Testing required?


Yes
NO
Produce test documentation
Test setup/ rig procurement
TEST
Result analysis
Fail
Update Prioritisation Log (Testing outcome)
Pass
Product Review Meeting STOP/GO
STOP
Update Prioritisation Log & R.V.V
GO
Stage 4: Commercialisation
Yes
Prototype sent to customer for trial
Update Prioritisation Log. Add date of delivery
Contact by Account Manager to monitor progress
Act on Design change Request
Customer Feedback Logged using Design Review Form, & update Prioritisation Log
Unsuccessful outcome
NO
Successful Outcome
Notify customer. Go to unsuccessful outcome
Final review (Meeting): Director Production Authorisation **Complete R.V.V**
Review Project & Process
- Assign part no./input on SAP -Add to pricelist -Add Item to KTP cost benefit log
Update Prioritisation Log. Make note of production number
Determine Reasons for Failure
Production Run
File Paperwork Update Log
Note production number on Prioritisation Log & R.V.V

A2. Stage Sign off

Design and Development

Stage Sign Off

Project Title: Click or tap here to enter text.

Development Number: Click or tap here to enter text.

Coordinator: Click or tap here to enter text.

Initial VOC Capture and Concept Generation (Stage 1)

Reviewed (×/✓) Verified against inputs (×/✓) Proceed to Stage 2 (×/✓)

Name: _____ **Sign:** _____ **Date:** _____

Design, Analysis and Optimisation (Stage 2)

Reviewed (×/✓) Verified against inputs (×/✓) Proceed to Stage 3 (×/✓)

Name: _____ **Sign:** _____ **Date:** _____

Prototype and Testing (Stage 3)

Reviewed (×/✓) Verified against inputs (×/✓) Proceed to Stage 4 (×/✓)

Name: _____ **Sign:** _____ **Date:** _____

Commercialisation (Stage 4)

Reviewed (×/✓) Verified against inputs (×/✓) Proceed to Manufacture (×/✓)

Name: _____ **Sign:** _____ **Date:** _____

A3. Product Development Project Summary

Product Development Summary – Project Title

Stage 1

Criteria and Constraints (e.g. Customer requirements, Regulations, Ease of manufacture)

Criteria	Constraints

Environmental Considerations

Impact reduction of manufacturing	Impact reduction of use	Impact reduction of disposal

Specification

Concepts

Concept 1	Concept 2	Concept 3
☐	☐	☐

Stage 2

Calculations

Hand Calculation	CAD Calculation
Final Specification ☐	Image ☐
Summary:	

CAD Design based on optimisation

Stage 3

Estimated Cost of Prototype

Click or tap here to enter text.

Test Requirements

Summary: Click or tap here to enter text.

Test Proposal

Summary: Click or tap here to enter text.

Test Results

Summary: Click or tap here to enter text.

Stage 4

Chosen customer for trial

Click or tap here to enter text.

Customer Feedback

Summary: Click or tap here to enter text.	
Successful	Unsuccessful
☐	☐

Final Review

Summary: Click or tap here to enter text.

A4. AUS Legacy Design and Development Documentation.

8.0041.4

Date:	
Name:	

AUS Design & Development

				Project Owner	
		1 off	**Prototype**		
No:					
Customer:		**Contact:**			
		Tel:			
		E-Mail:			
Description:					
Performance Criteria:					
Applicable Standard(s):					
Customer Timescale:					
Reason (Benefit)					
Target Price:					
Conclusion:					
Approved By Director :					
Production By:		Production Start Date:		Production Due Date:	

Sketch/Drawing/Photo (Attach additional drawings/Specifications/Photographs as applicable)

No:
Sheet No:
Coordinator:

Design & Development
Review, Verification & Validation

Initial Design & Development

Comments:					
Review (x/✓)		Verify Against Inputs (x/✓)		Validate: Ok to progress to prototype Stage(x/✓)	
Approved by					

Prototype Produced

Comments:					
Review (x/✓)		Verify against inputs (x/✓)		Validate ok to proceed to testing/trial (x/✓)	
Approved by					

Prototype Tested /Modified

Comments:					
Review (x/✓)		Verify against inputs (x/✓)		Validate ok to proceed to testing/trial (x/✓)	
Approved by					

Return from Customer Trial

Comments:					
Review (x/✓)		Verify against inputs (x/✓)		Validate ok to proceed to testing/trial (x/✓)	
Approved by					

*Final Design review/*Review of process (*Delete as necessary)

Comments:	
Directors	
Log Updated	
Part No Allocated	

8.0047.0

Design & Development Log.

No.	Date	Customer	description	Concept approved	Prototype Approved	Customer Trails	Approved for Production

Appendix B: Stage 1 Templates and Supporting Information

B1. The AUS Initial Idea/Enquiry Form

Project Title: Click or tap here to enter text.
Name: Click or tap here to enter text.
Date: Click or tap to enter a date.

1. **Customer**

Name: Click or tap here to enter text.
E-mail: Click or tap here to enter text.
Telephone Number: Click or tap here to enter text.

2. **Description**

Define the problem. Attach additional Information/drawings/specifications/photographs as applicable.

3. **Liability**

Who is liable? AUS is liable if AUS has designed the product. Liability if AUS acts as a subcontractor and is manufacturing provided technical drawings. If not AUS, fill field 4 to 6 with N/A.

4. **Risk Implications**

Risk implications for the end user (Electrical, Lifting Equipment, Working at Height, Other ?)

5. **Standards and Regulations**

List of standards specified by the customer

6. **Performance Criteria**

E.g. Expected Load, Environmental Conditions, etc. Provide mitigation (design requirements) for risks stated in field 4.

7. **Customer Timescale**

Give specific dates. Such as completion, concepts or prototype required by.

8. **Business Case**

Justification for proceeding with development.

Expected Sales Volume: Click or tap here to enter text.

Target Sale Price: Click or tap here to enter text.

9. **Director Approval**

State conditions of approval. E.g. Budget, Critical Dates, etc.

Name: _____ Sign: _____ Date: _____

10. **Project Number Assignment**

Project Number: _____

B2. Product Design Specification

Project Title: Click or tap here to enter text.

1. **Product Description**

Click or tap here to enter text.

2. **Product Specification**

Click or tap here to enter text.

3. **Contradictions**

List of contradictions highlighted using QFD

Appendix C: Stage 3 Templates and Supporting Information

C1. Prototype Production Order Template

Prototype Production Order

Customer:
Project Owner:
Due Date: ASAP

Development Number:
Document Date:

Item:
Quantity:

Components

Item Number	Description	Unit Cost	Quantity	Total Cost
				£0.00
				£0.00
				£0.00

Operations

Description	Est. Time (mins)	Total Cost
		£0.00
		£0.00
		£0.00
	Total Cost Estimate	£0.00

Name: Date: Sign:

Production Approval

Name: Date: Sign:

Actual Time:
(Include cause of delay if any)

C2. Test Proposal Template

Test Proposal

Objective of Test

Sample size & specification

Sample acquisition & Preparation

Description	Assembly quantity

Test Procedure:

1. Calibration of equipment – record date of last calibration or perform calibration with load cell.
2. Labelling/record the test equipment and specimens used with permanent marker or labels
3. Equipment Programming
4. Positioning of samples to ensure repeatability – note set up
5. Photograph/video test set up
6. Capture the following Data…
7. Video where possible + photograph and write a description for each specimen
8. Start test
9. Test end at predefined point
10. Record results in excel if possible & save data after each test
11. Carefully store labelled test specimens ensuring failed surfaces are not damaged in storage
12. Repeat from step 4

Approval (SG): Date:

C3. Test Report Template

DD/MM/YY

Title

Contents

Introduction 2

Objective of Test 2

Test Equipment and Preparation (set up) 2

- Equipment 2
- Preparation 2

Test Procedure 2

Pass Criteria 2

Risk Assessment 2

Results 2

Further Work/Calculation 2

Discussion and Conclusions 2

TEST LOCATION:
TEST OPERATIVE(S):
TEST TYPE:

AUS

DD/MM/YY

Introduction

Objective of Test

Test Equipment and Preparation (set up)

Equipment

Preparation

Test Procedure

Pass Criteria

Risk Assessment

Results

Further Work/Calculation

Discussion and Conclusions

C4. Test Reports

C4.1 Tensile Test Report: Tongue Compression End Fitting

Introduction

This report documents the testing of all variations of existing and new (designed and manufactured by AUS LTD) tongue compression end fittings. The fittings that are currently utilised by the Rail Industry are manufactured from malleable cast iron. AUS have manufactured a range of fittings that aim to resolve issues caused by water trapped within cantilever tubes, which can freeze resulting in tube failure. To ensure no water is trapped within the cantilever tubes, a drain hole has been incorporated into the design of the AUS fittings. This design has been validated using computation design analysis techniques; namely linear and non-linear Finite Element Analysis. This analysis has enabled AUS to optimise the design of the fittings and reduce component mass. AUS have manufactured two batches of the new fitting, one in aluminium and one in (galvanised) structural steel.

Objective of Test

To test various tongue compression end fittings to destruction in accordance with 8.2.1.5 of BS EN 50119.

Test Equipment & Set-up

Figure 1

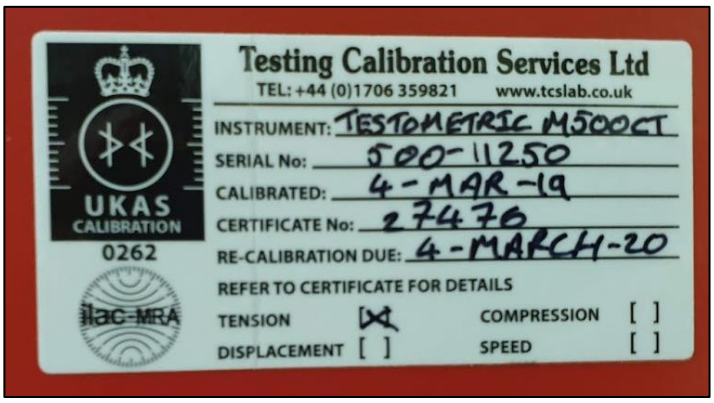


Figure 2

Figure 1 shows the test rig arrangement, this was consistent for all samples. The machine used was a Testometric M500CT, the capacity of this machine is 50KN. Figure 2 shows the machine's calibration certificate.

Samples for Test (Round 1)

Description	Quantity
Clevis & pin (142-050-01, 148-025-01)	1
48.3 machined fittings (steel)	4
42.4 machined fitting (steel)	4
48.3 machined fittings (Al)	4
42.4 machined fitting (Al)	4
142-090-001	2
142-16-001, 142-17-001	2
142-17-001	2
48.3 and 42.4 Tube	3.5m x 2
Machined Aluminium Pin (148-025-01)	4

Test Methodology

1. Calibration of equipment – record date of last calibration or perform calibration with load cell
2. Label/record the test equipment and specimens used
3. Programme equipment to start, apply load/displacement and end in line with 50119:
    - Step 1: Apply 10N preload at a 10mm/min rate
    - Step 2: Apply a displacement at 25mm/minute
    - End Condition: 60mm displacement or 95% reduction from peak force
4. Capture load (N) vs displacement and force vs time for the full elastic – plastic transition
5. Carefully position samples to ensure repeatability – note set up
6. Photograph/video test set up
7. Start test
8. Record results & save data after each test, note the following;
    - The failure load of the test specimen
    - The nature and location of the failure on the specimen
9. Carefully store labelled test specimens
10. Measure the test jig/clevis before & after each test and record the value. Compare the value to before testing to ensure no deformation has occurred in the jig

Note: All Aluminium fittings were tested using an Aluminium (6082T6 version to 148-025-01 dimensions) pin manufactured by AUS.

Pass Criteria

Item Number	Tube Size	'P' - Max Load (FOS=2.5) (KN)	Pass Criteria (P*FOS) (KN)
1/142/100	48.3x4	16.65	41.63
1/142/17	42.4 & 48.3x4	8.83	22.075
1/142/090	48.3x4	None Given	None Given
1/122/001	Clevis	17.65	44.125

Table 1

The Information within Table 1 has been taken from the relevant technical drawings for each item.

Results

Tube size – Description or P/N	SAMPLE ID	MAX FORCE (N)	Failure Mode
48.3 – 142-090-001	C8.1	45060	DNF (Did Not Fail)
	C8.3	45026	
48.3 – 142-16-001, 142-17-001	CA8.1	37632	Pulled out
	Sample 1 (Tested using The University of Huddersfield's test machine with a 600N/s load rate)	21223	
42.4 – 142-17-001	C2.1	45088	DNF
	C2.2	45019	
48.3 AUS machined fittings (6082 T6 Aluminium)	A8.1	45077	DNF
	A8.2	45145	DNF
	A8.3	45121	DNF
	A8.4	40541	Pulled Out
	Average	**43971**	
48.3 AUS machined fittings (Galvanised S275)	S8.1	45051	DNF
	S8.2	45019	DNF
	S8.3	45057	DNF
	S8.4	45156	DNF
	Average	**45071**	
42.4 AUS machined fittings (6082 T6 Aluminium)	A2.1	37480	Pulled Out
	A2.2	34702	Pulled Out
	A2.3	31211	Pulled Out
	A2.4	34472	Pulled Out
	Average	**34466**	
42.4 AUS machined fittings (Galvanised S275)	S2.1	45057	DNF
	S2.2	45060	DNF
	S2.3	45000	DNF
	S2.4	45033	DNF
	Average	**45038**	

Table 2

The failure mode described as ‘Pulled out’ was a gradual plastic deformation of the crimped connection.

The Results in Table 2 show that all AUS fittings exceed the loading requirements detailed within the technical drawings for item 1/142/17 and all but one (an aluminium fitting for 48.3 mm tubes) exceeded that higher load requirement detailed within the 1/142/100 drawing. Both variations of the steel fitting could withstand the force capability of the machine (45KN), as could all existing cast fittings that did not utilise an aluminium sleeve.

Existing fittings that do utilise an aluminium sleeve are significantly weaker than there non sleeve counterparts. Moreover, a higher level of inconsistency exists within aluminium sleeve connection results when compared to connections with no aluminium sleeve. One of the aluminium sleeve connections that was tested failed below the load requirement (22075 N) stated within the 1/142/17 technical drawing.

The AUS fittings remove the need for an aluminium sleeve, this combined with the improved accuracy of CNC machining and the drain hole will result in improved reliability in the crimped fittings and therefore less network downtime.

Further Work

Figure 3

All samples that have not deformed plastically (DNF's) will be tested to destruction. Alongside this, an Aluminium Clevis, as pictured in Figure 3, will be tested to destruction.

During this testing, a sample that consisted of an Aluminium tube and an aluminium fitting was tested with promising results. AUS plan to pursue this further with the goal of testing a lightweight, fully aluminium cantilever system. All future results will be shared as soon as they become available.

Results: Round 2

A second round of testing was completed at the University of Huddersfield's 'Harold' test rig to take the 'DNF's' to failure. The load capacity of 'Harold' is 250KN.

Tube size – Description or P/N	SAMPLE ID	MAX FORCE (kN)	Pass/Fail
48.3 – 142-090-001	C8.1	Not Tested	N/A
	C8.2	75.70	Pass
	C8.3	52.46	Pass
	Average	**64.08**	Pass
42.4 – 142-17-001	C2.1 grease	48.60	Pass
	C2.2	Not Tested	N/A
48.3 AUS machined fittings (6082 T6 Aluminium)	A8.1	Not Tested	N/A
	A8.2 no grease	75.70	Pass
	A8.3	Not Tested	N/A
	Average	**N/A**	**Pass**
48.3 AUS machined fittings (Galvanised S275)	S8.1 no grease	63.42	Pass
	S8.2 no grease	83.23	Pass
	S8.3 no grease	59.68	Pass
	S8.4 no grease	60.97	Pass
	Average	**66.83**	**Pass**
42.4 AUS machined fittings (Galvanised S275)	S2.1 no grease	55.94	Pass
	S2.2 no grease	51.59	Pass
	S2.3 no grease	56.46	Pass
	S2.4 no grease	53.27	Pass
	Average	**54.32**	**Pass**

Table 1

New Design

Following discussions with route asset teams, the decision was made to further optimise the fitting design to mitigate the risk of drain hole blockage by grease. The optimisation goal was to increase drain hole size and angle within the design space whilst finding the ideal balance between weight reduction and strength.

The resulting designs for 42.4 and 48.3 size tube were prototyped and tested using the same method as detailed in section 4 during the second round of testing. The 42.4 tube fitting design is shown in Figure 4.

The results of this testing are detailed within Tables 5-9.

Figure 4

Galvanised S275 Machined Fitting Results

Sample ID (42.4 Tube)	Failure Load	Pass/Fail
S1N grease	54.04	Pass
S2N grease	63.87	Pass
S3N grease	58.05	Pass
S4N grease	76.16	Pass
S5N grease	67.40	Pass
AVERAGE	**63.90**	**Pass**

Table 2

Sample ID (48.3 Tube)	Failure Load	Pass/Fail
1 grease	64.65	Pass
2 grease	49.66	Pass
3 grease	54.25	Pass
4 grease	54.22	Pass
5 grease	55.70	Pass
AVERAGE	**55.70**	**Pass**

Table 3

6082T6 Aluminium Machined Fittings Results

Sample ID (42.4 Tube)	Failure Load	Pass/Fail
A1N grease	48.72	Pass
A2N grease	44.29	Pass
A3N grease	49.28	Pass
A4N grease	44.78	Pass
A5N grease	45.09	Pass
AVERAGE	**46.43**	**Pass**

Table 4

Sample ID (48.3 Tube)	Failure Load	Pass/Fail
1 grease	40.17	Fail (142/100 load)
2 grease	33.33	Fail (142/100 load)
3 grease	37.70	Fail (142/100 load)
4 grease	42.79	Pass
5 grease	37.22	Fail (142/100 load)
AVERAGE	**38.24**	**?**

Table 5

6082T6 Aluminium Machined Clevis Results

Sample ID	Failure Load	Pass/Fail
C1-C (existing MCI)	61.06	Pass
C1-A (aluminium)	42.87	Fail
C2-A	48.69	Pass
C3-A	48.69	Pass
C4-A	42.93	Fail
AVERAGE ALUMINIUM	**45.80**	**?**

Table 6

Discussion & Conclusions

All galvanised S275 machined fittings met the pass criteria specified within BS EN 50119 (8.2.1.5) and the relevant drawings.

The 6082T6 aluminium machined fittings for 42.4 tube (142/017 equivalents) all met the pass criteria specified within BS EN 50119 (8.2.1.5) and the relevant drawings.

80% of the 6082T6 aluminium machined fittings for 48.3 tube (142/090 & and 142/100 equivalents) did not meet the higher pass criteria specified within 142/100, but could achieve a working load limit of 13.3kN.

50% of the 6082T6 aluminium Clevis assemblies tested met the pass criteria specified within BS EN 50119 (8.2.1.5) and in the relevant drawings. A working load limit of 17.1kN could be achieved based on this testing. A steel equivalent of this clevis will also be tested.

Table 9 draws comparisons between the new assemblies tested and their existing equivalents. Approved crimped assemblies that include an aluminium sleeve have shown to be weaker than crimped assemblies without a sleeve. The loads they can withstand are lower than those of the new equivalent AUS designs and they do not meet the pass criteria specified by the 1/142/100 drawing (16.65kN*2.5FOS). Based on these findings, we would strongly recommend that the sleeve (1/142/016) is made obsolete to improve the reliability of the network.

The AUS machined galvanised steel fittings (for 42.4 tubes) demonstrated significant gains in performance compared to the existing approved equivalents. The approved castings are close the limits of the tolerances specified on their technical drawings, and indeed are sometimes supplied outside of this tolerance – this could be a result of the aging tools used to cast these components that may not have been updated for decades. The slight decrease in performance demonstrated buy the AUS fittings for 48.3 tubes can be attributed to variation in tube geometry.

Given historic experience with wear of aluminium components, we would propose a trial of aluminium tongue compression end fittings and aluminium clevis assemblies in a low risk location. This would

allow for the wear between the aluminium clevis and the aluminium fitting to be monitored and conclusions to be made following a suitable trial period.

When comparing assemblies containing grease and assemblies without grease, looking at an average result from batches containing 5 samples, it can be concluded that the inclusion of grease within an assembly reduces crimped assembly strength by 18%, as shown in Table 10.

Fitting Comparison	Approved Fitting Average / kN	New AUS Design Average / kN	Percentage Difference
42.4 AUS machined fittings (6082 T6 Aluminium) vs 142-017	48.60	46.43	-4.57%
42.4 AUS machined fittings (Galvanised S275) vs 142-017	48.60	63.90	+27.20%
48.3 AUS machined fittings (6082 T6 Aluminium) vs 142-090	64.08	38.24	-50.51%
48.3 AUS machined fittings (Galvanised S275) vs 142-090	64.08	55.70	-13.99%
48.3 AUS machined fittings (6082 T6 Aluminium) vs 142-16-001, 142-17-001	37.63	38.24	+1.60%
48.3 AUS machined fittings (Galvanised S275) vs 142-16-001, 142-17-001	37.63	55.70	+38.72%
48.3 AUS machined fittings **(Galvanised Machined S275, grease vs no grease, respectively)**	66.83	55.70	-18.17%

Table 7 - Comparison between the approved Castings and the new AUS Fittings

C4.2 Test Report: The Effect of 5 Design Changes on AUS Insulated Operating Rod Strength.

Introduction

This report documents the testing of 26 AUS Insulated operating rod samples, a flexural test to failure, to determine the effect that of a number of design changes have on mechanical behaviour.

Bending was determined to be the most common cause of failure, hence that is the focus of this testing. However, insulated operating rods are used for a number of applications including:

- Lifting and applying/installing earthing equipment
- Sawing
- Pruning
- Pulling (hook adaptor)

These applications result in a number of load cases:

- Tension
- Torsion
- Bending
- Compression

The rods are manufactured from a 'pre-preg' E-Glass composite layers that are wound around a mandrel and cured before finishing on a centre grinding machine before a layer of lacquer is applied, due to time restrictions the decision was made to not lacquer the rods; the rods were tested in a 'raw' state.

In use rods are connected by a 6'' Spigot with an internal spring button interface that is secured (by the force of the spring) into two overlapping slots.

Experimental Details

Sample Description and Quantity

Table 1 gives an overview of the test samples including a brief description, Identity number and quantity. The following sections will give a more in-depth description of each sample. Each design change detailed has been made with strength, manufacturability and cost in mind to ensure any resulting design changes are commercially feasible.

A2-7: Standard intermediate rod

In order to determine the worst case loading position, in terms of button direction in relation to load direction, 6 control samples were tested in three positions: Button up (in the direction of load application), button side (rotated through 90^{o} from direction of load application) and button down (opposite direction of load application). There were two samples for each position.

B1-5: +2 wraps.

5 B rods were supplied with 2 additional 'wraps' of 'pre-preg' epoxy glass fibre. Other than the outer diameter, all other dimensions remained unchanged.

This design change will increase the cross-sectional area of the rod.

C1-5: 8'' Spigot.

5 C rods were supplied with a longer spigot. The concept of this design change is that the longer spigot should move the stress concentration from around the slot/button to the spigot end.

D1-5: 8'' Collar over button section.

5 D rods were supplied with a collar over the slot. This design change is in line with B rods; however, these rods are only reinforcement around the slot area (stress concentration area). The lack of additional wraps along the whole rod length reduces rod mass compared to B rods.

E1-5: Pips.

5 E rods were supplied with 'pips' instead of slots. This design change reduces stress raising effects of the slot; the pip is around a quarter of the size of a button.

A. standard (inter)	**ID**	**QTY**
1st test – Complete (see previous report)	1	1
button down	2-3	2
button side	4-5	2
button up	6-7	2
B. +2 wraps	1-5	5
C. 8'' spigot	1-5	5
D. collar over button area	1-5	5
E. pips	1-5	5
Total	26	

Table 8 – Sample description and quantity

Test Procedure

See Report Titled: Final Insulated Operating Rod Test Procedure.

Test Set up

As above please see the test procedure report. Videos and Photographs of each test are also available.

Equipment Calibration

Figure 1 shows calibration data for the load cell used for this testing.

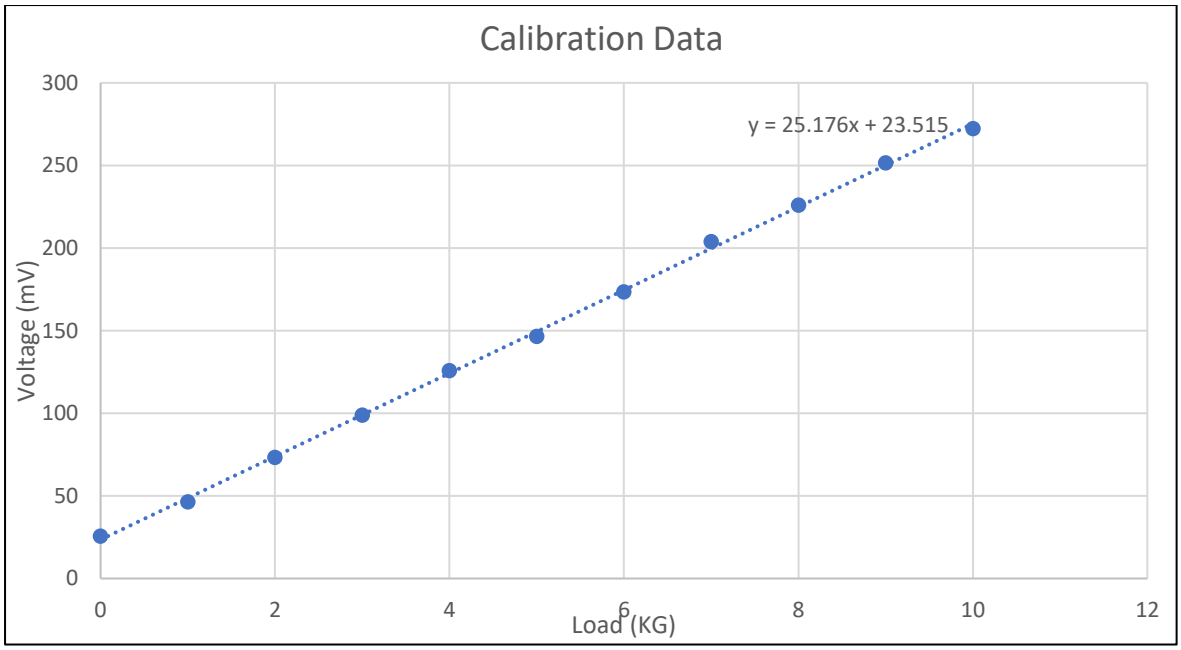


Figure 1 - Calibration data: Voltage vs Load

Based on a linear least squares trend line (dotted blue line in Figure 1), the relationship between the load 'x' and the voltage 'y' (y data recorded via Data Acquisition unit) is:

$$x = \frac{(y - 23.515)}{25.176}\ Kg$$

Results & Discussions

Fully tabulated results and equations can be found in P:\AUS Product Development\ESI\42 -Insulated operating rods\results.

Based on the results in Table 2, the worst-case position (or weakest orientation) was clearly button up.

Based on these results all further testing was set up in the worst-case position to ensure all further testing would give worst case failure loads. I.e. all tests were conducted with the button facing the load direction.

Button position	Sample ID	Load (Kg)	Average load (Kg)
Button up	**A2**	**41.011**	**42.24**
	A3	**43.473**	
Button down	A4	62.499	60.32
	A5	58.130	
Button side	A6	66.035	65.30
	A7	64.565	

Table 2 – Results for A samples

As seen in Table 3, the average failure load for B samples was 58.8KG. This shows that two additional wraps of glass fibre results in a 39% higher failure load. On occasion the rods failed internally, i.e. the failure was hidden by the external two wrap skin.

Sample ID	Failure Load (Kg)
B1	61.665
B2	63.770
B3	55.191
B4	55.191
B5	58.130
B AVERAGE	**58.790**

Table 3 - B Rods Failure loads

The average failure load, as seen in Table 4, for C samples was 51.1KG. Hence, a longer spigot resulted in a 21% increase in average failure load.

Despite the increase in spigot length, the actual slot position was not changed. Perhaps this resulted in a greater moment at the point of spigot button contact. This also highlighted the impact that the contact between the button and rod has; contact could explain why the button up position gives a worst case; as this position results in the largest area of contact in bending.

Sample ID	Failure Load (Kg)
C1	54.992
C2	46.452
C3	53.324
C4	47.882
C5	52.887
C AVERAGE	**51.108**

Table 4 - C Rods Failure Loads

As seen in Table 5, the average failure load for D samples was 56.7KG. This shows that a 'collar' over the button yields a 34% improvement inn required failure load. This improvement is slightly under that seen for b rods with 2 additional wraps. D samples weigh 0.1 KG (D = 0.7Kg) less than B samples.

Sample ID	Failure Load (Kg)
D1	56.859
D2	56.700
D3	59.203
D4	53.086
D5	57.812
D AVERAGE	**56.732**

Table 5 – D Rods Failure Load

The average failure load for E samples, seen in Table 6, was 49.5KG. Hence, based on this data changing buttons for pips gives increases the average failure load by **17%.**

Sample ID	Failure Load (Kg)
E1	50.385
E2	47.882
E3	50.742
E4	49.193
E5	49.312
E AVERAGE	**49.503**

Table 6 - E Rods Failure Data

Students T Test

Table 7 looks at the quality of the data & so the results. Each line in the Table compares the results from a group of samples (e.g. B samples) against the control sample A. The P-Value is the probability that the two groups of data are significantly similar. Other than A vs E, where there is a 7% probability that the difference in averages is due to chance, all samples have a less than 1% chance of not being significantly different. I.e. the data & results are high quality.

T.TEST	P- Value (%)
A vs B	0.09
A vs C	1.06
A vs D	0.54
A vs E	6.97

Table 7 - T.Test results

Summary of Results

To conclude, Table 8 summarises the average results for all tests.

Sample ID	Failure Load (Kg)	% improvement compared to control samples A
A.	**42.240**	**Control Sample**
B. +2 wraps	**58.790**	**39**
C. 8'' spigot	**51.108**	**21**
D. collar over button area	**56.732**	**34**
E. Pips	**49.503**	**17**

Table 8 - Average failure load summary Table

Clearly, the greatest improvement was the addition of two wraps (B samples) with the collar over the button area (D samples) not falling far behind. A discussion could be had as to which change would be best from a commercial point of view when considering the following:

- Cost of change
- Weight 0.1Kg per rod saving for D samples
- Strength

The change to spigot length did not prove to be as beneficial as anticipated. As discussed, future testing could look at the relationship between the longer spigot and varied slot position.

The introduction of pips is a relatively simple change and yield a healthy improvement on failure load. Based on the p value, there is a 93% probability that this change would result in this improvement consistently.

Appendix D: The Objectives, Milestones and Deliverables of the AUS/University of Huddersfield KTP.

D1. Milestones

1. Initial KPI's Identified
2. Current VOC method appraised and revised
3. 20 design concepts generated (Structured innovation tool applied by associate and presented to the project management team)
4. Highly constrained, multi criteria optimisation techniques develop by the associate and presented to the management team.
5. Robust design analysis applied by the associate and presented to the project management team
6. Prototype samples of product 1 produced
7. Supply chain identified for product 1

D2. Deliverables

1. Road map of standards
2. CAD and analysis vendor/trainer identified
3. Fully detailed design
4. Concept generation documentation
5. Design simulation and optimisation manual written
6. Prototype testing manual generated
7. Test data for product 1
8. Supply chain identified for products 2 & 3

D3. Objectives

1. Define a design and analysis functionality development strategy
2. Embed a design simulation and optimisation process within the company
3. Define and embed a design communication methodology within the company
4. Develop and embed a prototype test process within the company
5. Develop and train staff on new supply chain management procedure
6. Carry out staff training to ensure that design and test data is used effectively during the marketing process

D4. Other outputs

1. Candidate products for potential redevelopment and ranked and agreed with the company management team
2. Current NPD process mapped and documented in knowledge bank
3. Customer requirements specified
4. PDS generated incorporating qualitative and quantitative design constrains and criteria
5. Concept selected for detailed development
6. Pareto optimal design set and active constraint set identified
7. Robust design identified
8. Pool of staff trained in concept generation
9. Testing requirements for product 1 defined
10. Potential suppliers identified for product 1
11. Supply chain management procedure written