Combining Design Thinking and Systems Engineering in a Large Engineering Organisation

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Abstract

Design processes and the management of design processes are critical components of the ability for engineering organisations to generate revenue and create innovative solutions to societal problems. Furthermore, appropriate design processes are presented in the literature as being directly linked to overall business success and customer satisfaction. Two such design processes are considered in this investigation, Design Thinking (DT) and Systems Engineering (SE). At their core, DT places an emphasis on understanding user needs and generating a solution that delivers value to a customer whereas SE provides a rigorous framework that manages the delivery of complex systems that meet customer expectations.

This research explores how DT and SE can be implemented in a Large Engineering Organisation (LEO), specifically within a single Case Study Division (CSD). This investigation utilised a mixed methods approach, where interviews and questionnaires were considered alongside quantitative data analysis to contextualise the CSD, generate solutions and analyse proposed outcomes. DT and SE were considered as functions of their core components in solutions generated, and direct comparisons to traditional process implementations were made.

The key contributions to knowledge of this research are found when considering this investigation's research questions. A total of four areas were identified within the CSD as optimal locations for the implementation of DT and SE and each location's applicability is discussed with respect to other organisations. Next a total of 11 attributes to implementation were identified that significantly affect the implementation of DT and SE in an LEO. Further, results showed that the selection of appropriate change management methodologies is critical to successful implementation, and this is highlighted in all attempts made. Finally, the CSD proposed a number of desired outcomes that would demonstrate where areas of value were perceived to be present, and recommendations are made for potential objectives for future implementations of DT and SE.

Further novel contributions to knowledge include; the validation of this investigation's findings through comparison data from culturally similar cases, the identification of organisational zeitgeist as a key attribute to the implementation of DT and SE within an LEO, the creation of merged DT and SE processes for differing applications and the identification of an optimal time to implementation that is equally as important as an optimal location for implementation.

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Glossary

Commercial Triage - A rapid assessment conducted at a pre-process stage that evaluates the technical risk of a proposal against its commercial viability.

CSD – Case Study Division

CSO – Case Study Organisation

Customer Journey Mapping - A Design Thinking activity that encourage practitioners to identify and consider key aspects of a product or service lifecycle so that features of value can be generated for end users.

Design (Noun) - A plan or specification that details the construction of a product or service.

Design (Verb) - The intellectual act of creating material that details the construction of a product or service.

Design Process - A structured series of activities that are used systematically to generate a design.

DT - Design Thinking

Empathy Mapping – A Design Thinking activity that encourages practitioners to empathise with the end user of a product or service so that negative experiences can be identified and removed.

Engineering – The scientific discipline that considers the design, development and construction of products and services.

LEO – Large Engineering Organisation

Opportunity Triage Review - A review to ensure that adequate information has been gathered to suitably de-risk a proposed project and further understand why a problem is being engaged with.

Persona - A Design Thinking activity that creates an exemplar character to represent a series of customer characteristics.

Prototyping - The generation of a representation, of a feature or series of features for the purpose of generating more data around a potential product or service.

Requirement - An explicitly stated, desired property to be considered in the design of a product or service.

SE - Systems Engineering

Specification - A series of requirements for a product or service.

System Requirements Review - A review to ensure that the requirements and selected concepts are suitable in resolving a problem.

TE – Traditional Engineering

User Centred Design - A series of design activities that place an emphasis on human factors and the usability of a product or service.

1.0) Introduction

Engineering occupations were found to contribute 21.4% of the UK's £5.7 trillion turnover in 2018 and work in the engineering sector accounted for 19.0% of all UK (United Kingdom) occupations (Engineering UK, 2019). In 2022, the engineering sector was predicted to contribute £608.1 billion to the UK economy GDP and is expected to employ around 5.8 million people (Centre for Economics and Business Research, 2015). Therefore, the efficient operation of engineering companies and firms is vital to sustain the economy. However, design projects undertaken by Large Engineering Organisations (LEOs) are beset with a number of problems and constraints that include technological, social, cultural, behavioural, economic and political factors. This research investigates alternative design processes as a means through which to improve the delivery of projects in LEOs and the potential for the development of innovative solutions to complex problems.

It is common that as a design develops and gets closer to production within the Traditional Engineering (TE) process; the costs incurred for changing any aspect of the design increases dramatically (Baxter, 1995). As a project progresses, the design becomes more fixed and project artefacts such as technical drawings, prototypes and manufacturing techniques are created, meaning that changes to the design of the part itself has implications for other work that has already been conducted thus far. Systems Engineering (SE) is a design process that was developed to reduce the probability of changes occurring later in the design process as SE aims to ensure that the implementation that has been selected is suitable for stakeholder needs. SE presents an alternative approach to TE techniques as it focusses on the design of an entire system and its subsystems, by considering the wider context, to resolve the stakeholder needs. In SE, a system is considered in its simplest form to be a set of parts and interactions that work together to resolve a design requirement (Cloutier, Baldwin and Bone Alice, 2015:19). Due to the consideration of a system in this way, emergent behaviours that arise due to the interactions between each individual part also need to be considered when conducting the design process.

The application of SE as a process to generate success is well documented (Smartt and Ferreira, 2014; Yasui, Shirasaka and Maeno, 2016 and Kasser and Schermerhorn, 1994). However, Monat and Gannon (2018) identified case studies for which the SE process was not effective. Analysis identified four rationales; 'failure' to identify environmental factors, 'failure' to understand that the problem could not be solved simply using technological innovation but requires other considerations (economic, political or sociological as examples), 'failure' to address interactions between the systems components that are either

planned or unplanned and 'failure' to recognise that the product is part of a user experience system so that the product fails to be useable. This research proposes that principles of Design Thinking can be utilised to address these 'failures'.

Razzouk and Shute (2012:1) defines Design Thinking (DT) as '*an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback and redesign*'. DT is seen as an interdisciplinary tool that takes a pragmatic approach to design and considers human needs as the centre of the design process (Brenner, Uebernickel and Abrell, 2016). As such it introduces a design toolbox that focusses on the in-depth investigation of the customers wants and needs prior to the design, development and prototyping stages. Academic publications on DT are mostly theory based (Kimbell, 2011) or the study of how DT can be applied in experimental settings (Seidel & Fixson, 2013). DT in organisations is often publicized through the repetition of a number of successful case studies in organisations or in books written specifically by DT practitioners (Johansson-Skoldberg, Woodilla and Çetinkaya, 2013).

DT techniques focus on the overall user experience, ensuring that the needs of the end user are identified early and iterated throughout the design process. Importantly, DT techniques help the conceptual shift of the design of a product from a marketable item to a resolution for a customer problem. As DT puts more emphasis on considering the potential consumers and the scenarios that the solution may be implemented (Seidel and Fixson, 2013), it generates an in-depth understanding of the problem space that will include a human centred element when creating a solution.

DT has been selected in this context over other design processes as the strengths of DT complement the weaknesses of SE. This is especially true in situations where the problem considered is very complex, or wicked, and potentially has several distinct factors causing the issue and thus potentially has several complex solutions (Bhooshan, 2017). Other human centred design approaches were considered for this project; one of which was Agile for its flexibility and the ability to create products rapidly (Islam, 2011). This was not chosen for this investigation due to the emphasis it places on the frequent development of software which is something that will simply not be possible on the types of projects that are being undertaken with the sponsor (Islam, 2011).

This research develops the understanding of DT and SE implementation as a means with which to generate positive outcomes within industryspecifically an LEO. Research methods are used to identify and triangulate a number of key themes to consider in design process

implementation that may be prevalent attributes to industry that must be overcome. Furthermore, this investigation generates solutions derived from company need and details of these implementations are documented so that investigated methods for managing these attributes are shown. Finally, areas of value for this combination of design process have been explored based on the aforementioned company needs leading to a number of key areas of consideration for future implementation.

1.0.1) Scope

This investigation aims to identify the attributes, processes and outcomes associated with implementing DT and SE within an LEO. The scope of this PhD is limited to one LEO and operations that are undertaken therein, henceforth referred to as the Case Study Organisation (CSO). The CSO is an LEO based in the United Kingdom and after its creation, developed into a globally distributed organisation of over 4000 employees. The CSO is a FTSE 250, publicly limited company that generated over £650 million in revenue in the 2022 fiscal year. This investigation took place during the COVID19 pandemic and UK furlough periods, which had impacts on the methodology and findings of this work, that are discussed in relevant sections.

Although no implementation of DT has ever taken place in the CSD, SE started to be implemented in some aspects of the division's design process around the start date of this body of work in one strategically critical project. SE was considered to be vital to requirements generation and management but was not well known or understood within the organisation as this SE implementation was ultimately unsuccessful. The effects and implications of this are discussed in relevant chapters but can be summarised as pre-conceptions of SE processes and methods, its value and its place within the CSO, which importantly were not always accurate. This made change more complex, as participants in change activities perceived that they had a suitable understanding to accept, or more often reject, a change based on these pre-conceptions. This was often displayed as poor support for new change initiatives or challenge in getting one solution created that would fit the organisation's needs.

The CSO proposed that this body of research would benefit them in two core ways; the education of individuals on DT and SE processes, and the creation and implementation of SE and DT processes within CSO operations. However this was not a view shared by all members of the CSO, as many individuals had conflicting views on what the value of this research

would be within the CSO due to their differing perceptions on the organisation and its requirements (later revealed to be due to cultural differences, presented in section 4).

1.1) Research Questions

The main research question is as follows;

1) **How can Design Thinking (DT) and Systems Engineering (SE) be combined and implemented in a Large Engineering Organisation (LEO)?**

To define, research question 1 considers the implementation of a combined DT and SE process (and not independently or with any other process) within an organisation suitably defined as an LEO. Importantly, the proposed strengths and benefits of each process, from literature, will be sought within a combined process that leads to positive outcomes when compared with the case study LEO's existing process. This can be split into;

1A) What are the optimal locations for DT and SE to be implemented in an LEO?

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

1C) What procedures support the implementation of DT and SE within an LEO?

1D) Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?

Research questions 1A to 1D reflect directly on the gaps in literature identified in section 2.10, the outputs of which are combined to answer the main research question. To summarise; research question 1A aims to understand where DT and SE can be implemented within an LEO to achieve positive outcomes compared to its existing design processes; research question 1B aims to understand what the barriers or enablers are, referred to as attributes, as literature highlights that they be specific to an organisation, to the implementation of a DT and SE process might be; research question 1C aims to understand what change management processes, or components therein, can support the implementation of a combined DT and SE process; and research question 1D aims to understand what the benefits of implementing a merged DT and SE process within an LEO might be.

The research questions proposed address the knowledge gap outlined in the section 2.10 and provide opportunities to add value to the current knowledge base.

1.2) Methodology Overview

This investigation utilised a single case study methodology within the CSD with the intent to generate a high level of detail in the data generated; the generalisability of which was assessed against literature and comparison data gathered from other divisions within the organisation. A mixed method research strategy was conducted within the division that aimed to answer the research questions appropriately and methods included interviews, questionnaires and examination of internal company documentation and systems. The interviews were conducted over virtual communication systems with participants either in their respective normal office environment or in a working from home environment. The questionnaire was conducted using Qualtrics software over a fixed period of time. Throughout all stages of this research, GDPR (General Data Protection Regulation) guidelines were followed in line with the University of the West of England Ethics Committee. A critical methodological element of this investigation was failure-based learning as any challenges that were present in the implementation of DT and SE within an LEO provided further evidence to answer this investigation's research questions.

1.3) Thesis Structure

The other chapters in this paper will be organised as follows: the introduction is presented in the first chapter; chapter two details an in-depth literature review on DT, SE, previous implementations and the attributes that were found therein; chapter three considers the methodology used in this research and provide a discussion on how engagement was maintained with the CSO; chapter four details the findings of the research conducted; chapter five discusses the relevance of the findings to wider academia and chapter six concludes this investigation and discusses relevant further work that should be conducted to advance this field. References and appendices are presented at the end of this thesis.

2.0) Literature Review

This chapter provides a discourse on the relevant literature present in the field of DT and SE and their applications within LEOs. First, traditional engineering, SE and DT are introduced, and relevant case studies examined to understand the applicability of these processes within an industry setting. Next, literature is presented regarding understanding organisational culture with a particular emphasis placed on attempts to measure organisational culture, on the differences between types of culture and its influence on organisational change. The limitations of project scope are discussed and the core values of DT and SE from industry are stated. Next this chapter outlines a comprehensive literature review into the thematic attributes to implementing DT and SE in an LEO; so that validation can take place later in the research process. DT and SE methods utilised in literature to measure the concept of design are outlined so an assessment can be made about the value of implementing these within an LEO. Finally, a discussion is presented on the novelty of merging design solutions within industry and academia with specific reference to the implementation of DT and SE.

2.1) Introduction to Traditional Engineering

Traditional, or sequential engineering, is the process by which a product is designed and all additional functions add their input to the design in an iterative sequence of activities until a satisfactory output is generated (Yazdani and Holmes, 1999). Prasad (1995) proposed that in most sequential engineering processes it was normal for a market research department to determine customer needs and deliver these to a project management team. Next, this project management team determines technical requirements for a product which are passed to the product engineering teams, who design and develop the product in near isolation from manufacturing. This design would then be presented to manufacturing groups to identify if the solution were manufacturable given the tolerances, timeframes and volume required by the customer needs identified by the market research department. If the proposed solution is not manufacturable, this process reverts back to the design stage and continues iteratively until the proposed is suitable. A representative model of traditional engineering is presented in figure 1 (Yazdani and Holmes, 1999).

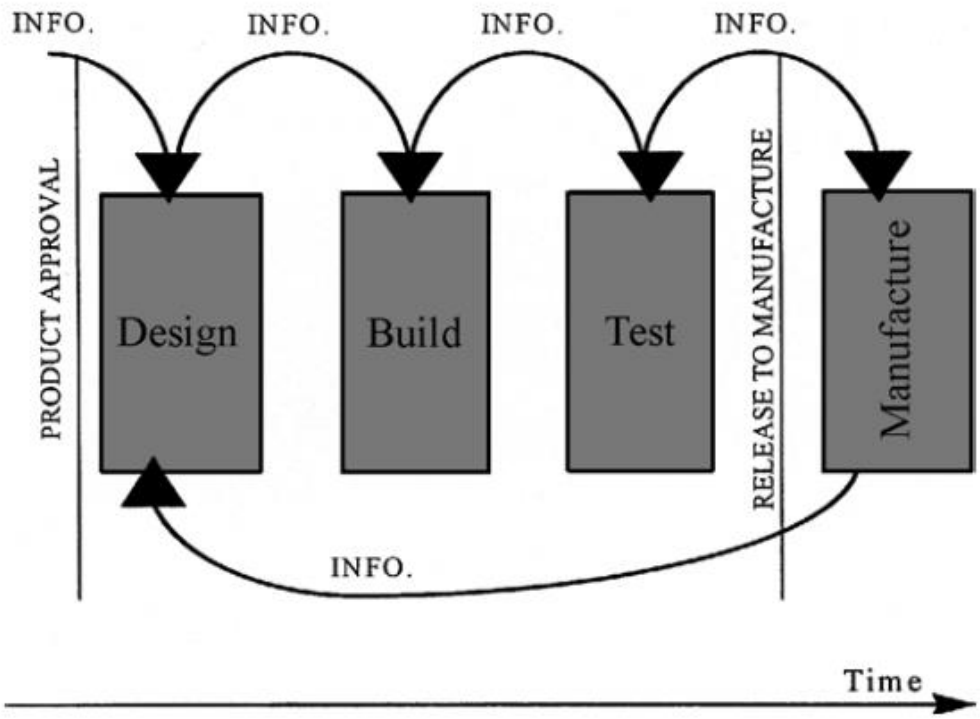

Figure 1 - Mapping the Traditional Engineering Process (Yazdani and Holmes, 1999; p.28)

2.1.1) Traditional Engineering Limitations

Traditional engineering design processes were found to be not sufficient when tackling more modern industry problems as quality, cost and time pressures are becoming increasingly demanding (Stalk and Hout, 1990).

The Traditional Engineering (TE) design process shows that as a design develops and gets closer to production; the costs incurred for changing any aspect of the design increases dramatically (Figure 2; Baxter, 1995). This is because as a project progresses, the design becomes more fixed and project artefacts such as technical drawings, prototypes and manufacturing techniques are created, meaning that changes to the design of the part directly inflict changes on other work that has already been conducted.

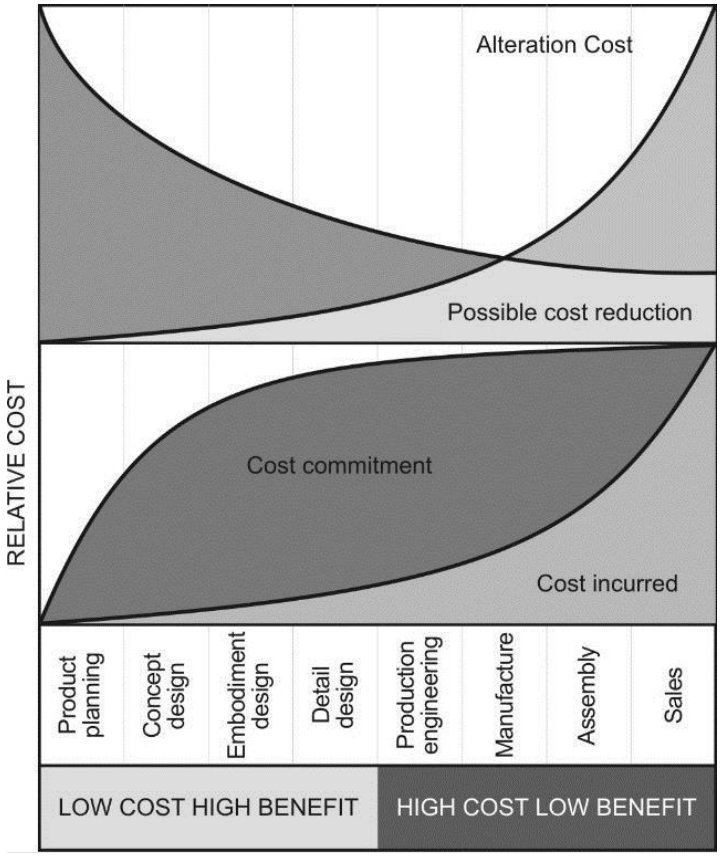

Figure 2 - Cost Incurred as a Function of Project Time (Baxter, 1995; p.28)

A number of characteristics were identified in the use of traditional engineering, these were;

- Slow time to market (Yazdani and Holmes, 1999).
- A high overall design process cost (Yazdani and Holmes, 1999)
- Poor final design quality (Yazdani and Holmes, 1999)
- Unsuitable product design for production (Prasad, 1995).
- Unavailability of suitable manufacturing equipment (Prasad, 1995).
- Tight tolerances which lead to extra manufacturing input and the wastage of high volumes of material (Prasad, 1995).
- Issues with part assembly (Prasad, 1995).
- Inability to utilise existing production equipment or the requirement to identify new, costly manufacturing methods bespoke for one product (Prasad, 1995).
- Low levels of risk when considering project outputs that are both incremental and revolutionary where these levels of risk are perceived to directly lead to poor quality, cost and time outcomes (Yazdani and Holmes, 1999).

Finally, traditional engineering methods are viewed as having inconsistent design, analysis and documentation methodologies that can lead to last minute engineering changes and higher manufacturing costs due to the failure to consider these earlier (Prasad, 1995).

2.2) Introduction to Systems Engineering

SE is defined as "an engineering approach that provides an understanding of the interaction of individual parts that operate in concert with one another to accomplish a task or purpose" (Cloutier, Baldwin and Bone Alice, 2015:p.2). Hossain and Jaragat (2018: p.7) state that "SE is a management-based, holistic, interdisciplinary approach that addresses the entire product lifecycle which involves designing and integrating system elements to meet consumer demand". Due to its emphasis on traceability (Tomita et al, 2017), systems engineering processes are well designed for complex solutions spaces where information is discussed amongst a large range of staff across multiple fields. In SE, a system, considered in its simplest form, is a set of parts that work together to resolve a design requirement (Sillitto et al, 2019). Through the characterisation of a system in this way, emergent behaviours that arise due to the interactions between each individual part also need to be taken into account (Sillitto et al, 2019).

SE uses a range of tools to ensure that this implementation is suitable. For instance, SE requires that designers and stakeholders first complete a specification; a series of requirements derived by systems engineering practitioners from the stakeholder needs (Sage and Rouse, 2014: p.79). This is considered to be a strict contract between the designer and stakeholders and ensures that the stakeholders have been forced to consider what they want as a part of the final design. This reduces the possibility of any changes being required at the end of the product development and thus reduces the possibility of an additional large design cost. As a part of this specification design, SE uses formal methods such as 'must, may, should and could' to describe to the designer what the system needs to achieve (Wright, 2018). These formal language methods describe the requirements that need to be completed as a minimum for the project to be a success and outline the other aspects that designers should aim for in the instance that additional functionality is possible considering project resources. Finally, SE considers validation and verification throughout the design process (Kossiakoff et al, 2011). Validation acts early on in the design process and aims to confirm that the derived specification accurately reflects the needs of the end user; whereas verification aims to confirm that an implementation satisfies the prior determined

specification. Again, both tools are used primarily to prevent any late design changes in a project and so to keep costs to a minimum.

Carr (2000) considered SE through the perspective of Requirements Engineering and management and found that poorly identified requirements were the root cause of the most serious failures in projects; leading to late delivery, overspend on budget and poor or incorrect performance. There are key symptoms that demonstrate where poor requirements are generated, to include (Carr, 2000);

- Project deadlines are constantly missed
- The system costs are over budget
- Performance is not what is expected by the end user
- Engineers complete significant amounts of re-work due to vague requirements generation and incurred faults.

Carr (2000) also proposed that the costs to resolve problems increases rapidly during the course of product development (similarly to Baxter, 1995 in figure 3) but more closely links this to key stages in the SE lifecycle and provides estimates on the cost at each stage.

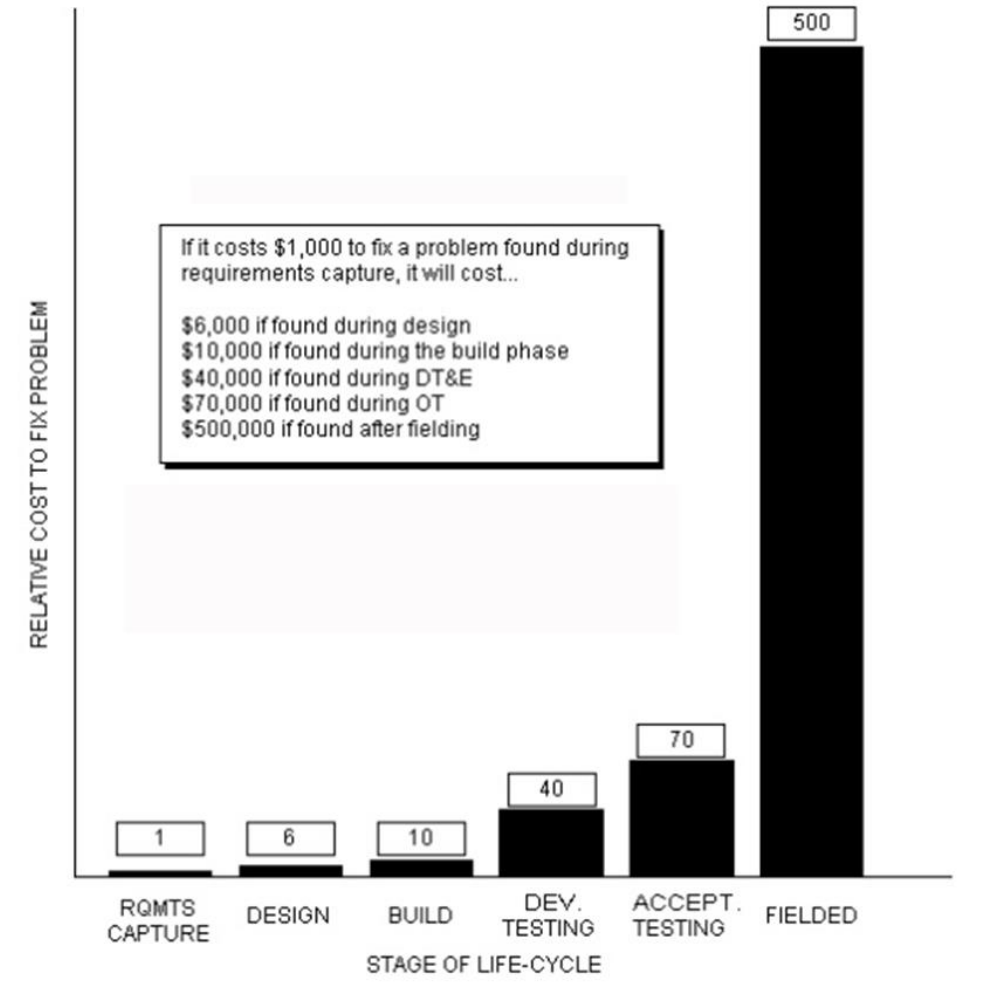

Figure 3 - Cost to resolve issues late in design (Carr, 2000; p.404)

There are a number of ways of considering SE as a process, a selection of which will be outlined below. The first is through a V (or 'vee') model which aims to model high-level and low-level design and integration activities from the generation of customer requirements through to the final completion of full-scale testing (Buede and Miller, 2016:10). The left side of the V model, seen in figure 4, represents the decomposability of customer requirements, through the development of system level requirements and to the development of component-based requirements (Buede and Miller, 2016:11). The right-hand side of the V model outlines the integration and qualification activities that are undertaken in the engineering of a system.

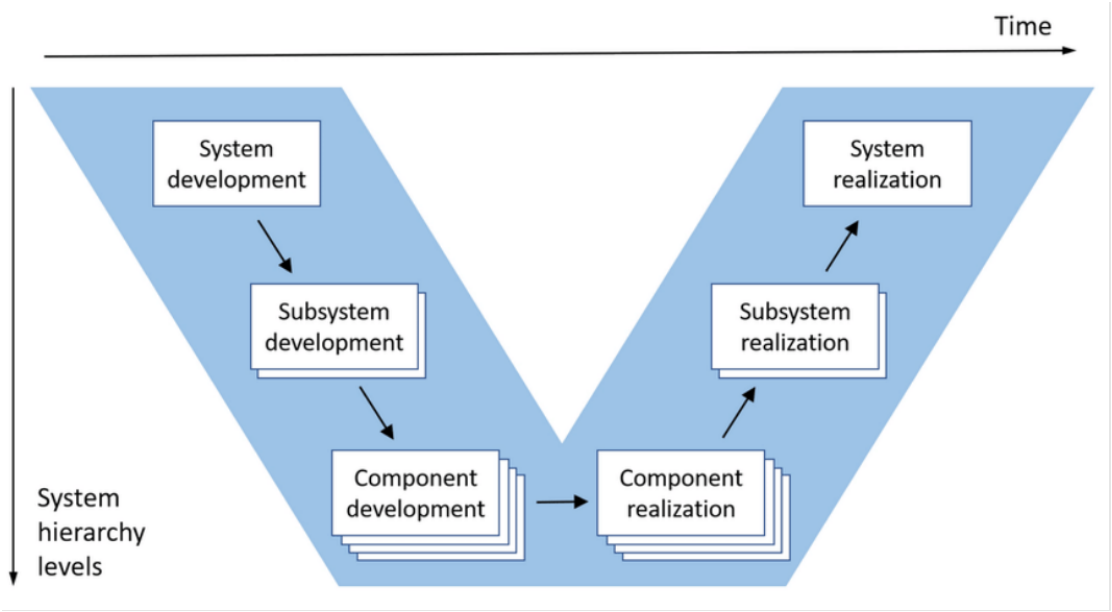

Figure 4 - V Model (based on Forsberg and Mooz, 1991; p.5)

Another application of systems engineering considers a multiple V model approach, where V models can be adapted and suited to different aspects of a design process (Lake et al, 2000). In the model proposed in figure 5; one V model focusses on developing a concept demonstrator that aims to de-risk any proposed outcomes and generate a preliminary system specification (Lake et al, 2000), the second V model considers product development and uses inputs that were created within the concept demonstrator model, and the final V model considers production and the challenges that may be faced therein (Wright, 2018).

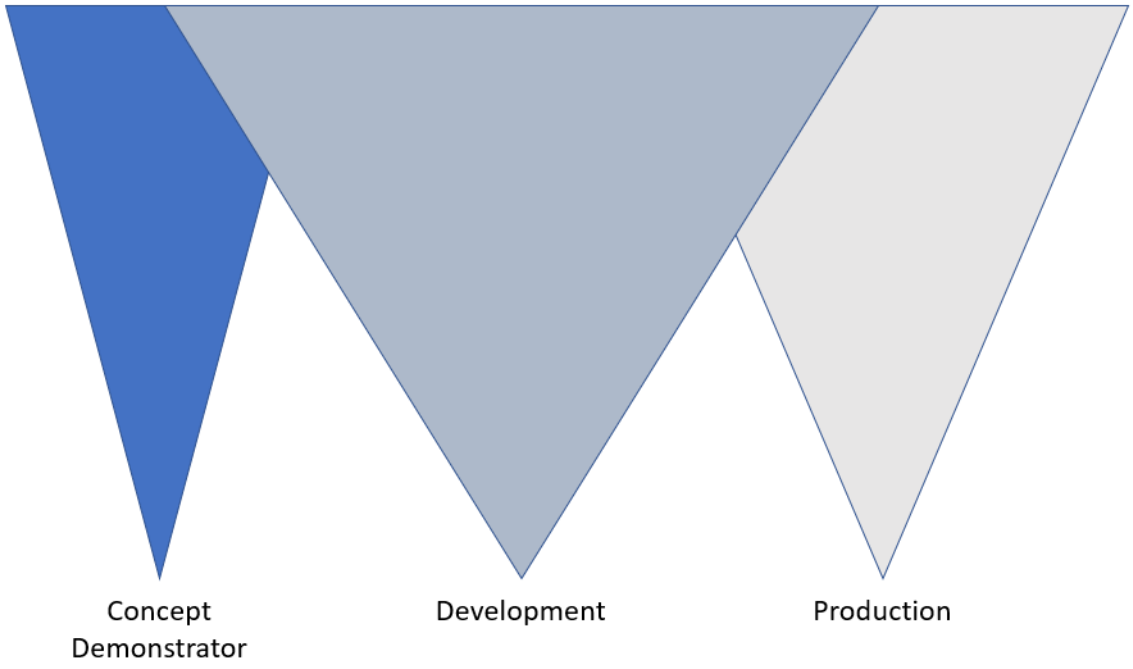

Figure 5 - Multiple V Model (Wright, 2018)

The waterfall model considers product design through a linear and sequential process (Adenowo and Adenowo, 2013). In the traditional waterfall model, once each stage in the waterfall model is completed there are no opportunities to revisit it again. However, if an issue is identified in one of the later stages of the waterfall model that requires amendments to be made in an earlier stage of design, then the waterfall process does not accommodate this.

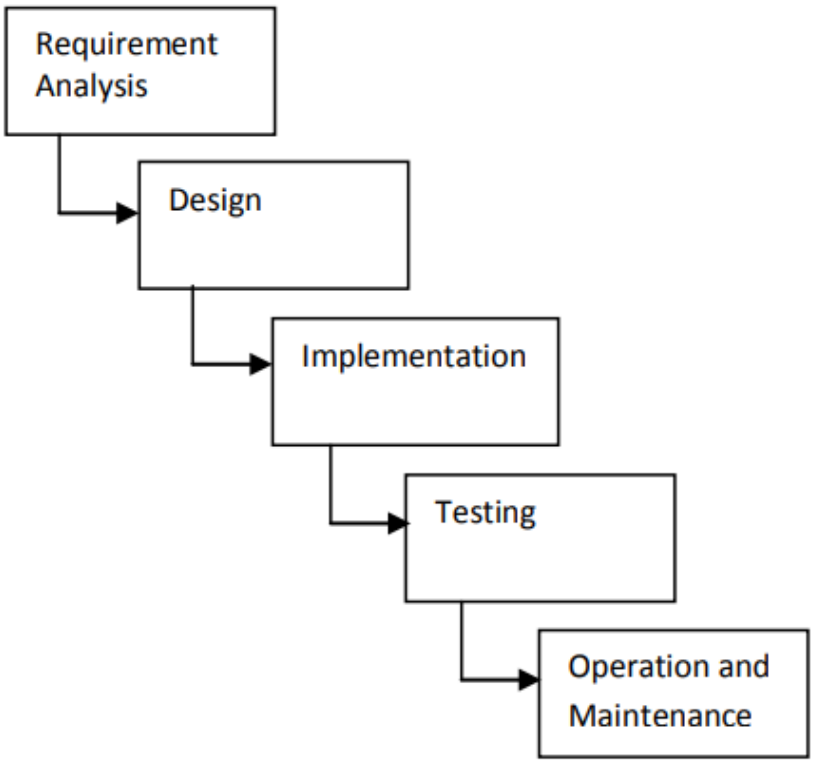

Figure 6 - Waterfall Model (Pfleeger and Atlee, 2010: p.39)

A final considered SE model is the spiral model, that places an emphasis on risk and risk reduction by breaking a project into smaller segments and provide more ease when change needs to occur (Alshamrani and Bahattab, 2015). Alshamrani and Bahattab (2015) also proposed that there are four commonly used stages in the spiral SE process; planning, risk analysis, development/engineering, and evaluation; that iteratively revolve as presented in figure 7.

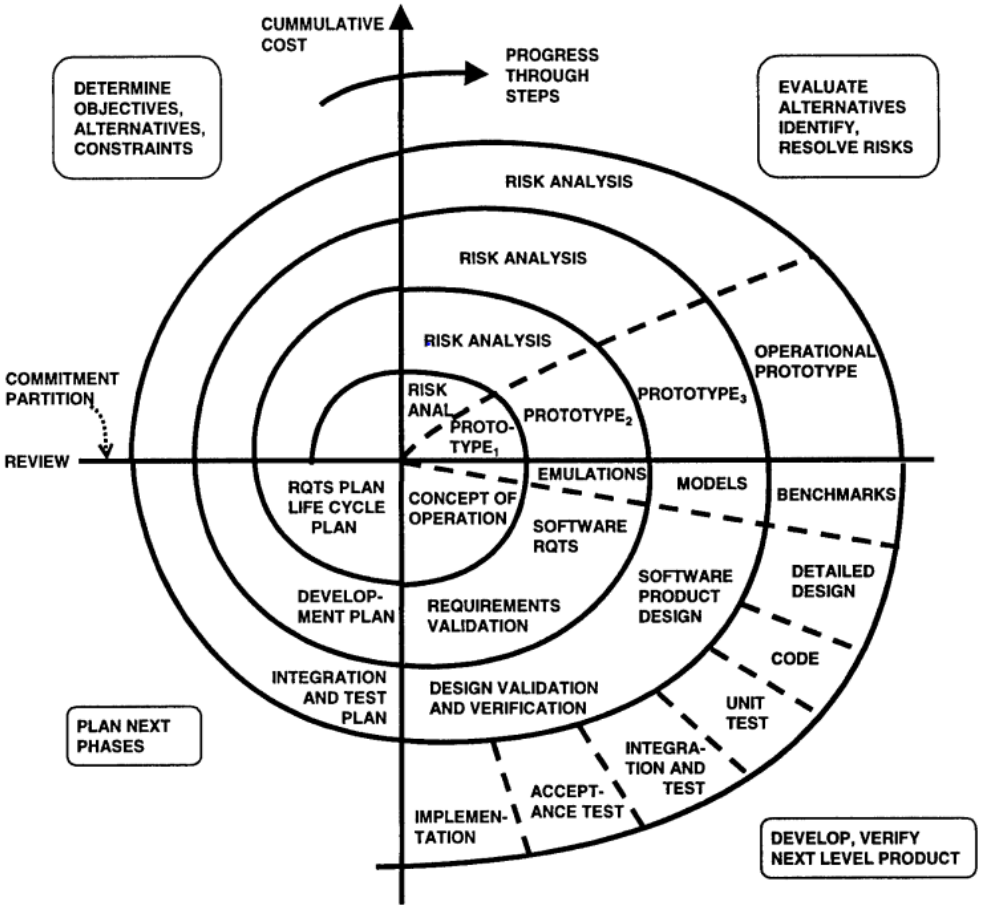

Figure 7 - Spiral Model (Boehm and Hansen, 2000; p.2)

Micaelli et al (2013) proposed that there are five key elements that must be demonstrated for a process to be considered to be SE. These are;

- Abstraction – where requirements must be created to generate an understanding of a system rather than a solution.
- Decomposability – systems are composed of smaller elements, or subsystems.
- Pluralism – the system can be designed in many different ways and structure should be created that allows knowledge transfer.
- Alignment – SE is implemented considering both the product and the overall design process, meaning that all involved stakeholders should be working aligned to agreed upon SE ideals.
- Incremental Improvement – learning from mistakes is key in SE to prevent a repeat of these mistakes in later work.

2.2.1) SE Case Studies

This section aims to highlight a number of SE case studies that outline the value of SE within previous applications and consider SE implementation. Importantly, these case studies are critical to facilitate the implementation of SE within the CSD of this investigation.

Literature identified that responses and acceptance of SE were more supportive after participants had completed a design project utilising SE (Blizzard et al, 2012). It also found that participants better understood the value behind considering whole system design and that views were overall better aligned with SE educational material (Blizzard et al, 2012).

SE has been shown to fail in implementation even when documented process has been followed (Schmidt et al, 2011). These instances included; limited SE experience and ineffective decision making, lack of understanding of SE, failure to identify one suitable solution and inexperience with project management.

Finally, literature identified previous case studies in SE that have failed (Monat and Gannon, 2018) as either a failure to follow SE principles or a failure in the principles themselves. These case studies can be presented within four categories; failure to identify environmental factors, failure to understand that the problem could not be solved simply using technological innovation but requires other considerations (economic, political or sociological as examples), failure to address interactions between the systems components that are either planned or unplanned, and failure to recognise that the product is part of a user experience system so that the product fails to be useable.

To summarise, although the implementation of SE is not necessarily novel in an LEO there is a range of literature that discusses failure; these reasons would be important to consider when attempting the implementation of SE. Failure has been identified when SE processes are still being followed (Schmidt et al, 2011), when SE processes fail to be followed (Monat and Gannon, 2018) and when SE processes fail themselves (Monat and Gannon, 2018).

2.3) Introduction to Design Thinking

DT is defined as “an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback and redesign” (Razzouk and Shute, 2012)DT is seen as an interdisciplinary methodology that takes a pragmatic approach to design and considers humans as the centre of the design process (Brenner, Uebernickel and Abrell, 2016). As such it introduces a new design toolbox that focusses on an in-depth

investigation of the customers wants and needs prior to the design, development and prototyping stages.

DT has been suggested to have been developed and most effective when applied to wicked problems where normal methods of problem solving might struggle to find solutions (Bhooshan, 2017). Wicked problems were defined by Buchanan (1992) as ten properties:

- First, wicked problems have no definitive single user need, but every user need that leads to a wicked problem corresponds to a single solution.
- Wicked problems have no stopping rules in terms of when the problem no longer is a problem.
- Solutions to wicked problems cannot be true or false, only positive or negative solutions.
- When solving wicked problems, there is no exhaustive list of solutions.
- For every wicked problem, there is always more than one explanation as to why the problem has formed.
- Every wicked problem is a symptom of another higher-level problem.
- No solution to a wicked problem has a definitive method of testing to ensure that this is accurate.
- Solving a wicked problem will have no room for trial and error – there is one chance at solving the problem.
- Every wicked problem is unique.
- The wicked problem solver is fully responsible if they are wrong.

An important paper in the investigation of how DT is used in large organisations was undertaken by Carlgren, Elmquist and Rauth (2016B) who aimed to generate an empirical understanding of DT's applications in practice using an interview study of six organisations that had been using DT for between four and ten years. These interviews found that DT has not been implemented in one fixed way across all the different organisations. For instance, it is reported that one organisation was inspired to create an explicit cascade process for all of their projects that were determined to require substantial amounts of innovation. A second variant found was that DT could be used, less as a process that needs to be followed but more as a mindset and set of principles that should be adopted as a part of a design process. The third reported use of DT was as a process for side projects that differ from the current trajectory of the company.

Carlgren, Elmquist and Rauth (2016A) identified five themes that were characteristic of all DT taking place within each organisation. These are;

1. A User Focus – Developing solutions with the user in mind and placing a greater emphasis on empathising and designing for user needs. This involves a fundamental shift from the acceptance and use of technology drivers to the use of user drivers.
2. Problem Framing – Through repetitive challenging of the originally proposed problem, the widening and reframing of the problem space to prevent the early decision to adopt one particular solution.
3. Visualisation – The development of ideas and concepts through the use of prototypes. Importantly, prototyping was not only about testing but was also a way to communicate and share insights.
4. Experimentation – The use of iteration through testing ideas in different ways. Findings also proposed that solutions are tested as soon as possible to obtain user feedback and a 'fail often and fail soon' mentality is encouraged.
5. Diversity – The collaboration of a diverse range of teams and the consideration for a diverse range of user perspectives on the design process. The inclusion of differing skillsets, mindsets and hierarchy within design is seen as essential.

Carlgren, Elmquist and Rauth (2014) aimed to develop an empirical understanding of how DT is presented and perceived within LEOs using a multiple case study approach. They found that organisations that used DT often failed to define a clear answer as to what it meant to them but did use more general terms like 'user centred innovation' or 'a current name for really good user centred design'. Carlgren, Elmquist and Rauth (2014) found that in some cases it was defined more through the use of particular design methodologies, or a process to create new ideas or solve problems systematically whereas in other cases DT is described as a mindset or a set of principles that are thematically applied to a problem at hand. Importantly, these themes are reported to be the reframing of the initial problem, considerations for design iterations and the use of prototyping. Further Carlgren, Elmquist and Rauth (2014) identified that there was a clear split in adoption, some organisations adapted their culture to accept DT but more often DT is used predominantly in the early, more strategic phases of innovation and less so when delivering product development.

When considering its implementation, most of the firms interviewed by Carlgren, Elmquist and Rauth (2014) have a formal development process in place that is in some way connected to DT, rather than being any one DT process. In some cases, this link was only present where

projects or problems were perceived to require major strategic innovation or in the development of radical projects outside of the traditional development process. Finally, Carlgren, Elmquist and Rauth (2014) identified that where DT is adopted within organisations there was often a dedicated group of DT experts that were responsible for its implementation and education.

DT is commonly proposed to be a five-step process, shown in figure 8 (Interaction Design Foundation, 2022).

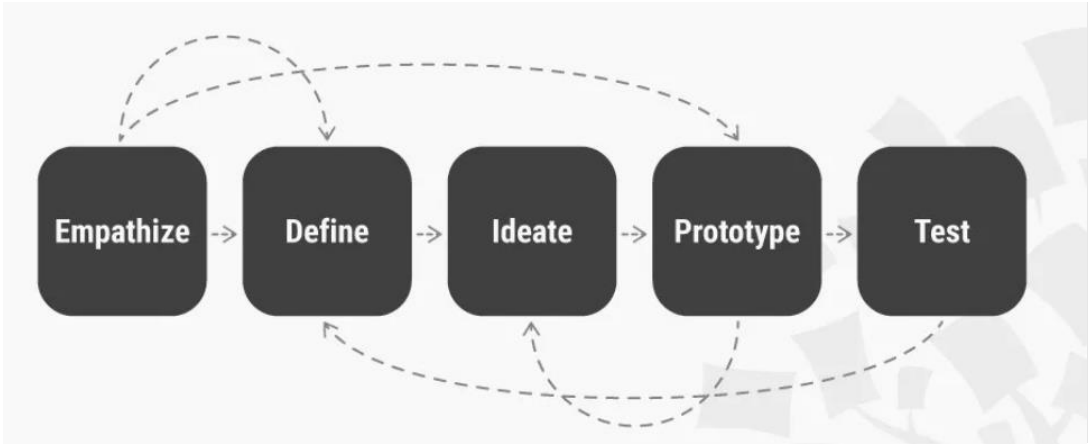

Figure 8 - The Design Thinking Double Diamond (Interactive Design Foundation, 2022)

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Royalty and Roth (2016) and Plattner, Meinel and Leifer (2016) proposed that there were a number of key reasons that organisations might turn to DT. These were;

- A realisation of a companywide disconnect between an organisation and its end users.
- The fear that start-up or smaller businesses might begin to take future business opportunities.
- The desire and drive for teams to work in more innovative ways.

Literature has discussed the concept of failure in engineering design and how this should be considered to be something that is positive; this paper discussed the idea of failure more as the concept of “inconclusive outcomes” (Von Thienen, Meinel and Corazza, 2017). Failures are difficult economically and for a design team as they can cost a company incredible amounts of time and money. However, they can be used to aid in learning and this paper argues that they should be used in the later development of other concepts. Importantly, positively defined failures should depict areas in which the current attempt at an

implementation does not work and should be clear enough to show adaptions that need to be made to generate a more suitable iteration. This is key as it denotes that not all failures are positive in industry, some failures are simply due to poor implementation and need to be drastically changed to generate a viable implementation. If an implementation meets the majority of the requirements but has failed in certain areas then this can be used as a platform for more novel ideas that would "lead to thorough changes in problem and solution space, allowing for revolutionary shifts both in terms of knowledge and practical applications." Von Thienen, Meinel and Corazza (2017) suggests that industries should incorporate failure-based learning and failure theories as possible tools for industry and practice so that more novel designs can be developed.

2.3.1) DT Case Studies

This section will present DT literature that outlines the successes and challenges found in research that may be prevalent to consider when implementing DT within an LEO. Importantly, findings from these case studies can be applicable to this investigation and the implementation of DT.

Particular tools and activities within the DT process have been found in literature to have an effect on the acceptance and use of DT in industry. For example, the use of prototyping, brainstorming and debate were found to be optimisable as tools when considering the concept performance and concept selection of a design (Seidel and Fixson, 2013). Further research considered the use of primers and identified that the effective selection of working location can lead to more positive outcomes from DT activities (Plattner, Meinel and Leifer, 2018 and Von Thienen, Meinel and Corazza, 2012). The application of empathy mapping and personas was found to help individuals better understand a problem space and lead to stronger solution generation when faced with new challenges; arguing that the true problem can only be resolved once it has been identified (Abdussamad, 2014). However, literature also identifies challenges that might be had when engaging with DT tools. For example, empathy-based techniques were found to be challenging in one case study as participants failed to see things from another's viewpoint which, consequentially, meant that they struggled to adopt these techniques within their own working (Valentim, Silva and Conte, 2017). Similarly, brainstorming and co-creation were seen as difficult tools to use for some who held on to their own ideas rather than compromising and co-operating with other members of their team (Valentim, Silva and Conte, 2017).

Case studies were identified in literature with the aim to identify the education and use of DT more generally. Valentim, Silva and Conte (2017) found that while DT was beneficial in helping participants to think of innovative features, and DT methodologies to help improve team interaction, two implementation-based challenges were identified. First, some participants failed to generate consensus on additional features that were to be implemented in the final design. Second, some participants did not feel comfortable participating in the DT methods and in their project-based discussions within each session. When considering the implementation of DT, literature highlights the success of lectures, workshops and practical application as being quick to lead to the implementation DT and important in generating a DT mindset (Mubin, Novoa and Al Mahmud, 2017). Similarly, literature also identified that the careful presentation of DT methods was critical in adoption, and that these tools should be presented so that participants can see the potential uses of them within their own working environment (Hare et al, 2018). This is especially important as if participants feel like there is no need for change, or perceive DT as being poor or unnecessary, then they will be considerably more resistant to change (Crisan and Caldarusa, 2017) and attitudes to DT and innovation as a whole improved after education was conducted. Case studies found that companies that adopt DT methods often struggle to see the bigger picture for their customers and companies struggle to communicate the value proposition of their newly identified solutions (Rau, Zbiek and Jonas, 2017). Finally, Royalty and Roth (2016) proposed that failures in the implementation of DT could be due to an organisation's use of efficiency and productivity-based metrics, which directly contradict with the exploratory nature of DT. Instead, the presence of these metrics can disincentivise DT activities as employees are not being rewarded, or may be actively reprimanded, for more exploratory based work.

Finally, literature was conducted that identified a number of challenges in implementing DT that were linked to the characteristics of DT itself (Carlgren, Elmquist and Rauth, 2016A). These challenges were;

- A misfit with existing processes and structures - where DT clashes with established ways of design and is abandoned in times of high workload. Perceptions to the value of DT may also be misaligned, DT may be implemented in parts and challenges may be found when short term gains and long-term outcomes compete.
- The resulting ideas and concepts from DT can be difficult to implement - where outputs from DT activities can be too complex or could be found to contradict organisational strategies and future product plans.

- The value of DT is difficult to prove - where participants reported that DT implementations were challenged by management looking for proof of its success, which in turn led to pressures to generate results quickly. Pressure was specifically felt regarding the short-term goals of the company, where DT may be implemented to improve long-term innovation. It is also especially difficult to evaluate the effectiveness of DT in organisations where there is a long time to market and where metrics do not align with DT goals.
- Principle or mindset clash with existing organisational culture - where risk acceptance, the requirements for consensus, alienation due to the light heartedness of DT, requirement for user interaction and changes in national culture were examples of resistance to implementation of DT.
- Existing power dynamics are threatened by the implementation of DT – where DT experts were perceived to be challenging the established way of doing things, the expertise of existing design teams and the status quo. As decision making is moved from the management level to the team level, individuals with power may believe that they have reduced authority and power.
- Communication styles may differ from those already in the company – where methods of communication that differ from existing processes are viewed as unspecific and non-technical.

To summarise, this section considered literature around the implementation and use of DT within an LEO. First, DT tools and activities were discussed to identify their applicability within implementation. Next case studies were presented that considered the implementation of DT more generally and identified points that must be considered in its future implementation. Finally, challenges were identified that were directly linked to the characteristics of DT.

2.4) Measuring Design

The action of measuring design is proposed in literature to be difficult (Mabogunje, Sonalkar and Leifer (2016), Royalty and Roth (2016), Seidel and Fixson (2013) and Blizzard et al (2012)) as it is difficult to assign a tangible measure to a piece of design work as an accurate replication of its value. However, literature has proposed that the implementation of DT and SE will require metrics for design to be identified as the CSD project timeframes were long and used traditional metrics (Royalty and Roth, 2016), which were both found to not always be supportive of DT and SE activities. This section will present some of the attempts

identified in the critical literature review to identify suitable methods of measuring design and the philosophies behind this.

Mabogunje, Sonalkar and Leifer (2016) outlined three key constraints to improving and evaluating design across all disciplines in a systematic manner. These are;

- Engineering design is a broad subject as it can range between sectors such as defence, energy and medicine and so it can be used and measured in a number of different ways.
- Engineering design is often measured through economic variables such as return on investment which is not a reflection on the intellectual activity of design itself but more on the design as a holistic development.
- There are a lack of standard measurement units in engineering design which means that the effective measurement of a design improvement is often open to interpretation.

Literature has often found it to be difficult to measure the impact of DT once it has been implemented. Schmiedgen et al (2016: p.157) aimed to identify how organisations currently measure this impact; although it was also found that the definition of DT is not commonly known within DT and management users. The vast majority of participants (71%) perceive some kind of positive impact but very few (24%) have made attempts to identify what that impact is. Those that have not made any attempt at measuring this effect have stated that they either do not know how to measure it or do not have the available resources to do so. Furthermore, this investigation identified that there was no one single Key Performance Indicator (KPI) that was affected by the implementation of DT as DT techniques affected a range of areas from team collaboration and engagement to reduced time to market and better customer outcomes, meaning that the impacts of DT are unable or very difficult to be measured simply (Schmiedgen et al, 2016). However, those that did make attempts to measure these impacts found that DT led to improved customer feedback and satisfaction.

Finally, literature has been conducted to develop tools that can measure the concept of a DT mindset in order to establish whether an individual might be a good DT practitioner (Dosi, Rosati and Vignoli, 2018). If validated this would be proposed to allow a case study to measure the effectiveness of a DT implementation, through participants mindsets, and assess DT post implementation as a tool for innovation.

2.4.1) Process Quality

Process quality is defined in the ISO 9000 standards as "the degree to which a set of inherent characteristics of an object fulfils requirements" where an object can be anything that is perceivable or conceivable (Hoyle, 2017:p.8). Literature proposed that design process and related activities lead to 40% of product quality problems (Leonard and Sasser, 1982) and moreover accounted for 80% of the overall product quality (Dowlatshahi, 1992). This is expressed graphically by Zhu, Alard and Schoensleben (2007), faithfully recreated in figure 9.

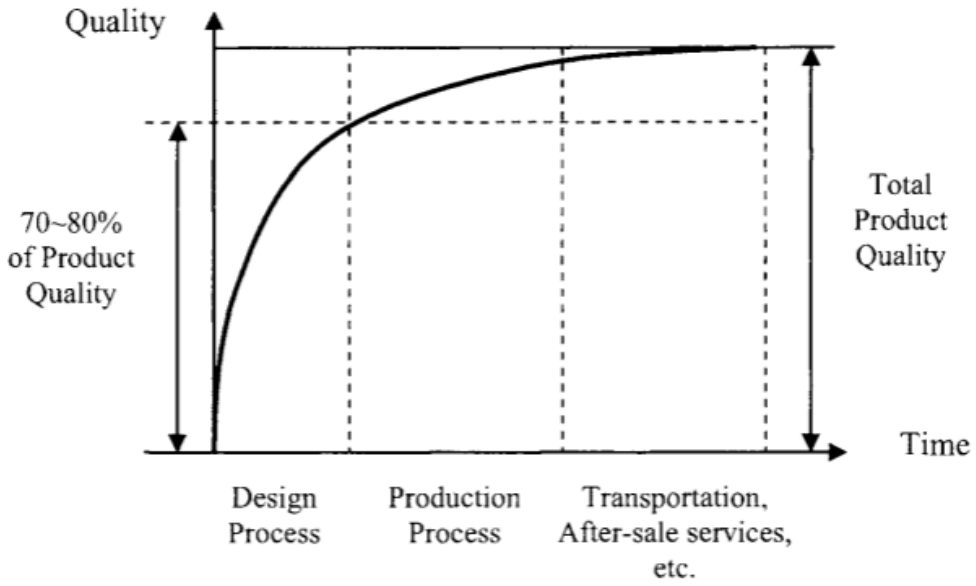

Figure 9 - Understanding Design Process Effects on Product Quality (Zhu, Alard and Schoensleben, 2007; p.136)

From the definition presented above in the ISO 9000 standards, and the consideration of process as a design tool aiming to resolve project requirements, when considering process quality it is important to first identify what the key measures are that are perceived to be valuable to an organisation so that the measure of 'quality' can be conducted. For example, if an organisation was to place value on the timeliness of projects, then this could be considered to be a suitable measure of process quality.

2.5) Organisational Culture

Literature proposed that the implementation of process is often linked with cultural change (Ragsdell, 2000 and Carlgren, Elmquist and Rauth, 2016B) as the existing organisational culture present may not be suitable for the proposed process change. This section aims to define organisational culture and evaluate how organisational culture affects process change.

Due to the difference in understanding and agreement of organisational culture, it is important to frame organisational culture through the understanding of an agent of changes conception of organisational culture (Willcoxson and Millett, 2000). In this case, organisational culture is defined as a set of norms, beliefs, principles and ways of behaving that gives an organisation a distinctive character (Brown, 1995). At organisational conception, these characteristics are considered in the literature to be reflective of factors externally to the organisation (Gordon, 1991) and are formed and transformed over time as these expectations change.

Organisational culture is primarily proposed to be formed due to the beliefs and behaviours of early leaders as these are interpreted as guiding assumptions for an organisation (Willcoxson and Millett, 2000). These assumptions are proposed to be interpreted by all individuals within an organisation sub-consciously and are not easily displaced by new values and beliefs that leaders aim to articulate to their employees. Furthermore, these values and beliefs are proposed to take a lengthy period of time to be accepted satisfactorily. Therefore, understanding the organisational culture present in an organisation is critical to enacting change within an organisation as solutions that directly contradict the organisational culture will find difficulty in being successfully implemented.

Literature identified a total of four properties of organisational culture (Bellot, 2011);

1. Organisational culture exists.
2. Organisational culture is ill-defined and includes contradictions, paradoxes, ambiguity and confusion.
3. Organisational culture is socially constructed by groups with shared experiences.
4. Organisational culture is unique to a given organisation and malleable.

The work of Cameron and Quinn (2011) proposes that an organisation's culture reflects its management style, strategic plans, climate, reward system, means of bonding, leadership and basic organisational values and thus, that these aspects must be identified in any attempts to manipulate organisational culture. When commenting on the individuals that could be change leaders, Cameron and Quinn (2011) concluded that change management must start with managers near the top of an organisational structure.

Finally, O'Reilly et al (2014) investigated whether senior leaders within organisations in the technology sector affected their organisational culture. O'Reilly et al (2014) found that there was a direct link between an organisation's CEO (Chief Executive Officer) or similar role,

organisational performance and organisational culture. Importantly, the longer the tenure of a CEO in an organisation, the more of an impact that they had on that organisation. Therefore, the impacts and responses from senior management to proposed changes during the course of this research could be perceived to be critical in the overall success of the implementation of DT and SE within an LEO.

2.5.1) 'Hero' Culture versus 'Process' Culture

Within organisations, Crosby (1979) proposed that a relative scale from poor process quality to strong process quality can be considered to understand organisational attitudes towards process quality (defined in section 2.4.1) and that these attitudes can help characterise the responsibility placed on individuals within that organisation (figure 10 has been created to aid in clarity). In this model, poor process quality on the process quality scale is referred to as uncertainty where management has little knowledge of quality at a strategic level and, at best, views the inspection of finished products as the only way to achieve quality (Crosby, 1979). The uncertainty environment elicits heroes, due to a lack of process or metrics, who are key individuals that can work with a relatively unstructured process and within this context are critical for success and the completion of product development. The concept of organisational uncertainty is characterised by poor process quality and a lack of metrics and aforementioned heroes conducting projects how they may choose to achieve project goals (Crosby, 1979). On the other end of the proposed scale, at strong process quality, is absolute certainty, where management structures are confident that process quality is sufficient and understands why this is the case. In the case of absolute certainty, Crosby (1979) proposed that more research orientated individuals can be found in an organisation; whose role can dedicate time to incrementally improving the established process without creating detrimental side effects.

Figure 10 - Implications of Process Quality on Organisational Culture (Crosby, 1979)

This scale between poor process quality and strong process quality can be explored further when considering this in collaboration with other literature around organisational culture. First, literature identified a distinct link between the views of senior management within an organisation and an organisation's culture (O'Reilly et al, 2014). Next, the values that an organisation has within its culture reflect directly on the organisation's choice of design process (Cameron and Quinn, 2011). Finally, as mentioned in this section, the value placed on process quality is directly linked to either a 'hero culture' or 'process culture' (Crosby, 1979). These links have led to inferred organisational properties; this logical progression can be constructed from literature as proposed in figure 11 and figure 12.

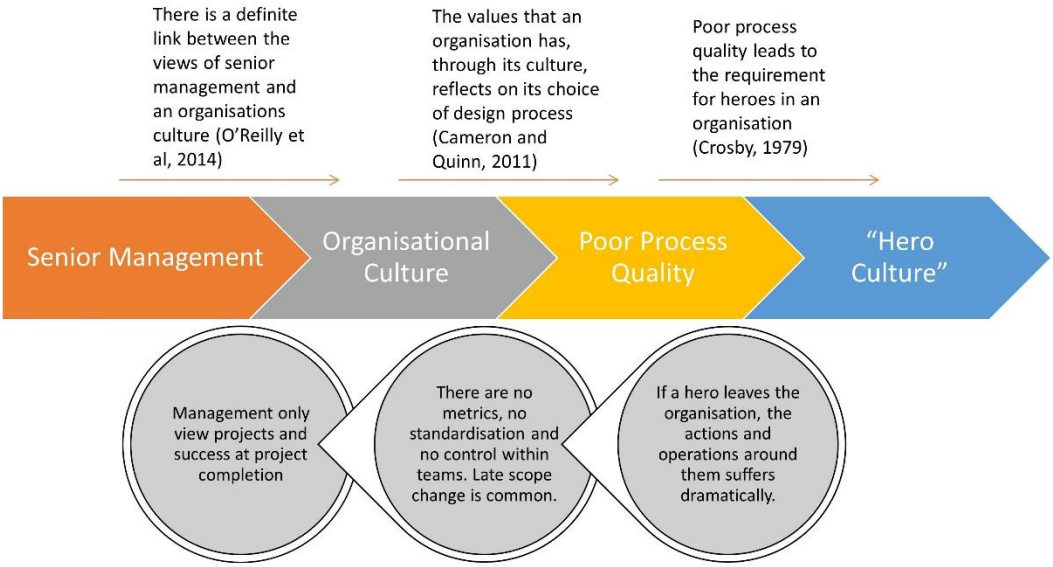

Figure 11 - The Link between Senior Management and Hero Culture

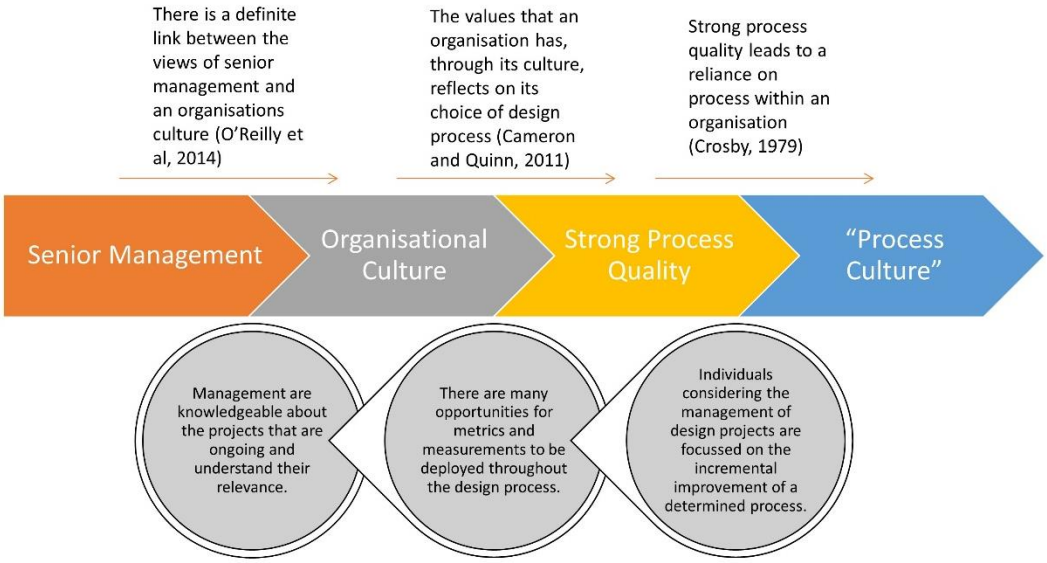

Figure 12 - The Link between Senior Management and Process Culture

In conclusion to the review of hero versus process culture, this analysis identifies that there is an inherent link between senior management, organisational culture, process quality and culture at a design level. Attempts to characterise an organisation and its culture should be aware of the link identified, in figures 11 and 12, due to the effects that a hero or process culture may have on change management activities.

2.5.2) Unitarist versus Pluralist versus Radical Cultures

Fox (1966) and Fox (1976) identified three distinct silos of culture in organisations; a unitarist organisation, a pluralist organisation and a radical organisation. In the case of a unitarist organisation, Fox (1976) used the analogy of all team members 'pulling in the same direction' and towards the same goal, with further implications of harmony, co-operation, effective leadership, high performance towards a common purpose and team spirit which yields healthy productivity. In comparison, the pluralist organisation operates as several groups with one governing body that makes decisions to direct each group towards a common goal. Importantly the interests of employees, managers and their respective cultural 'group' may have differing, and in some cases completely contrasting, interests and these are considered when coming together to progress organisational goals. Finally, a radical organisation is proposed to be a composed of two directly opposing classes; a high paid, low work, managerial role that gives orders and a low paid, high work group of 'order-obeyers'. In this case, both sides are proposed to believe that a gain for one side means a loss for the other and so interests are fully opposed, pull occurs in completely opposite directions and continuous friction and distrust leads to a poorly performing organisation.

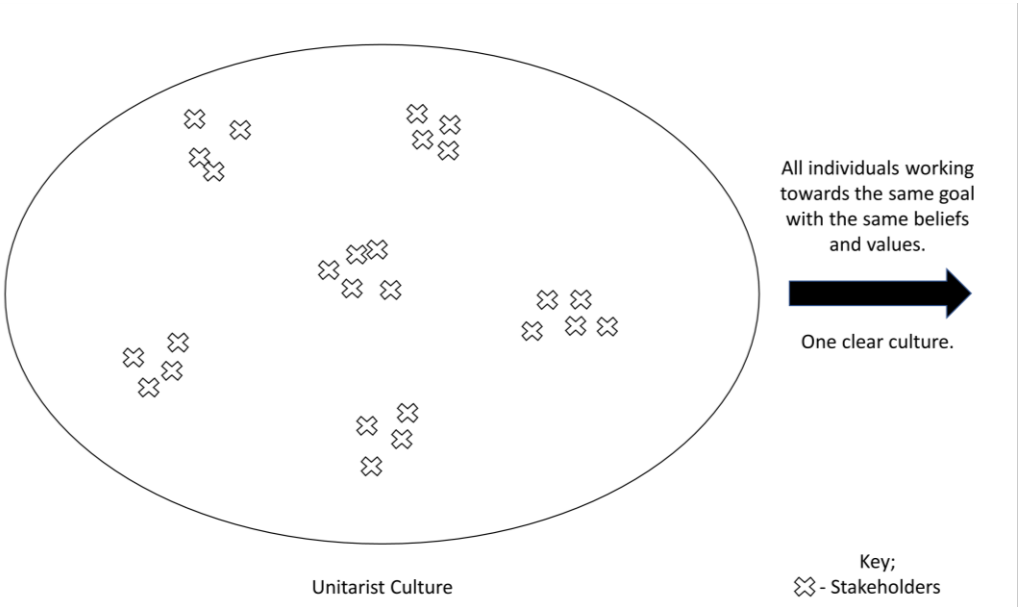

Figure 13 - Unitarist Culture

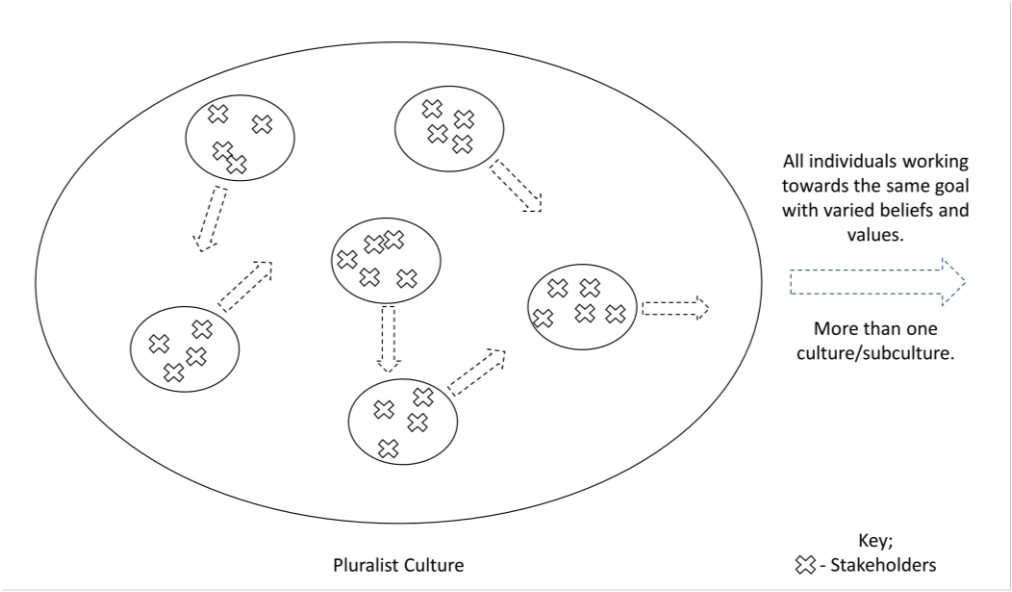

Figure 14 - Pluralist Culture

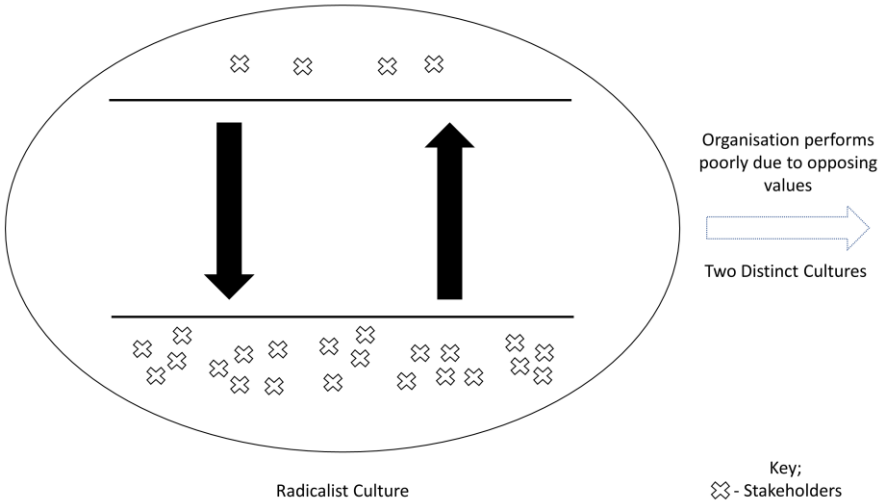

Figure 15 - Radicalist Culture

These cultures can be identified using a Relational Quality Index (RQI) whereby a low value can represent a radical culture and a high value can represent a unitarist culture (Kaufman et al, 2020). Using the RQI, literature identified a series of variables that can begin to characterise what a high RQI culture may present when compared with a low RQI culture. For example, a high RQI value is linked to positive management styles, justice within the workplace and above average wages and benefits whereas a low RQI value is linked to poor perceptions of trust between more and less senior individuals, roles that are tightly constrained and uninteresting and workplaces with significant organisational disruption.

When considering process implementation, Prajogo and McDermott (2005) proposed that the implementation itself could be considered from either a unitarist or a pluralist perspective. The unitarist perspective considers the implementation of process as a fixed set of practices or activities that can only be applied within one specific cultural type, where practices are strongly recommended to be adopted as a whole rather than selected as parts. The pluralist perspective however considers multidimensional cultures and proposes that process implementation must be aware of its own limitations when aiming to engage between these and adapt accordingly by ensuring that proposed implementations are suitable for the culture that they will be engaged with. Finally, Prajogo and McDermott (2005) proposed that it is organisational culture that affects the success of process implementation, and not the implementation of process affecting culture, which thus suggests that the understanding of an organisation's culture is critical to being able to manage and deliver process implementations.

2.5.3) Summary of Organisational Culture

The discourse presented in section 2.5 outlines the importance of understanding organisational culture in change management activities. First, literature identified that the implementation of process is often linked to cultural change as the existing process may not be supportive of proposed changes (Ragsdell, 2000 and Carlgren, Elmquist and Rauth, 2016B). Next organisational culture was defined (Brown, 1995) and the properties of organisational culture outlined (Bellot, 2011).

Section 2.5.1 considered the concepts of hero culture versus process culture and identified a distinct link between senior management, organisational culture, process quality and culture at a design level. Literature suggests that the implementation of process orientated change must consider whether the culture at design level prioritises heroes or process as this has significant implications on the scope of proposed change. For example, if an organisation has a hero culture, then literature proposes that a degree of cultural change must be enacted in order for individuals within the organisation to accept process. Alternatively, if an organisation has a process culture, then literature proposes that process orientated change may be more easily accepted if the cultural values and process values align.

Section 2.5.2 considered the difference between the cultural characteristics of (Fox, 1976);

- Unitarism (where all employees share one culture),
- Pluralism (where a number of sub-cultures are present),

- Radicalism (where a high seniority culture and a low seniority culture work in opposition to each other).

These distinct cultural characteristics were found to directly impact the operations of an organisation (Kaufman et al, 2020) and should reflect on the choice of change management strategy (Prajogo and McDermott, 2005). If the CSD is found to be unitarist, then change can also be unitarist, and one culture must be considered in the implementation of DT and SE within an LEO. However, if the CSD was found to be pluralist or radicalist, then the change proposed must also be pluralist, and attempts made to engage with each of the identified cultures for DT and SE implementations to be valued by all members of the CSD.

2.6) Organisational Change Management

When enacting organisational change, literature proposed that there were two approaches to engaging with an organisation's culture, conforming (and maintaining the status quo) or transforming (and changing the existing cultural characteristics) (Bate, 1994). When deciding on the which of these approaches is suitable, the change management proposed must consider the internal and external environment that is present within an organisation (Bate, 1994). Thus, an understanding of the organisational culture and the paradigms adopted by management in response to these stimuli must be understood in order to enact successful change management.

A number of different organisational change management methodologies and mentalities were considered and utilised to further the research in answering the research questions. One change management approach was proposed by Lewin (1947) and Burnes (2017) where openness and accountability are stressed as vital to the change management process. In particular, all employees in an organisation are provided with the information and support to challenge any particular course of action and hold their leaders accountable for any changes made to the overall plan. This is inherently a very ethical approach to organisational change as all stakeholders are aware and actively participating in the initiatives that are ongoing around them, and thus facilitates activities such as co-creation well. However, this proposal can be difficult to implement in organisations where individuals of power are not supportive of the change that is being proposed and in cases of high pressure as change activities can be looked upon unfavourably within an organisation over completing essential engineering tasks, as discussed in section 2.5.

Figure 16 - Change Management Process Proposed by Lewin (1947) Summarised

Another change management methodology considered was proposed by Bass (1985) and Kotter (1996) who portray an organisation's employees as resistors to change and stress the importance of management driven initiatives and radical change outcomes. This is most commonly portrayed in Kotter's eight step model (1996) which outlines a series of change management activities that aim to support these beliefs. However, Kotter's change management approach is criticized as accomplishing change and rewarding leadership roles at a high cost to the employees that are being affected by change and in downplaying the impact and role that leadership positions must take in the change management process (Hughes, 2015). Unsurprisingly therefore, this change management methodology found similar issues to the one proposed by Lewin (1947) and Burnes' (2017) in that power dynamics and internal company culture made this difficult to sustain during periods of high pressure.

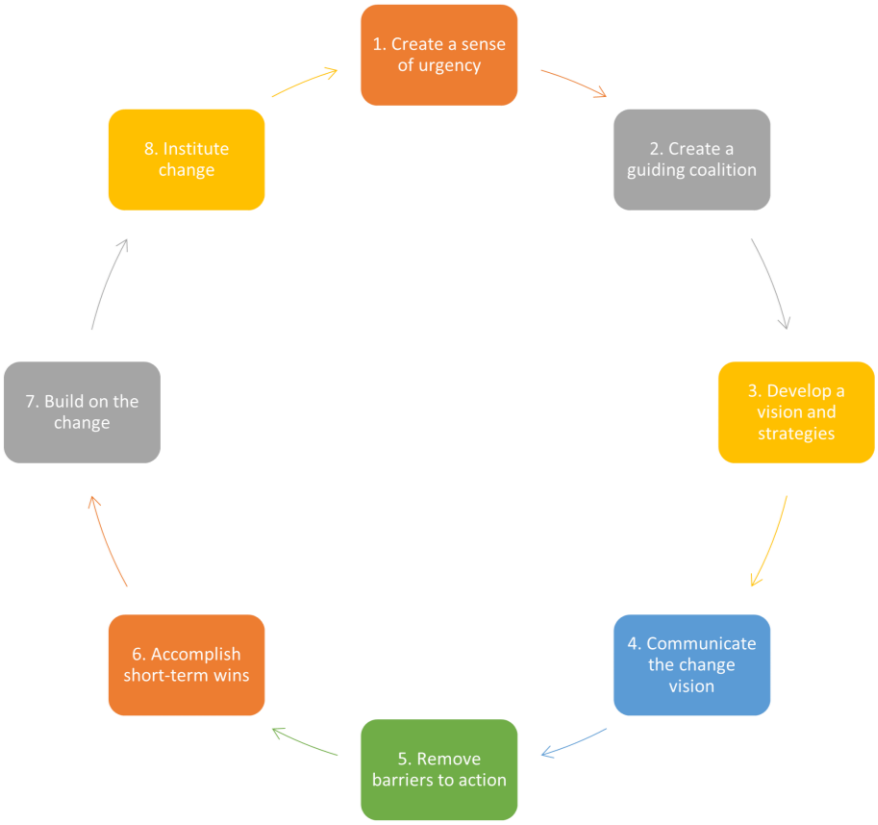

Figure 17 - Kotter's Eight Step Model (1996; p.23)

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Another plausible change management methodology that could be considered is Grassroots Organisational Change. This is where change managers collect actors at lower levels of seniority within an organisation to collectively create and manage change (Mars, 2009). Furthermore, individuals leading grassroots change were identified by Mars (2009) to have two prominent traits; a capability to mobilise people and create collective action, and an autonomy from recognised authorities. This therefore may offer an alternative to the change management methodologies proposed by Lewin (1947) and Burnes (2017) and Bass (1985) and Kotter (1996) in that the management of senior stakeholders would not be vital to the development and implementation of change. This is expanded on by Heyden et al (2016) who proposed that change could be considered as 'top down', where the most senior management are initiating the change and middle management are acting as executors, and 'bottom' up, where middle managers initiate and manage change but with resistance from the most senior individuals.

Literature has also been identified that proposes particular considerations with regards to the implementation of SE within an organisation. For example, Armstrong (2000) proposed that the social aspect of SE process implementation should be emphasised more and suggests that a different process (figure 18) should be considered. Each of these proposed stages is characterised by a perceived level of resistance to change and actions taken at each stage to encourage engineers and their customers to overcome these proposed obstacles.

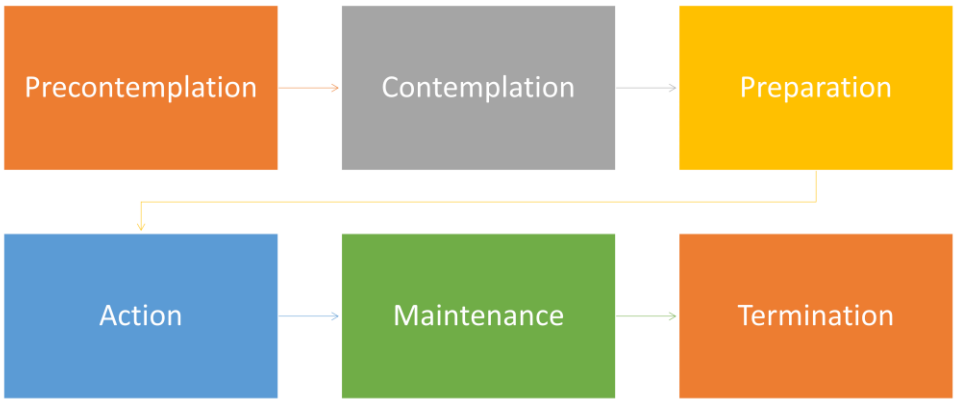

Figure 18 - Change Management Model Proposed by Armstrong (2000; p.301)

On the other hand, literature also proposes that there are specific considerations that need to be made in change management when considering the implementation of DT. Liedtka (2018) proposed that these can be separated into three core deliveries; superior solutions, lower risk and costs, and employee buy-in. When these deliveries are perceived and accepted by the organisation, then the implementation of DT would be considered to be successful. Liedtka (2018) also proposed that the use of organised process helps keep organisational individuals on track and reduce their fear of failure when trying to utilise innovation-based processes. This reduction in fear of failure could be then proposed to aid in the process implementation of DT.

The change management processes considered and discussed thus far are all defined as programmatic change management methodologies but it is important to consider opportunistic change methodologies (Wisegarver, 2019). In programmatic change management, the desired change situation is known and change can be managed and manipulated deliberately knowing its context. In opportunistic change management, a change individual or change group aim to take advantage of unplanned or unforeseen events

or situations to institute change. Wisegarver (2019) proposed that this is most useful for culture or organisational change as these are more difficult to change than procedures and processes. The primary leverage of opportunistic change was found to be the perception of major crisis; where the greater the perception of crisis, the more leverage there is available to instigate change.

The final change management methodology considered was the DMAIC framework proposed as a part of Lean Six Sigma which identifies change as a five-step process of define, measure, analyse, improve and control (Uluskan, 2016). Culturally, Six Sigma is accepted within the CSO as a process implementation tool and thus, the familiarity of this would support change management activities undertaken. This framework could be coupled with one of the previously identified mentalities and the techniques that follow to implement proposed DT and SE solutions.

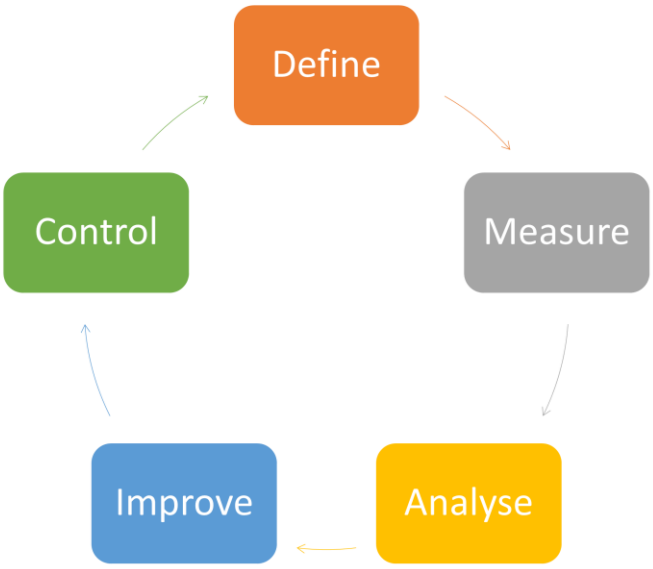

Figure 19 - Lean Six Sigma DMAIC Framework (Shankar, 2009:p.xviii)

Co-creation is raised in the organisational change management methodology proposed by Lewin (1947) and Burnes (2017) as a vital tool to the acceptance of change management by all members of an organisation. Furthermore in this case study, individuals within the organisation have a considerably greater understanding and experience with any particular issues within the CSD and as such would have a greater understanding of the divisional nuance that is present and may need to be overcome for successful implementation. Due to

this, co-creation is used in all aspects of the creation of solutions and where possible this is also considered in the implementation of said solutions. Co-creation also allows for a level of validation over time, as repeat engagement from participants in the organisation about the same topics or points means that despite the structural or hierarchical changes being found in the organisation, these points are still relevant to the CSO.

2.7) Thematic Attributes to the Implementation of DT and SE in an LEO

Acknowledging that section 3.12 makes the argument that the solutions generated in this investigation consider the core components of DT and SE, the same argument must apply to the opportunities and barriers (henceforth referred to as attributes) that are identified in literature. To define within this investigation; attributes to implementation positively or negatively, directly or indirectly, affect the implementation of a process. Therefore, literature outlining any attribute relating to the implementation of either DT or SE should be considered as a potential attribute to the implementation of a merged DT and SE solution. This is represented figuratively in figure 20.

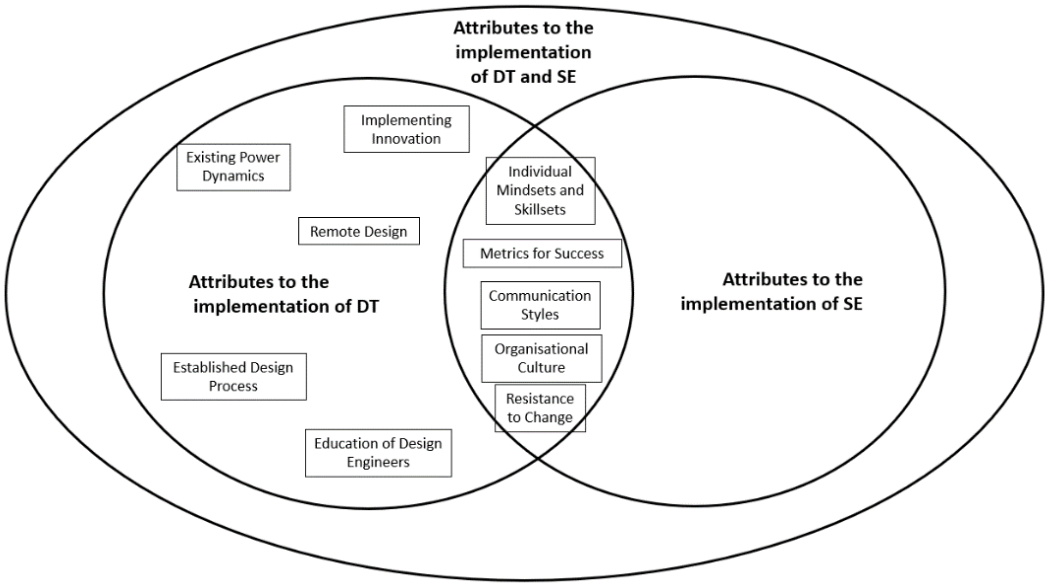

Figure 20 - Attributes Affecting the Implementation of DT and SE within an LEO

Through inference of the literature, the attributes identified in literature were proposed to affect change as shown in figure 21.

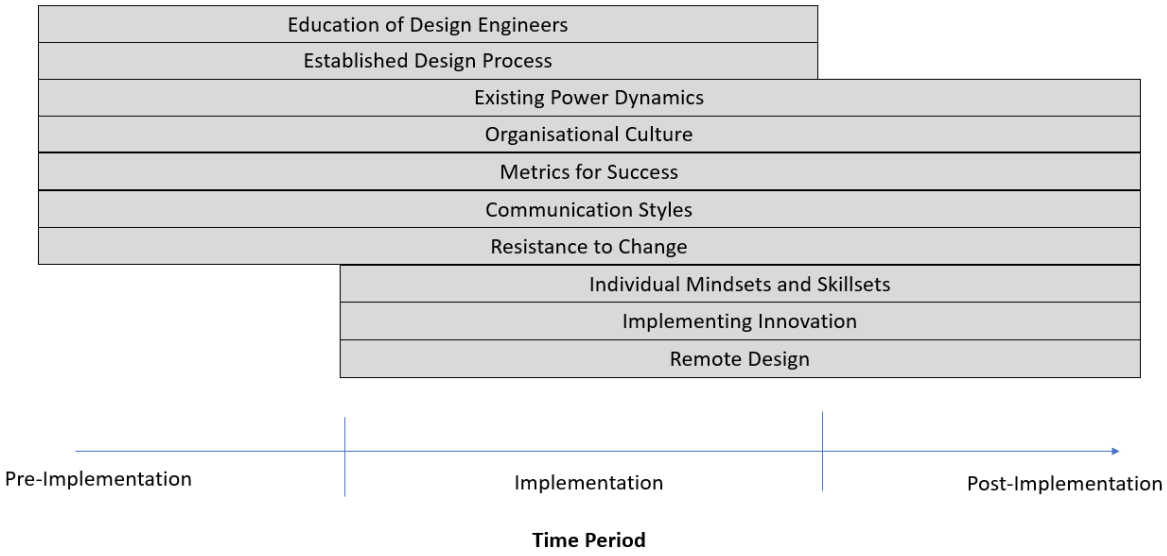

Figure 21 - Interpreting when literature's attributes to implementation would affect change activities

Furthermore, the attributes to implementation identified were inferred to have a level of abstraction as proposed in figure 22.

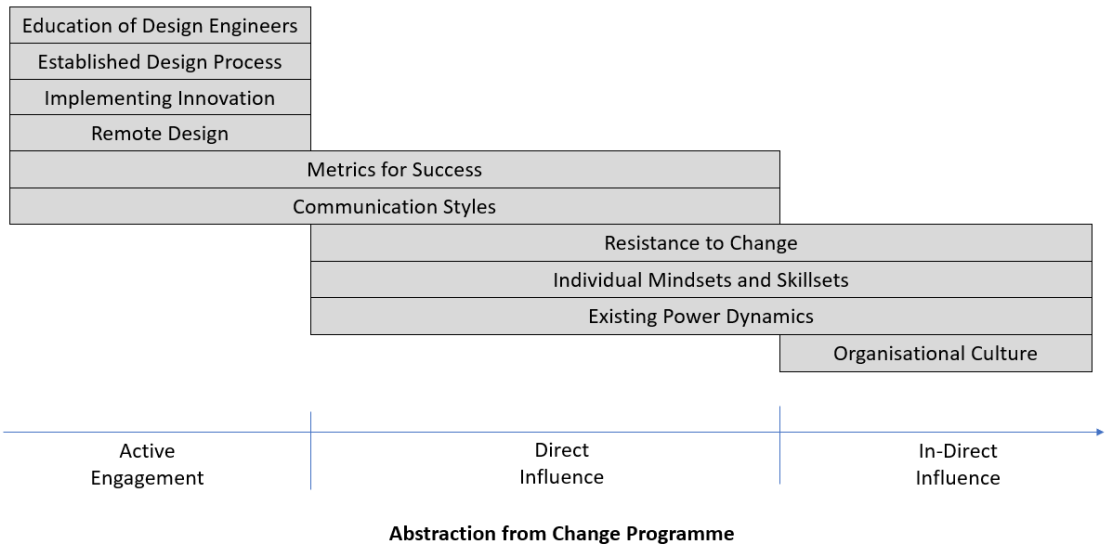

Figure 22 - Interpreting how literature's attributes to implementation would affect change activities

2.7.1) Education of Design Engineers

When implementing DT tools, literature found that once individuals had been educated regarding the tool itself there was no certainty that the individual's inherent way of thinking would support a proposed implementation (Valentim, Silva and Conte, 2017). For example, the persona and empathy map techniques were not found to be easily picked up as some participants failed to see things from the viewpoint of another and brainstorming and co-

creation activities were found to be difficult for participants that failed to let go of their original ideas. Similarly, some participants did not feel comfortable giving their views on a subject, which in turn prevented group interaction. These points show that DT teams need to be carefully chosen, or that individuals engaged in DT activities need to be given ample training for it to be effective. This theme of education is complemented by the work of Hare et al (2018) who determined in their investigation that it would be key in the implementation of DT to present methods carefully, so that participants can see the applications and benefits of each tool within their own working environment rather than offering them all tools at once. In theory this should allow for a greater uptake of tools and methods from participants and allow for a more successful implementation of DT. This is supported in other literature that identifies that the use of case studies to display how DT can be used aided in the understanding and adoption of DT practices (Mubin, Novoa and Al Mahmud, 2017).

2.7.2) Individual Mindset and Skillset

Carlgren, Elmquist and Rauth (2016A) proposed that the mindset of an individual aiming to conduct DT work was key in the effective use of DT. Aspects of this mindset were found to be critical in the product development process and so it is critical that this is obtained within a design team. Furthermore, literature found that implementing DT affected the mindsets of the people in an organisation and lead to positive attitudes towards innovation, which would support the theory that an individual's mindset is not fixed, and that the implementation of DT could occur in any organisation (Crisan and Caldarusa, 2017). Literature has also considered how to measure this mindset (Dosi, Rosati and Vignoli, 2018) which concluded that the DT mindset could be represented by 22 constructs and measured using questionnaire techniques. If an individual can effectively meet the proposed criteria, then they are thought of as effective DT practitioners.

Considering SE, literature proposed that projects following a SE process can fail due to a lack of prior experience of relevant skills that are required as a part of the SE process (Schmidt et al, 2011). Where project teams did not have previous experience of utilising SE, projects were deemed to fail due to an individual's understanding of SE processes.

2.7.3) Resistance to Change

Crisan and Caldarusa (2017) identified a key issue in the implementation of DT, that can likely be expanded to the implementation of any new design process, in that if individuals perceive DT to be poor or that the status quo is satisfactory then there will be strong resistance to change. In addition, design process implementations are commonly reported as finding a

lack of support from LEOs, in particular resistance from management and disciplines that might not perceive value in implementing the new process (Armstrong, 2000).

Change can be separated into two distinct types (Rafferty and Griffin, 2006). The first is transformational change, where individuals perceive that the core components of an organisation, such as ways of working, values, structure and strategy, have been modified and the individual will have to operate differently due to these changes. Rafferty and Griffin (2006) propose that this is seen as threatening to the individual as this is a novel event and they will now need to adopt new values and ways of working in order to continue working with an organisation. The second type of change is incremental and holds relevance for any change whereby aspects of the organisation are changed but are not perceived to have affected the core organisational components. The type of change proposed in implementing DT and SE is likely to be transformational for an LEO unless the organisation itself already has large components of both user centred design and SE methodology in its existing processes.

There are a number of reported characteristics that can influence recipient perceptions and support towards proposed change (Heyden et al, 2016). These are;

- They have accurate information needed to reduce uncertainty (Sharma and Good, 2013).
- They feel part of the process in delivering and developing the change and overall have control of part of it (Greenberger and Strasser, 1986).
- They feel confident in their beliefs that the organisation can successfully implement change (Griffin, 2007).

2.7.4) Established Design Process

DT methodologies are sometimes not implemented as a singular process but incorporated into another design process with the intent to create innovative outputs but retain metrics such as efficiency and design time. Where this is the case, Carlgren, Elmquist and Rauth (2016A) found that DT is perceived to be resource heavy and difficult to prioritise in instances where the organisation has high workload situations. One of the interviewees of Carlgren, Elmquist and Rauth (2016A) reported that when deadlines were tight and there was no room for failure, the resulting solutions were bound to be less innovative. Interviews with middle management revealed that resources were often not directed towards DT activities as these are thought of as additional, non-essential costs. However, in instances where DT has been implemented in organisations as a singular design process, a gap began to form between the

design concepts that were being developed by a DT team and the technological feasibility and manufacturability of a product. This was reportedly because the DT team failed to address the balance between innovation and technical feasibility during the product development process and this resulted in poor outcomes.

2.7.5) Implementing Innovation

In some instances, organisations can appreciate innovation and innovative design but fail to capitalise on this. Some literature reports that this is one of the key issues in implementing DT in LEOs; although novel concepts and themes can be identified that could be continued in later design, the concept itself is not feasible to create or manufacture (Carlgren, Elmquist and Rauth, 2016A). This means that DT can be perceived as unsuitable for the organisation and not adopted any further. Since SE places a great emphasis on the idea and management of risk (Orlowski et al, 2015), a DT and SE merged implementation may not find that this barrier has as large of an impact as an unedited DT solution.

2.7.6) Metrics for Success

Mabogunje, Sonkalar and Leifer (2016) identified a number of constraints to improving design in a systematic and iterative manner that stem from the lack of metrics possible in design. One of these identified constraints is that is difficult to tangibly measure design performance; engineering design is often measured through the use of economic metrics but this is not a reflection on the actual design process of generating intellectual activities. Instead, when compared to the rest of engineering which is normally measured in standard metrics, there are no standardized measurement figures for design and design development.

Academic literature has identified a number of potential metrics that could be used in the measure of the effectiveness of DT. Rapp and Stroup (2016) proposes six such indicators for success that could be considered further.

1. The first is customer feedback, which is often gleamed through testimonials, and can be used to determine the impact that DT has had on an organisation's customers.
2. The second is frequency and attendance of DT activities as this displays the acceptance of DT within an organisation and may indicate the value that employees place on DT processes.
3. A similar metric suggested is the immediate impact that is found from employing DT, measured through a record of all of the projects or aspects of projects that are implemented as a result of DT activities.

4. Traditional KPIs such as financial performance, market success and revenue can also be used to evaluate the effectiveness of a DT implementation as these can be compared to previous or similar projects that did not utilise this process to identify its impacts.
5. Reflective measurements such as questionnaires and surveys completed by participants in the DT process, from the designers and management to the external stakeholders identified, can be used to identify people's perceptions about the process and the eventual outcomes.
6. The working culture within an organisation is the final proposed metric, whereby team motivation, collaboration and engagement can be monitored to identify the impacts of DT in developing an innovative and collaborative company culture.

In comparison to this, metrics for SE have been identified by Kasser and Schermerhorn (1994), Sheard (2000), Chaves (2016) and Orlowski et al (2015) and in SE documentation published by Antony et al (2010) such as;

1. Measuring requirement stability as a function of the number of requirements that have changed since the last baseline meeting, divided by the number of baseline requirements. This is an example of a progress measure.
2. Measuring defect density as the weighted number of major defects per given project at a standardized size. This is an example of a product measure.
3. Measuring a set project parameter, such as review rate, and making comparisons across all projects to identify statistical norms. This is an example of a process measure.

This metric barrier is therefore listed because although there are suitable metrics for a DT and SE implementation, the organisation must be willing to accept these alongside traditional metrics such as time to market and overall project cost if long term implementation is to be successful.

2.7.7) Organisational Culture

Literature regarding the implication of organisational culture has previously been discussed in section 2.5 but literature specific to DT and SE will be discussed in this section.

LEOs are traditionally risk-averse in nature as the effective reduction in risk in a project supports the theory that the planned outcome will be successful (Huber and Rothstein, 2013). This is different from the principles of DT, which suggest that making a mistake and

learning from it is beneficial to the design process of a product or service (Dosi, Rosati and Vignoli, 2018). Furthermore Carlgren, Elmquist and Rauth (2016A) found that employees from LEOs perceived DT as less serious than their traditional approach to design and that aspects of the process were seen as "unnecessary nonsense". In some cases the project teams were prohibited from engaging with their end user for fear of leaking sensitive information. This would suggest that investigating and understanding the organisational culture of a company would be vital in the implementation of DT.

Some research proposes that there will always be a trade-off between achieving the organisational efficiency wanted by management and the innovative solutions that are required to engage and build on the customer base (Liedtka, 2018). This may reflect on an implementation of a merged design process in this manner, based on an organisation's requirements, and thus should be considered in further work.

2.7.8) Existing Power Dynamics

The implementation of a new design process in organisations can have implications on the architecture of an organisation and the roles that each person completes. Carlgren, Elmquist and Rauth (2016A) found through an interview investigation, into a number of organisations that had implemented DT for more than five years, some employees in the product development process felt threatened by the introduction of DT and that the introduction of this process questioned the capabilities of established groups and team members. Further since some of the decision-making process was perceived to shift from management down to a team level, this reduced management authority and lead to power shifts. Raharjo and Eriksson (2015) place leadership as a strong predictor of human resource development, information and analysis, management of process and strategic planning.

2.7.9) Communication Styles

It is vital that an effective communication system be established within an organisation for DT and SE to work effectively. Literature identified that in some cases, organisations had a fundamental communication barrier to overcome as they would simply not accept outputs in materials other than they were used to (Carlgren, Elmquist and Rauth, 2016A). One of the examples presented was where information could not be directly translated into hard technical requirements as the communication between members of the design team and management break down as there is no fixed proposed project outcome. In this investigation the management teams reported that they did not know how to support the projects and could not dedicate resources to the project without an inherent risk due to the perceived

lack of clarity. The barrier therefore lies in presenting an idea based on subjective data and user centred values in a manner that is accepted and understood by the relevant internal stakeholders.

The value of effective communication processes has been highlighted by Kasser and Schermerhorn (1994) who, when considering SE, identified that poor communication is the prime reason for almost any kind of failure. Therefore, one of the potential attributes to implementing SE in any organisation is the strength of the internal communication process that currently exists. If this is poor, then it is likely that SE implementations will have negligible effect on the overall outcomes of projects and thus be seen as unnecessary.

2.7.10) Remote Design

The final attribute to implementation identified was the concept of remote design, where individuals in geographically distributed locations work together on design projects. Haramundanis (2008) identified that user centred design was possible due to an LEO's application of a knowledgeable team, planned meeting structure, sufficient time, open and reliable communication and reasonable working schedules across time zones. However in hindsight, this would suggest that any of these factors could be key in the success or failure of DT as a remote tool.

Studies have also been conducted regarding the use of DT versus co-located working at CERN (Ultriainen, 2017), findings reveal that whilst it was possible to conduct DT remotely, every task was reported to be easier when done in person. Data reported that this perception was due to the following issues;

1. The use of low-quality internet connection between participants.
2. Working across different time zones.
3. The perceived need for a decision to be agreed by all members of the team in a remote working environment and required all the team members presence.
4. Groups often found that they were stuck in conversations that that did not lead onwards as they were not sure about when to stop talking and start acting.

Since virtual environments have the opportunity to be faster, cheaper and smarter (Furst, Blackburn and Rosen, 1999) this will likely become a major issue that should be considered in future work around the implementation of design process.

2.8) Implementing DT and SE

Although very little research has been completed considering the implementation of DT and SE within an LEO, literature can be identified that highlights the implementation of DT or SE with another design process. This section aims to detail attempts to investigate DT or SE when they are merged with other processes so that key findings can be carried out within this investigation.

The merging of one design process with another is not a novel idea and literature indicates that there is a range of potential merged design processes that can be generated and utilised effectively. For instance, merged implementation research considered the implementation of DT with Requirements Engineering as it suggested that the traditional Requirements Engineering process was not suitable for resolving problems that are rapidly changing (Vetterli et al, 2013; Hehn and Uebernickel, 2018). One key area of implementation considers the difference between the notion of 'requirements' and 'customer needs' and proposes that DT's focus on exploring these customer needs allow more innovation in the design of new products or services (Vetterli et al, 2013). Hehn and Uebernickel (2018) consider this combination and identify further areas of implementation, such as; the use of DT to identify non-functional requirements, the use of DT to identify product architecture, the communication of requirements through an interdisciplinary and interconnected team and in the generation of project estimates. Furthermore, the information generated through prototyping could be proposed to aid in the understanding and development of a concept (Schmidt et al, 2011; and Seidel and Fixson, 2013), and identify the limitations of innovation that might be present within a solution. An example of this could consider the low fidelity prototyping activities present in DT and the structured test plans and programmes present in SE, combined to form one solution.

Yasui, Shirasaka and Maeno (2016) proposed a theoretical merged design process based on the properties of SE and DT; with the proposed perception that SE is a well-tested and reliable way of designing systems whereas DT promotes creativity in design. The framework for this method is based on the SE V-Model but is proposed to have a more human centred and holistic toolbox. Although data was not presented within this particular paper to suggest

the suitability of this proposed design within an LEO, figure 23 does present an interesting proposition that could be considered in future work.

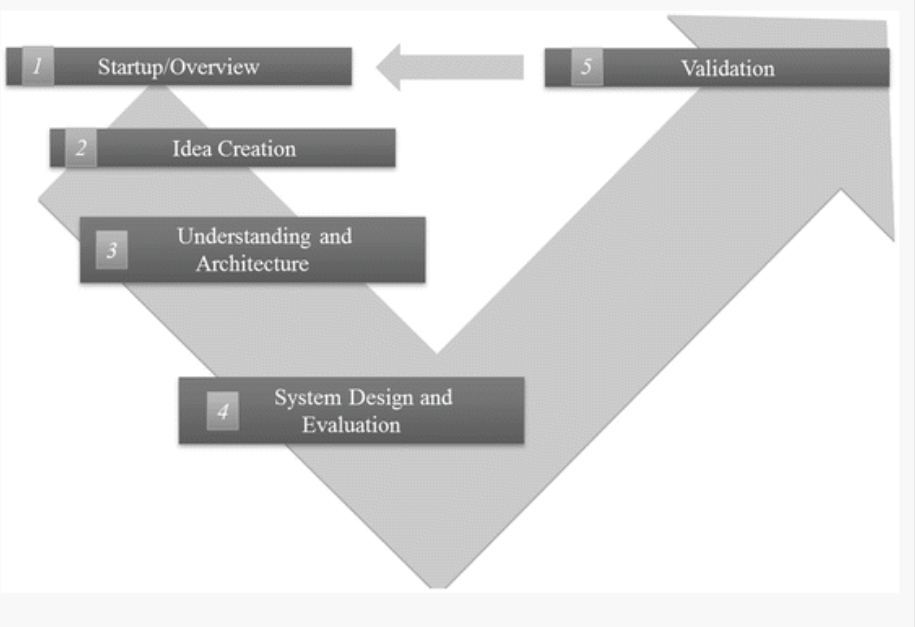

Figure 23 - Proposed Merged Design Process (Yasui, Shirasaka and Maeno, 2016: p.86)

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In this process, Yasui, Shirasaka and Maeno (2016) proposed five separate phases in their merged design process and a number of different tools that could be applicable at each stage as a part of the design toolbox. These phases are; start-up/overview, idea creation, understanding and architecture, system design and evaluation and validation and information about each of these is available in table 1, faithfully recreated.

Table 1 - WISDM Toolbox recreated from Yasui, Shirasaka and Maeno (2016:p.6)

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Phase	Tools (examples)
Start-up/Overview	Team building, design and philosophy, iteration for creation
Idea Creation	Brainstorming, KJ method, mind map
Understanding and Architecture	Observation, CVCA, WCA, value graph, scenario graph, use case
System Design and Evaluation	Enabler framework, QFD, FFBD, OPM, morphological analysis, Pugh concept selection, prototype for empathy
Validation	Prototype to test, AHP, interview, expert judgement, questionnaire-based poll survey

Similarly, research has considered the merging possibilities of DT and Engineering Systems Thinking based on the fundamental positions of each design process (Greene et al, 2017). Although Engineering Systems Thinking and SE are different (the prior referencing the holistic perspective over all internal and external interactions whereas the latter being an interdisciplinary approach to develop suitable systems through customer requirements (Monat and Gannon, 2018)) this still presents an interesting discussion about how a similar process could be merged with DT. This is especially true as engineering systems thinking considers a similar perspective that should be adopted when using SE. Greene et al (2017) proposed four models; the distinctive model, the comparative model, the inclusive model and the integrative model. These are shown in figures 24, figure 25, figure 26 and figure 27 respectively and present different compositions of a DT and SE solution in implementation.

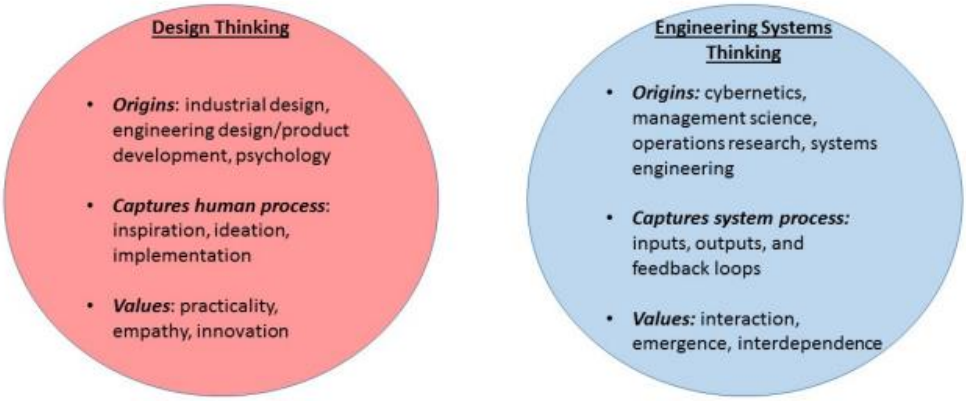

Figure 24 - Distinctive Concept Model of DT/EST (Greene et al, 2017; p.7)

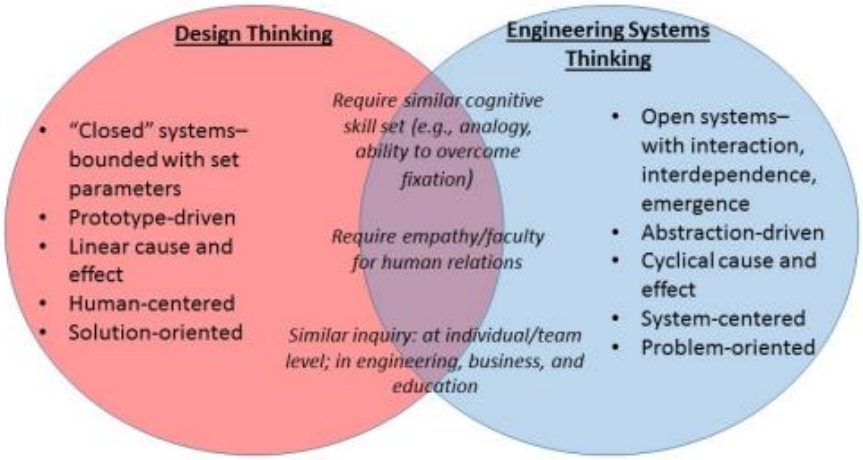

Figure 25 - Comparative Concept Model of DT/EST (Greene et al, 2017; p.7)

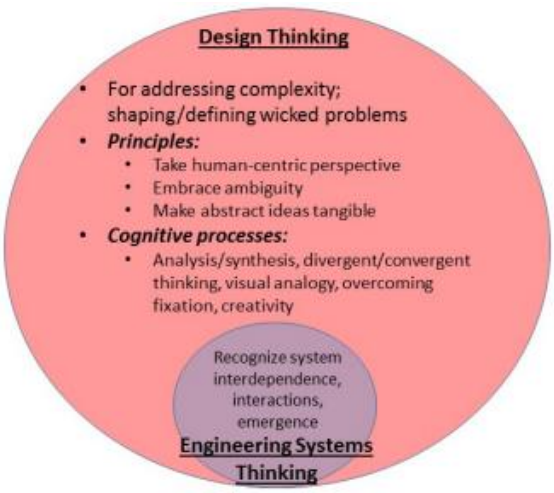

Figure 26 - Inclusive Concept Model of DT/EST (Greene et al, 2017; p.8)

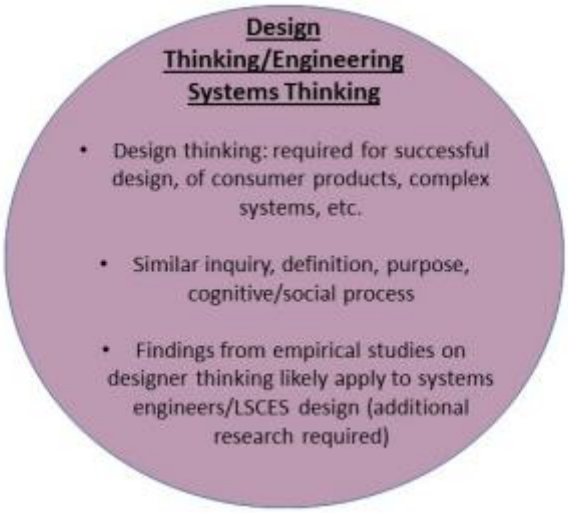

Figure 27 - Integrative Concept Model of DT/EST (Greene et al, 2017; p.9)

The literature surrounding these proposed merges does not indicate that one of them is superior to any others but instead argues that the choice of one of these models depends on the context that is presented.

Finally, Darrin and Devereux (2017) proposed a number of practical implications that should be considered in the specific implementation of DT and SE. These include;

- Customer involvement in the design process means constant, regular customer engagement with the team.
- Regular updates in the requirements needed would occur through the iterative nature of DT.

- Iterative changes can be made as designs evolve that are supported practically through regular system releases.
- The use of an iterative process can aid in the identification and generation of multiple design and implementation options, which in turn increases an organisation's agility and reduces risk and uncertainty.

2.9) Summary

Chapter 2 presented a narrative of the comprehensive literature review conducted as a part of this investigation. First, traditional engineering, Systems Engineering and Design Thinking were introduced, and case studies identified for each process that aimed to highlight its application. Traditional engineering was identified to be a sequential process that led to poor time to market, high process cost and poor final design (Yazdani and Holmes, 1999). SE was introduced as an engineering approach to the entirety of the product lifecycle (Hossain and Jaragat, 2018:p.7) and SE processes such as the V model (Forsberg and Mooz, 1991), multiple V model (Wright, 2018), Waterfall model (Adenowo and Adenowo, 2013) and Spiral model (Alshamrani and Bahattab, 2015) were introduced. However, although SE case studies identified a number of areas of successful implementation, they also identified a number of failures that characterise SE processes (Monat and Gannon, 2018). DT was then considered, which was introduced as having a user centred design process and a design toolbox that considers the user through the design, development and prototyping stages of its design process (Brenner, Uebernickel and Brell, 2018). DT case studies highlighted a variety of applications to societal problems (Abdussamad, 2014) but identified a number of challenges in its implementation (Carlgren, Elmquist and Rauth, 2016A).

Section 2.4 identified that the action of measuring design was proposed in literature to be very difficult (Mabogunje, Sonalkar and Leifer (2016); Royalty and Roth (2016), Seidel and Fixson (2013) and Blizzard et al (2012)) and a number of methods of measuring design were proposed.

Section 2.5 considered organisational culture and previous attempts to measure organisational culture due to its reported importance in the change management process. Importantly, this section identified the key organisational characteristics of hero cultures versus process cultures (Crosby, 1979), and unitarism, pluralism and radicalism (Fox (1966) and Fox (1976)) as defining features in an organisation. This section concludes by commenting on the consideration of change as unitarist or pluralist and identified that understanding cultural phenomena is critical to delivering process implementation (Prajogo

and McDermott, 2005). This leads into section 2.6, which considers organisational change management and introduces the change management approaches proposed by Lewin (1947), Burnes (2017), Bass (1985), Kotter (1996), Armstrong (2000) and Lean Six Sigma (Uluskan, 2016). Literature also identified considering grassroots organisational change (Mars, 2009), differences between 'top-down' and 'bottom-up' change (Heyden et al, 2016) and opportunistic change (Wisegarver, 2019) as potentially important methodologies that may be implemented within this investigation.

The literature review conducted then considered the scope of this investigation and the initial reported perception that implementing a process to replace the existing, major design process within the CSD was not possible. Due to this, the core elements of DT (Carlgren, Elmquist and Rauth, 2016A) and SE (Micaelli et al, 2013) were identified and processes were compared (Darrin and Devereux, 2017) so that any solutions generated during the course of this investigation were based in DT and SE theory. From this consideration, an argument was made that the attributes to implementing DT and SE within an LEO reflected on the attributes to implementing DT or SE as individual processes. A total of ten attributes to implementation were identified in literature based on this argument to be considered in later stages of this research. These were;

- Education of Design Engineers
- Individual Mindset and Skillset
- Resistance to Change
- Established Design Process
- Implementing Innovation
- Metrics for Success
- Organisational Culture
- Existing Power Dynamics
- Communication Styles
- Remote Design

The implementation of DT and SE in literature is considered in section 10 and, although there was very little literature identified regarding the implementation of DT and SE in LEOs specifically, cases were presented that consider the implementation of DT and SE with other design processes or theoretically. These included; DT and Requirements Engineering (Hehn and Uebernickel (2018) and Vetterli et al (2013)), theoretical implementation of DT and SE

(Yasui, Shirasaka and Maeno, 2016), and DT with engineering systems thinking (Greene et al, 2017).

2.10) Gaps in Existing Knowledge

The literature review undertaken, and the summary presented in 2.9 outline a number of gaps that exist within the current knowledge that could be considered within this investigation. These will be briefly outlined in this section, and any key points identified will be analysed to help the reader understand how the research questions proposed, were formed. First, although DT and SE have been implemented previously, or with other processes (Hehn and Uebernickel, 2018; Vetterli et al, 2013; and Greene et al, 2017), these utilisations have not considered the specific implementation of DT and SE within one case study. Importantly, previous literature has not considered the structure or form of a DT and SE process in implementation, with the closest identified being Yasui, Shirasaka and Maeno's (2016) theoretical proposal of how the core concepts of DT and SE could be combined. Therefore, there is a clear gap in the literature to understand how a DT and SE merged process could be formed and what its purpose within an organisation might be. This led to the creation of research question 1A.

Second, research identified a significant number of attributes to implementation (often through the consideration of barriers) for DT and SE processes or concepts, as singular entities (section 2.7). This would be critical to acknowledging in this investigation, as a merged process may lead to the cancelling out of attributes, the compounding of attributes or the creation of new attributes due to interfaces between the DT and SE elements of a merged solution. This would have a significant impact on the success of a DT and SE implementation in future, and so this led to the creation of research question 1B.

Next, although literature has been identified that considers organisational change management (section 2.6), the findings of Armstrong (2000) suggests that there are optimal change management methodologies for different design processes. For example, literature cannot elucidate whether Lewin (1947), Kotter (1996) or Armstrong (2000) would be the most appropriate method to implement DT and SE within an LEO or what other elements of change management might be important to consider, such as organisational culture (section 2.5). Therefore, this led to the creation of research question 1C, where organisational change management is considered in its more fundamental form as a series of procedures that support DT and SE implementation.

Finally, although some literature has considered the merging of core components of DT and SE (Yasui, Shirasaka and Maeno, 2016) and literature has explored the benefits of implementing SE and DT independently (section 2.2.1 and 2.3.1 respectively), no literature has been found that explores the value found when implementing a merged SE and DT process. Similarly, to when considering the attributes to implementation, the benefits found could either be mitigated, compounded or new benefits found entirely through the implementation of both DT and SE within an LEO. This therefore led to the creation of research question 1D.

The overarching research question is a summation of these four key components to consider the holistic implementation of DT and SE within an LEO. Without any one of these components, there are still questions to be answered around the implementation of DT and SE as a merged process.

Other opportunities to contribute to the existing knowledge base do exist based on the literature review conducted in section 2.0. For example, section 2.5 proposes an immature understanding within the literature of the influences of organisational culture on the implementation of design processes, and thus more specifically DT and SE, that could have been considered in this investigation. It is also possible that other gaps in existing knowledge will be identified during the course of the implementation of DT and SE, as there is such little literature on the implementation of this specific combined process, meaning that the existing literature in this field may not be suitably mature to identify further gaps in knowledge. This proposes that additional contributions to knowledge will likely be found at the conclusion of this investigation that will further develop the maturity of this field.

3.0) Methodology

3.1) Introduction

This chapter will detail the ontology, epistemology, methodology and methods used to investigate the research questions proposed with commentary on the consequences of these decisions on the overall outcomes of this research. This chapter will initially construct a summary of the research methodology conducted whereby the reader is encouraged to conclude the applicability of this against the research questions generated. The following section will consider the methods of data collection and outline the considerations made using the selected research ontology and epistemology. Next, the main study will be discussed including the choice of organisational change methodology, selection of participants, interview process and data analysis and discussions will be presented considering the remote working restrictions imposed by the COVID19 pandemic. Finally, this chapter will present a discussion on efforts made to improve the reliability and validity of the data conducted. A summary of the key considerations made is presented below;

- Research Philosophy: Critical Realism
- Research Approach: Inductive
- Research Purpose: Exploratory
- Research Type: Mixed Methods
- Research Strategy: Participatory Action Research Case Study
- Data Collection Techniques: Interviews and Questionnaires
- Data Analysis: Thematic Coding

Figure 28 graphically presents the investigative process used in conducting this research and is split into five key stages. Stage 1 aims to understand the literature that is present regarding the implementation of Design Thinking (DT) and Systems Engineering (SE) in a Large Engineering Organisation (LEO), to build an understanding of the field and identify research questions. Stage 2 aims to identify an appropriate philosophical position to answer the proposed research questions and from this understand the methodologies that are required. Stage 3 considers the “pre-implementation” investigations that are conducted within the CSO and the use of co-creation to understand, define and implement solutions. Stage 4 considers the management of the implementations conducted and identification of any outcomes that may be present. Stage 5 considers these outcomes contextually to present research findings, that are then used to generate discussion considerations and conclusions, ultimately, that reflect on the research questions proposed.

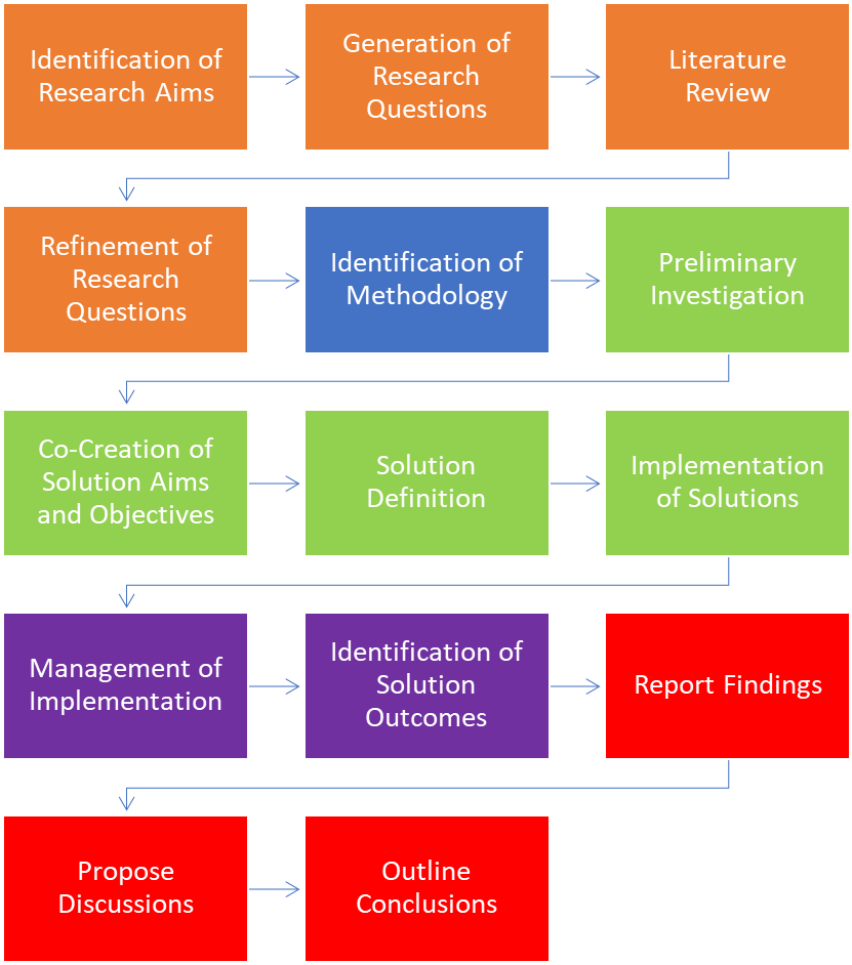

Figure 28 - Overarching Map of Research Process

3.2) Research Questions

For ease of reference, the primary research question is;

1) **How can Design Thinking (DT) and Systems Engineering (SE) be combined and implemented in a Large Engineering Organisation (LEO)?**

Which can be split into;

1A) What are the optimal locations for DT and SE to be implemented in an?

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

1C) What procedures support the implementation of DT and SE within an LEO?

1D) Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?

3.3) Research Philosophy

The research philosophy section aims to define and explain the philosophical position taken by the researcher when conducting this investigation by considering common ontological and epistemological positions and discussing their applications to the proposed research questions.

Berryman (2019) describes ontology as the philosophical study of being or the description of what can be known. This is further contextualised within this case by Bryman (2008) who presented the concept of differing social ontology, where social constructions can be considered either as objective entities that occur separately from social actors or alternatively are pure social constructions that can be understood through considering the actions, perceptions and interpretations of individuals within said construction. Alternative literature questions whether any social construction can exist entirely independently from human interpretation and further, whether there is one shared social reality or multiple that are impacted by context and perception (Granovetter, 1992). Table 2 outlines the common ontological positions present in literature.

Table 2 - Defining Common Ontological Positions

Ontology	Definition
Relativist	The philosophical standpoint that reality is a finite subjective experience (Denzin and Lincoln, 2005) and that nothing exists outside of an individual's own thoughts. From this perspective, reality is indistinguishable from the experience of reality (Guba and Lincoln, 2005), in that reality is human experience.
Realist	The philosophical standpoint that proposes that concepts that are known exist independently, regardless of whether anyone is thinking about or perceiving them (Niiniluoto, 1999).

Epistemology is the way of looking at the world and making sense of it through an understanding of knowledge (Crotty, 1998). Bryman (2008) defines epistemology as the understanding of what should be considered to be acceptable knowledge within a discipline. Table 3 outlines the common epistemological positions prevalent in literature.

Table 3 - Defining Common Epistemological Positions

Epistemology	Definition
Positivism	The world is objective, and research undertaken does not impact this objective truth (Snape and Spencer, 2003) Research is simply discovering meaning that has always been present within a context (Crotty, 1998).
Interpretivism	The world is subjective, and an individual's interpretations and perceptions of the world can be used to understand phenomena (Bryman, 2008; Crotty, 1998). Knowledge is explored and understood rather than discovered (Ormston et al, 2014).
Critical Realism	The social world can only be understood when researchers can understand the unobservable structures that take place (Buch-Hansen and Nielson, 2020).

This research has been conducted considering a realist ontology due to the identification that there is a reality independent of an individual's own perceptions of the world. The adoption of a realist ontology also identifies organisational properties within the CSD as constant and allow for research methods to investigate organisational phenomena without affecting them. Furthermore, the critical realist epistemology acknowledges that knowledge is a social construct and is linked to those who produce it which will place an increased emphasis on participant perspective within research. Importantly, the adoption of a critical realist epistemology will place an emphasis on the unobservable structures that are present within the CSD (Buch-Hansen and Nielson, 2020) and aid in the understanding of why findings may or may not have been achieved. For example, the use of a critical realist epistemology is vital in this investigation's adoption of failure-based learning (section 3.8.5).

3.4) Research Approach

An inductive research approach is defined as using existing knowledge or observations to make predictions about novel cases (Hayes, Heit and Swendsen, 2010; p.278). An abductive approach is defined as "inference to the best explanation" (Walton, 2014; p.4) where conclusions are constructed based on the inference of available information. Finally, a deductive approach is defined as the generation of conclusions that are logical, and argue that where the conclusion's premises are true, the conclusion must also be true (Johnson-Laird, 2009; p.8).

Although a deductive approach would yield logically, valid conclusions (Johnson-Laird, 1999; p.110), the limited body of knowledge surrounding the specific implementation of DT and SE

within an LEO limits the applicability of this approach where novel conclusions could be generated. Therefore, this investigation considered an inductive approach where primary data was gathered and analysed iteratively in conjunction with the theoretical framework and case study analysis to develop conclusions to this investigation's research questions.

3.5) Research Purpose

The research purpose, described in this section, should define the researcher's intent in conducting the work presented throughout this thesis and in the answering of the proposed research questions. Marshall, Rossman and Blanco (2021) categorise research purpose into table 4.

Table 4 - Categorisation of Research Purpose (Marshall, Rossman and Blanco, 2021; p.67)

Used with permission of Sage

Research Purpose	Definition
Exploratory	To investigate little understood phenomena, identify and discover important categories of meaning and generate hypothesis for future research.
Explanatory	To explain the patterns related to a particular phenomenon and identify plausible relationships that shape it.
Descriptive	To document and describe the phenomenon of interest.
Emancipatory	To create opportunities and the will to engage in social action

As defined above, the research purpose of this investigation will predominantly be exploratory due to the lack of research present within and around the CSO or in the field of a merged DT and SE approach to design. However, this investigation's research purpose is also emancipatory, as attempts are made to create opportunities for the implementation of DT and SE and engage employees to adopt them. Therefore, the proposed research questions will consider and follow more general statements such as "What are the themes, patterns or categories of meaning for participants?" and "How do these patterns interact with one another within this social construct?" (Marshall, Rossman and Blanco, 2021).

3.6) Research Type

This investigation utilised a mixed methods approach to answer the research questions proposed. This research type was chosen for this research as it was perceived to better contextualise and measure the case study ecosystem, and thus holistically answer the research questions proposed, when compared to qualitative or quantitative data alone

(Sendall et al, 2018) whilst still being considerate of the proposed realist ontology and critical realist epistemology. For example, qualitative research methods will be used to encourage case study participants to explain their experiences in their own words, and thus extract a suitable level of depth in the data gathered, whereas quantitative methods will be used to identify an overview of data, to understand scale or to measure metrics such as cost and time to market. This selection of research type does, however, mean that considerations need to be made throughout the investigation to ensure that quality research is conducted, with particular considerations to research by Cope (2014), Guba and Lincoln (1994) and Polit and Beck (2012); summarised in section 3.11.

The research philosophy utilised in this investigation lends itself to both qualitative and quantitative research types. Qualitative data can be used to develop key insights in a complex problem; the findings from which can be implemented to create real world change (Maher and Dertadian, 2018). On the other hand, quantitative data investigates the breadth of a field or particular problem from a number of different data points to ensure that data can be generalised to a population as a whole (Thomas and Magilvy, 2011). The use of a mixed methods approach therefore, ensures that ample data will be generated in this investigation to effectively answer the research questions.

3.7) Research Strategy

Research strategy considers the overarching strategy utilised to answer the proposed research questions. The research strategies considered in answering these research questions are briefly summarised in table 5. Each was perceived to be applicable to answering some or all of the research questions proposed.

Table 5 - Overview of Considered Research Strategies

Strategy	Outline
Ethnographic Review	Ethnography is the study of social interactions, behaviours, and perceptions that occur within organisations with a core aim being to generate rich insights into individual's perceptions using detailed observation and interview (Reeves, Kuper and Hodges, 2008). The research questions considered could be answered qualitatively through the accurate documentation of culture, perspectives and practices that are of interest within an organisation.
Narrative Research	Narrative research focuses on chronological, story orientated questions that focus on the life experiences of an individual and how they unfold over time (Creswell, 2007). The chronological focus of this research strategy could be used to identify the causes of perspective and beliefs within an organisation.
Case Study Research	Case study research aims to answer in depth descriptive questions about a context or phenomena and in doing so help develop an understanding of how different cases provide an insight into an issue of interest (Creswell, 2007).
Grounded Theory	Grounded theory is an inductive approach to research where researchers develop a theoretical account of a particular study of interest whilst defining the theory in empirical observations or data (Urquhart, Lehmann and Myers, 2009). There is a continuous interaction between the data that is collected and the data analysis. The main purpose of this research strategy is to build a theory about how something occurs.
Phenomenology	Phenomenology is useful for exploring questions that aim to understand what experiences individuals may have within particular phenomenon (Creswell, 2007).

Ultimately, this investigation used a case study research strategy in collaboration with one LEO CSD. A single case study was chosen in this instance as this research is aiming to develop an understanding as to how this particular case may generate specific insights into the implementation of DT and SE in an LEO (Creswell, 2007) and due to its detailed investigation into a single phenomenon at one particular moment in time (Payne and Payne, 2004). The literature review discussed in chapter 2 concludes that there is very little literature into the joint implementation of DT and SE under these conditions and so through considering this at a case study level, ways of understanding the associated phenomenon can be identified and considered in future research (Payne and Payne, 2004). Houghton et al (2013) argues that prolonged engagement with participants helps in building trust and rapport and in doing so

helps foster rich, detailed responses to research methods. This premise is also supported by Lincoln and Guba (1985) who propose that focussing on the emotions and feelings presented by participants, through persistent observation, leads to data with more depth. This would present the argument that conducting single case study investigations within fields that are relatively unknown leads to the generation of rich data sets that can be conclusive with regards to particular research questions.

The implementation of a case study does include its own limitations. One of the most prevalent to this investigation is the lack of control over other extraneous variables and events within the case study setting that will inevitably impact the findings of any chosen research methods (Yin, 2014), for example a period of redundancies in the organisation would negatively affect mood and may lead to participants becoming disillusioned with the company or management at a particular point in time where they may not normally present significant opinions. To mitigate the impacts of this, journaling techniques were employed by the primary researcher throughout the body of research that, discussed in section 3.11.6, documented any and all changes that occurred within the organisation that might impact this research. If necessary and applicable, countermeasures such as asking participants to report their thoughts on a particular day and over a period of time were deployed. Where this was not necessary or applicable, the extraneous variable was recorded and used to further contextualise the particular point that participants were trying to make. Although this is inherently subjective and could be considered as a fundamental bias from the perspective of the primary researcher, this has been documented and presented in 4.0 so the validity of this work can be assessed by the reader. However, by utilising action research methodologies, the data that is collected will naturally be biased towards the assumptionthat this research is supposed to resolve a problem (Mejía, López and Molina, 2007). Attempts were made to mitigate this through critically reflecting on the journaling techniques outlined previously but this was unlikely to be entirely removed from this investigation.

3.7.1) Action Research and Participatory Action Research

Action research is defined as an inductive research methodology where researchers are co-practitioners within the confines of where research is taking place and are actively aiming to contribute to the practical concerns of a population with an immediate solution (Mejía, López and Molina, 2007). Payne and Payne (2004), suggests that there are two types of action research. The first considers a gap in the current knowledge base that researchers are aiming to resolve by testing current theories against new evidence with the researcher

aiming to be objective, detached and only aim to conduct observations of a phenomena. The second application of action research is to incite change and may be considered as more of an applied research methodology. This investigation will consider the second proposed application of action research and, as such, the primary researcher acted as an agent of change in an attempt to develop solutions that answer the research questions proposed with the full understanding of the context of a case studies culture, process and structure. By detailing the context of the organisation in this way, the generalisability of the research conducted can be assessed by the reader for other applications in industry or academia.

The second application suggested by Payne and Payne (2004) can also be referred to as participatory action research, which focuses on answering research questions that have a focus on developing community action or exploring questions about how change occurs within a community (Creswell, 2007). Participatory action research is a research method that involves an overt and specific call for change; where researcher and participant are equal participants within the research process. Both qualitative and quantitative research methods are utilised as a part of this research strategy and critical reflection is employed on social constructs to take action, create change and radically question the cultures that are being investigated. This approach differs from other approaches to research because it is based on reflection, data collection and delivering action to improve the current way that something is done (Baum, MacDougal and Smith, 2006). It is also referred to as an iterative approach where data must be collected, analysed and new action taken based from this.

Selecting participatory action research does come with a number of challenges however. First, close attention needs to be paid to the power relationships that are present in the research and how well blended the researcher is with their participants (Baum, MacDougal and Smith 2006). The researcher will also have an impact on the phenomena that is being observed and their preconceptions to the research will likely bring an influence and bias to the research. Finally, participatory action research also suffers where participants are less willing to be included in the research conducted or do not want to be included at all.

3.8) Data Collection Techniques

Literature proposes that mixed methods approaches can allow a broadened perspective of a project scope when compared to any other one methodology (Sendall et al, 2018) and present opportunities for the triangulation of data (Flick, 2018). This is especially vital within the confines of a single case study where resources are already limited. The following sections discuss the data collection techniques that were considered in this investigation and

the application of these methods within the mixed methods methodology. These are as follows;

- Interviews
- Questionnaires
- Quantitative Analysis
- Focus Groups
- Failure-Based Learning

3.8.1) Interviews

Interviews can be defined as verbal exchanges in which one person, the interviewer, attempts to gather information and understanding from another person, the interviewee (Rowley, 2012). Literature also proposes that interviews are a useful way for researchers to learn about the experiences of other individuals (Qu and Dumay, 2011). This section will briefly summarise an understanding of the different types of interviews from literature before highlighting the selection made for the particular research conducted in this investigation. Table 6 summarises the work of Wilson (2013) who expressed interviews in three distinct categories; structured, semi structured and unstructured.

Table 6 - Summary of Interview Techniques (Wilson, 2013)

Type	Structured Interviews	Semi-Structured Interviews	Unstructured Interviews
When should this be used?	To ask specific questions when the broader field surrounding it is well understood.	To gather data on complex issues where probing or clarification might be required.	When exploring a new field where the researchers are not sure what the key issues may be.
Strengths	Untrained interviewers can conduct these more easily than semi-structured and unstructured interviews. It is easier to compare responses as all data answers the same questions. Data analysis is relatively simple as questions have structured responses.	Previously unknown issues can be uncovered. Complex problems can be addressed through probing. There is flexibility for interviewers and broad comparisons can be made across interviews.	Establishing a rapport with participants is much easier due to lack of formality. Interviews are incredibly flexible in the way in which questions can be worded and information probed for, and participants can describe issues in their own words. Issues can be revealed that may otherwise have been hidden.
Weaknesses	Validity and reliability are core issues in application. Where the domain has not been identified, answers may not be relevant to the investigation being undertaken. Interviewers must be consistent in their approach to each interview which is difficult. Aiming for standardisation makes it difficult to build rapport.	The findings of semi structured data sets are hard to generalise across all data sets. The interviewer can impact the data gathered through inexperience or inconsistency.	Small studies can generate vast amounts of raw data that takes time to process. The data gathered will be rich but may not be replicable. Data analysis may require qualitative analysis software to identify insights.

Considering the applicability of interviews proposed above, semi structured interviews were chosen for this investigation as they were perceived to have the flexibility to investigate the research questions proposed with the limited knowledge available for the specific implementation of a merged DT and SE solution at project conception.

3.8.1.1) Non-Face-to-Face Interviews

Due to varying restrictions imposed by the COVID19 pandemic (outlined in section 3.14), qualitative data collection was required to be conducted consistently but without the use of face-to-face communication.

One non-face-to-face method considered was the use of a telephone interview. However, Shuy (2002) proposed that it is difficult to complete interviews over a telephone when complex questions and answers are involved due to interviewee fatigue. Literature also proposed that there was a greater non-response rate with regards to telephone interviews than face-to-face interviews (Groves and Kahn, 1979). A second viable alternative to a telephone interview was to use a remote video software such as Zoom, Skype or Microsoft Teams. Gray et al (2020) identified that there were a number of strengths to using this method compared to traditional face-to-face interviews such as; convenience and ease of use, enhanced interface for discussing personal topics, savings of time and accessibility. However Gray et al (2020) also raised that virtual interviews have specific weaknesses. For instance, interruptions to internet connectivity can lead to unplanned disruptions that break the flow of conversation and lead to points being lost or incomplete. Furthermore, and similarly to telephone interviews, conducting interviews in an uncontrolled environment can lead to distractions that take time away from the content being discussed and take time from the interview itself. Ultimately interviews were conducted over Microsoft Teams, a video calling platform that was prevalent in the CSO where individuals can set up specific calls with specific people and engage in video or telephone calls using the internet.

The COVID19 and UK furlough restrictions also impose a number of critical influences on the research data conducted that could be prevalent in its findings. For instance, Von Thienen et al (2012) identified that specific places can elicit particular behaviours and feelings from research participants and so conducting virtual interviews where both participants are present in their accommodation as opposed to their place of work may affect the data collected. This could not be mitigated within this body of research.

3.8.1.2) Interview Samples

Through the choice of research ontology and epistemology and the selection of a single case study research strategy, the findings generated as a part of this research cannot be presented as generalisable to all cases outside of the research context considered. Due to this and the relatively small population that is present in the case study selected, data from this investigation therefore is not statistically significant. Instead interview samples will aim to gather representative viewpoints from individuals with specialisms throughout the division and achieve theoretical data saturation for each qualitative research method. Table 7 identifies the different sampling methods presented in literature.

Table 7 - Considerations for Different Sampling Methods

Sampling Method	Stratified	Selective	Pragmatic	Snowball
Definition	Participants are grouped together by a particular characteristic and then sampled within these subgroups (Esfahani and Dougherty, 2014).	The researcher chooses participants from the population based on their perceived characteristics (Black, 2012).	Participants are selected based on who is available when the research methods are being conducted (Robertson and Sibley, 2018).	Participants are asked to get into contact with other individuals that may be participants (Parker, Scott and Geddes, 2019).
Strengths	Improved accuracy by reducing sampling bias.	Time and cost effective, and useful in qualitative work.	Quick and easy to obtain.	Useful when the population are hard to identify.
Weaknesses	Strata characteristics must be identified.	Prone to errors in researcher judgement with unrepresentative findings.	The sample may not be representative of the population	Selection bias.

Stratified sampling was initially selected, as this would mitigate bias within the CSD's relatively limited population, but due to the restructuring process that was ongoing in the division at the time this was quickly changed to a mixture of selective (to ensure representation of all roles in the division) and pragmatic (to increase sample size as quickly

as possible). However due to the use of a single case study methodology, which restricts the total possible population, and the shift away from stratified sampling methods, attempts were made to ensure that theoretical saturation had been achieved in data per field of expertise. Theoretical data saturation considers the point at which no new data would be collected from a select group of participants under select conditions if research methods were employed over a considerable length of time. Theoretical date saturation was important to achieve as it is unlikely that organisational phenomenon translate across every field of expertise, meaning that an individual working in one area may report significantly different data when compared to someone else within the same division that works in a different field.

3.8.1.3) Interview Process

To briefly overview the interview process, interviews were conducted virtually over MS Teams and the audio recorded using Panopto recording software. Initial interviews within the CSD were one hour in length but initial interviewees raised that this was too long to receive strong engagement. Therefore, the majority of interviews were planned to be 30 minutes long. In this investigation, speech from the recorded interview files was transcribed verbatim so as to prevent any loss of data due to bias introduced by the primary researcher. Transcription was conducted within three months of data collection and all data collected through this interview process was removed in its entirety at the end of the research project.

Interviews within this investigation were split into pre-implementation and post-implementation, outlined in section 3.10. The pre-implementation interviews were conducted before the implementation of any solutions and aimed to understand what attributes may affect the implementation of DT and SE in an LEO and identify early preconceptions to the optimal locations of implementation within the CSD. In contrast, the post-implementation interviews were conducted after the implementation of all proposed solutions and aimed to understand what impact these had within the division and what the experience was for involved participants.

3.8.2) Questionnaires

Questionnaires are defined by Franklin and Osborne (1971: p.337) as “an instrument consisting of a series of questions and/or attitude opinion statements designed to elicit responses, which can be converted into measures of the variable under investigation”. Lydeard (1991) proposed that questionnaires utilise questions based on four distinct categories;

- Attributes, or what things are,
- Behaviour, or what individuals do,
- Attitudes, or what individuals say that they want
- Beliefs, or what individuals think is true.

In this investigation, the use of questionnaires is considered when evaluating identified attributes to implementation and so is restricted to the categories attributes (to define attributes to implementation) and beliefs (to evaluate perceptions towards attribute strength. The complementary use of interviews and questionnaires in DT research is not novel (Valentim, Silva and Conte 2017 and Schmiedgen et al, 2016). In this investigation questionnaires were used to ensure that findings accurately represented participants' experiences, as a triangulation dataset and in the ranking of attributes to implementation. Table 8 considers the work of Vinten (1995) and outlines the types of questions that could be selected as a part of a proposed questionnaire.

Table 8 - Discussion of Question Types Summarised from Vinten (1995)

Question Type	Advantages	Disadvantages
Open Questions	Useful for testing hypotheses about different concepts or ideas.	Coding takes a long time and may be unreliable. These questions demand more effort from respondents.
Closed Questions	Useful for testing specific hypotheses with simple data analysis.	Bias may be present in the answer categories provided and the answers presented may not accurately represent respondents' positions.

The questions presented within this questionnaire were predominantly closed but did include one open ended question asking for any additional thoughts that the participant may have had on a particular matter. The choice of predominantly closed questions was due to the questionnaires roles in answering the research questions; methodologically the questionnaire was conducted after the preliminary interview series and an understanding of the implementation of DT and SE within an LEO had been formed. Therefore, the questionnaire created was not aiming to directly generate any additional new themes but to identify the significance of the attributes to implementation identified in the preliminary interview series and investigate whether the attributes identified considered all participant's beliefs.

3.8.3) Quantitative Data Collection

Quantitative research is regarded in literature to have high accuracy and credibility (Robson, 2002) and is normally aimed at achieving a level of repeatability and generalisability to other circumstances (Saunders, Lewis and Thornhill, 2009). However, to achieve accurate data analysis Denscombe (2010) proposes that there also needs to be a large sample size and thus, the limitation of sample size can lead to unreliable data. Considering this research is utilising a single case study research strategy, it is very unlikely that a representative sample size could be generated to achieve a suitable level of accuracy and so quantitative research overall would have very limited applicability. There were several areas of consideration for quantitative analysis within this body of research; the ranking of attributes to the implementation of DT and SE in an LEO through the use of a questionnaire, the analysis of data sets that were already present within the CSO and in a number of output measures used to evaluate the impacts of implementing DT and SE within an LEO.

3.8.4) Focus Group

In a focus group setting, a moderator guides a group interview while a small group discusses the topics that the interviewer raises (Morgan and Krueger, 1998). Focus groups are important when gaining a collective of ideas or reactions to a particular topic, in gauging attitudes towards a particular idea and in getting feedback on a product or service (Wilson, 2013). The application of focus groups in this investigation were limited due to the potential prevalence of a pluralist culture (section 2.5.2) highlighted in the preliminary interview series (section 4.1.1) as significantly differing viewpoints may prevent the open discussion of themes or topics of interest as more dominant individuals may introduce a skew in any data gathered (Wilson, 2013). In this investigation focus groups were utilised to evaluate the questionnaire; to ensure that the questions asked were of sufficient quality to convey intended meaning, and to ensure that the statements provided in closed questions accurately reflected on the attributes to implementation identified (Yin, 2014).

3.8.5) Failure-Based Learning

Aspects of the implementations proposed in this investigation may fail within the CSD due to a combination of attributes and external factors. Therefore, it is vital that failure-based learning is considered as a methodological tool to understand how and why failure may have occurred and develop answers to this investigation's research questions (Von Thienen, 2017). Literature proposes that failure can be split into failures between an actual and intended result and failures as a result of human error (Rong and Choi, 2019). The findings

and discussions chapters of this thesis present arguments on both, as the accurate identification of why failure occurred is critical to the understanding of the implementation of DT and SE within an LEO. To conduct failure-based learning literature proposes that an individuals must reflect on a failed experience, openly discuss why failure occurred, and identify the that need to be modified or changed in order to understand the root causes of the problem (Hirak et al, 2012).

3.9) Data Analysis

This investigation will predominantly utilise thematic analysis, which is a method of identifying, analysing and interpreting patterns of meaning, referred to as themes, within qualitative data (Clarke and Braun, 2017). It can be applied across a range of methodological frameworks and paradigms and places an emphasis on organically coding and developing themes to generate theoretical explanations for observed phenomena (Reeves, Kuper and Hodges, 2008). In thematic analysis, codes are small points of interest that provide an interesting insight or feature with regards to the proposed research question which are then used to create themes that are groups of codes underpinned by a key shared core idea (Clarke and Braun, 2017). Thematic analysis can be both inductive and deductive and is able to capture both the explicit and the latent messages within discourse.

Raw data was coded thematically using the qualitative analysis software NVivo, where interviewee's quotes were categorised as themes at a particular level of abstraction. Quotes coded could have been positively, negatively or neutrally discussing a particular theme as the aim of this interview series was to contextualise all aspects of the CSD and its design process requirements. An example of the coding conducted is presented in figure 29.

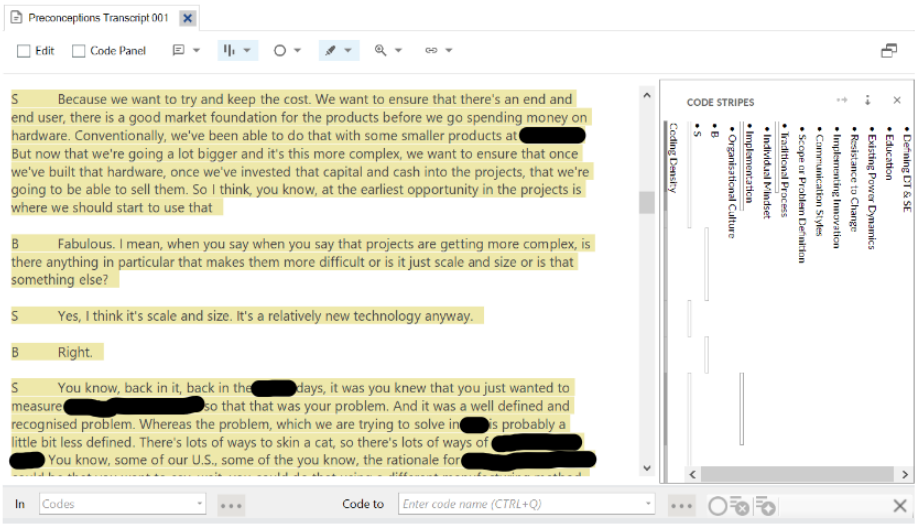

Figure 29 - NVivo Qualitative Software and Coding Example

Effective discourse analysis is vital to answering the research questions proposed and utilising thematic analysis. Carvalho (2008) proposes that this can be split into both textual analysis; where the actors, grammar, rhetoric and discursive strategies should be analysed, and contextual analysis; where data from one participant is compared to another and the social, political and economic context at the time. Commentary is proposed by Reeves, Kuper and Hodges (2008) whose research has been summarised into the below table;

Table 9 – Reeves, Kuper and Hodges (2008) Commentary on Discourse Analysis Summarised

Type of Discourse Analysis	Definition	Application
Formal linguistical Discourse Analysis	Formal linguistical discourse analysis is the microanalysis of linguistics, grammar and semantic uses and meanings behind the text	This analysis is key to investigations that require detailed analysis to understand what individuals might think and what that means in a given context.
Empirical Discourse Analysis	Empirical discourse analysis is the microanalysis and macroanalysis of the way in which language or texts construct social practices by looking at broad themes, the function of language and the study of patterns.	This analysis can be conducted on conversational material to analyse what individuals say and what the meanings of this might be.
Critical Discourse Analysis	Critical discourse analysis considers the macroanalysis of how discourse is used to construct the things that individuals and institutions think and speak.	This analysis is used to identify why something is the way that it is and any relationships that might be prevalent and as such can be applied to analyse and construct arguments to rethink why something is done in a particular way and present opportunities for improvement.

Interview data analysis within this investigation was therefore conducted using critical discourse analysis as the analysis and understanding of procedures and common practice were vital to answering the proposed research questions, whilst considering both the textual and contextual strategies outlined by Carvalho (2008). Dornan (2014) also identified that critical discourse analysis can be used when investigating how discourse affects and

represents social phenomena such as power and status and this would be vital to this investigation.

3.9) Research Ethics

A contemporary understanding of ethics was first formed after the end of World War 2 to ensure that future research protected vulnerable individuals and their role as participants in a research process (Rhodes, 2003). Ethical guidelines are proposed in both research (Greaney et al, 2013) and by governing bodies (UK Public General Acts, 2018 and European Parliament, 2016). Research that is conducted considering ethical behaviour is proposed to help protect individuals, communities and environments and offers the potential to increase the sum of good in the world (Israel and Hay, 2006; p.2). Pimple (2002) proposed that research ethics were required to answer three questions;

- Is research data true or is the science conducted accurate?
- Is research data fair and are authorship, plagiarism and informed consent considered?
- And is research data wise or will publication of this research better the human condition?

Ethical considerations were made in this investigation that considered fundamental ethical standpoints and the University of the West of England ethical guidance. This included the creation of research method specific participant information sheets, consent forms and research participant privacy notices (see appendices 1-4) that informed participants of the aims of the research and how their data may be used, and in turn giving them an opportunity to provide their written informed consent to participate. Participants were informed that they were able to withdraw their data for up to three months from the date of collection, at which point all data would be truly anonymised. Data was collected using a participant denominator rather than any identifying information (starting at P001 onwards) to ensure that if data were unintentionally released there would be no means of tracing this information back to an individual. Where it was not strictly required, identifying information such as participant name and age was not recorded at all. Finally, all quotes taken from interviews were also discussed carefully in documentation to ensure that there is no chance of participants, their fields of expertise or their teams being identified through them.

3.10) Overview of Main Study

Once the proposed methodology and methods had been identified, the main study could begin within the CSO. This section will detail the methodological process undertaken within the CSO, and the proposed aims and outcomes at each stage, with relation to the research questions identified through the analysis of existing literature. Figure 30 summarises the proposed timeframe of the implementations conducted against the timeframe for this investigation.

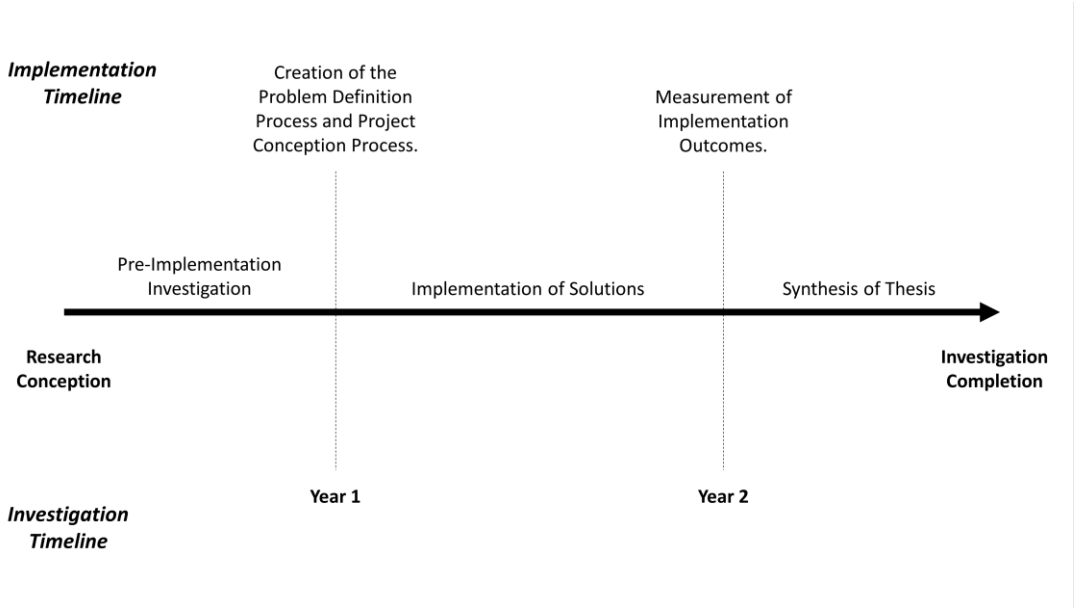

Figure 30 - Implementation Timeline Against Investigation Timeline

3.10.1) Pre-Implementation Investigation

The initial research methods undertaken were conducted with the aim of understanding what the strengths and weaknesses were within the CSD and the perceptions towards the implementation of DT and SE as possible solutions. This also encompassed initial insights into how these implementations might be structured and where they could be deployed for maximum effect. The research questions considered were;

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

It is important to reiterate that analysis of the critical literature review identified that the attributes to implementation from literature were predominantly derived from research methods involving perspective or failure-based learning data. Therefore, the steps proposed within section 3.10 regarding the attributes to implementation were not considered to be novel or unusual when compared to literature as they also considered perspective or failure-based learning data.

3.10.1.1) Preliminary Investigation

To answer the research question **1B) 'What are the attributes affecting the implementation of DT and SE in an LEO?'**, this investigation must first determine what constitutes an attribute. In this research, an attribute directly or indirectly affects the success or way in which DT and SE may be implemented in an LEO. Literature has already identified that there are a number of attributes to implementation present in the implementation of DT or SE as standalone processes (section 2.7) and this investigation aims to develop this further by considering the implementation of DT and SE as a merged process. For ease of readability, the attributes to implementation are kept consistent with those identified in section 2.7 but a comparison of these codes is presented in Appendix 11.

A total of 17 participants were interviewed using a semi-structured interview method in order to understand their perceptions. To identify the divisional attributes to implementation; an inductive thematic analysis was conducted using the interview transcriptions that had been collected. Each statement, or part statement in some cases, was considered contextually to identify a number of more abstracted themes; which were abstracted again based on identified commonality between them. These abstracted statements were then categorised into divisional strengths, divisional weaknesses and divisional attributes to implementation for further analysis. Data from the divisional strengths and divisional weaknesses categories were analysed again to understand the context surrounding implementing DT and SE in the CSD and to support the generation of later solutions. The divisional attributes to implementation dataset was also analysed further, but with the intent on defining what each of the abstracted terms or phrases meant. Since data had been collated from every field within the CSD, this meant that points related to communication, for example, could refer to internal communication, software communication, documentation, management driven communication, external customer communication and others but this would not be known without further definition. The emphasis on an inductive process for this research method was conducted to prevent confirmation bias.

3.10.1.2) Data Validation

Once the initial semi-structured interviews had been conducted, it was key to triangulate this against already existing literature in the field to identify whether the results found were representative of other LEOs. This is an example of a process called pattern matching (Yin, 2014) and is a research tool used to enhance the overall credibility and trustworthiness of the research (Cope, 2014). Therefore, a comprehensive literature review was conducted into

previous case studies, in particular to identify attributes that would affect the implementation of DT and SE in an LEO. Validation could then be conducted between the attributes found in literature and the points raised in the interview coding conducted previously. Comparison is especially key in understanding the similarities and differences between the two sets of data. Attributes raised in interview data that has been found to be similar to literature can be considered to be validated sufficiently as being representative of other LEOs whereas attributes raised in interview data that are dissimilar need to be questioned and the differences investigated further to identify if this could be due to case study specific phenomenon.

3.10.1.3) Rank Based Questionnaire

As raised previously, since the interviews conducted had been limited to 30 minutes in length, it may have presented the issue that participants had not raised all of the points that they had wanted during the time period allotted. Therefore, a questionnaire was conducted that aimed to rank each of these identified attributes so that a more thorough understanding of the organisation's needs could be established. If a point overall is ranked highly, then this would imply that this is something that is important to a significant number of personnel within the division. Snowball sampling was used in this instance as by this time the primary researcher had established strong working relationships with the division's technical managers and project managers, meaning that this sampling technique would likely ensure that the questionnaire would reach all members of the division through these contacts. The questionnaire itself used the software Qualtrics XM, a research-based software that focuses on the design and development of accessible questionnaires and had a total of ten questions (See appendix A). Importantly, the themes generated were represented as statements for improved clarity and to ensure that participants were able to categorise accurately.

The suitability of these statements and the questionnaire overall was tested with a focus group of four people. These participants were asked to take the questionnaire and be a part of a follow up focus group to discuss any issues in clarity and any concerns around the questionnaire's structure. Once this had been completed, the data collected to this point was removed and the questionnaire was released to the division. After two weeks, a reminder communication was sent to all divisional employees asking for their participation in the questionnaire. The questionnaire was considered completed four weeks from its initial dissemination. A total of 17 participants completed the questionnaire.

The initial questions in the questionnaire focussed on gaining ethical approval and demographic data; and included field of expertise and tenure with the company. Subsequent questions asked participants to rank themes highlighted from the interview series based off a number of criteria, meaning that the data collected from this questionnaire was organised by rank based on the average values that were obtained in the datasets. Standard deviation values were also obtained to identify whether there was consensus on particular themes and allow for further investigation. The last question in the questionnaire asked participants to leave their email if they were happy to be contacted about their responses and interviewed on how they would contextualise each attribute to implementation. Forty percent of the questionnaire population did this, and follow-up interviews were planned accordingly.

3.10.1.4) Questionnaire Follow Up Interview Series

Of the total number of participants that left their contact information at the end of the questionnaire, 71% (5 participants) went on to participate in follow up interviews. These participants were spread across the divisions fields of expertise and included at least one participant from engineering design, management, project management, sales and software.

Data from these interviews was analysed using a similar process to the initial interview series as the data collected is a theoretical extension of that body of work. However, in this case new themes were not formed from the codes generated as the interviews conducted had focussed exclusively on the themes that had been identified previously. Therefore, the data gathered here was used to strengthen the contextual understanding of each theme and support the future implementations.

3.10.1.5) Quantifying Cost of Scope Change

Early attempts to characterise the CSO highlighted that projects within the CSD frequently experienced large increases in time to market due to non-adherence to divisional processes. . Therefore, a mixed methods investigation was carried out using the division's internal accounting software, project management documentation and semi-structured interviews with key project personnel to identify whether this concern was supported by project data. Numerical data was collected from all available projects recorded in the CSD's accounting software over near a decade (between divisional conception in April 2011 and October 2020) and qualitative data was used to determine the cause of any discrepancy with particular attention being drawn to considerations of process quality (section 2.4.1). This would both; analyse and ascertain whether the concerns of individuals within the team were correct, and help characterise the organisational culture that was present within the CSD.

3.10.2) Co-Creation and Implementation

One of the outcomes from the interview series conducted highlighted that previous attempts to implement new design processes were often met with significant challenges, especially when they were attempting to replace the main company process instead of resolving what were believed to be the main divisional concerns. This was especially true of SE where attempts to implement SE as a replacement process to the main organisational process were being conducted up to three months before the beginning of this research work. This attempt at implementation, alongside the other two attempts to make process change at this scale, had unfortunately failed to find long term traction with the division due to a number of different perceptions; these are outlined in section 3.12 and are discussed in detail in later chapters. Therefore, instead of aiming to introduce DT and SE as a replacement divisional process, DT and SE was proposed to be tailored to combat the divisional concerns raised through the aforementioned research methods.

Due to the consideration of the research using co-creation and the potential deviation from the INCOSE 15288 SE standard (which outlines best practice for SE in application) and best practice outlined in literature for DT processes, research was conducted into the key, fundamental elements of each process to ensure that the solutions created were based on DT and SE principles (section 3.12). To stress this point, this research does not ignore previous standards, points of best practice, methods or structures to each process but instead aims to take a more holistic and flexible approach to the merging of these two processes in combatting specific design process issues in the case study.

The initial co-creation and solution generation change management approach considered was proposed by Lewin (1947) and Burnes (2017), where stakeholder analysis was conducted, stakeholders were identified and consulted on the change proposed and open communication techniques were used to keep affected parties involved. Where this did not successfully implement change, approaches by Bass (1985) and Kotter (1996), and the Lean Six Sigma DMAIC framework (Uluskan, 2016) were considered in order to implement change. In these cases participants were framed as resistors to change rather than contributors to a solution, meaning that the primary researcher had to place more of an emphasis on managing stakeholders and their expectations. The specific use of these change management approaches is discussed alongside each of the solutions created in section 4.2.

3.10.3) Education within Change

Literature has already shown that the education of new process is vital to its successful implementation. This includes the careful presentation of material so that stakeholders can see its value (Hare, 2018), that a lack of knowledge can lead to project failure (Schmidt et al, 2011) and the value of education in helping overcome resistance to change (Valentim, Silva and Conte, 2017). In this investigation, educational materials were created to educate participants within the CSD about the chosen aspects of DT and SE in generated solutions and the value of change management. A total of 26 workshops of 30 minutes to one hour in length were created with the aim to target specific groups that would need to adopt aspects of the proposed solutions in order for implementation to be successful, based on the pluralist culture identified in the preliminary interview series (section 4.1.1 and defined in section 2.5.2). Another six workshops of ten minutes in length were created to be implemented within team's morning meetings, as this was a further identified opportunity from the preliminary interview series.

3.10.4) Divisional Comparison Interview Series

Due to the use of the single case study methodology a comparison data set was generated using two other divisions within the CSO to present a discussion on the applicability of the work conducted to other organisations and cases. Comparison division one was focussed on generating relatively simple products but had complexity in the volume of production that was required for each one. Comparison division two on the other hand had similarly complex products as the CSD but had been established in its field for a significantly longer period of time and the hero culture present had a much greater reported knowledge base of market expectations. These divisions had not previously used DT or SE methods within their design activities.

A total of six participants were taken from each division, ensuring to get representation from at least one individual from engineering design, software design, management and the relevant customer facing sales role as findings from the previous interview series had shown that there was a dichotomy expressed between more senior and less senior organisational roles. Interviews lasted 30 minutes and the data gathered was analysed using thematic analysis, with a particular focus on extracting themes that highlighted perceptions to the positive or negative applicability of DT and SE within their division.

3.10.5) Outcomes Investigation

The final interview series undertaken aimed to measure the overall success of the solutions that had been implemented within the CSD and understand the experiences that participating individuals had. A total of 17% (21 participants) of the population of the division participated in this interview series and emphasis was again placed on getting representation from engineering design, management, project management, sales and software. These interviews were 30 minutes in length.

Data from this interview series was analysed using the same thematic analysis process as discussed previously and focussed on the identification of themes that could help explain the perceptions to why a particular solution had or had not been successful. Data analysis also focussed on identifying where partial or failed implementations could have been improved and where future work should be conducted to develop further understanding of the research questions proposed.

3.10.6) Influences of Action Research

As highlighted in section 3.7, when considering the research strategy, this investigation utilised a participatory action research strategy to enable the investigation. This choice of strategy led to a number of influences that affected the methodology and findings of this investigation. These are briefly highlighted in this section.

First, due to external factors such as the COVID19 pandemic and UK furlough period, it was very difficult to embed the primary researcher within the CSO as individuals were temporarily not working within one location and the CSO had recently shifted to virtual working for the first time. Because this was sustained for a long period of time, the primary researcher was always perceived to be external to the CSO (as is reflected in the interview series findings) which meant that participants were more open and honest with their responses but did not perceive the primary researcher as working within the CSO. In order to mitigate this, the primary researcher aimed to be onsite as much as practicable once the UK furlough period had ended and COVID19 pandemic had subsided.

Next, the primary researcher likely had an impact on the phenomenon observed, especially when asking participants for their thoughts on things that might support or block successful implementations or when asking about where implementations might best be placed, as this implies that aspects of the CSO can be categorised as either positive or negative. To mitigate the impacts of this on the findings of this research, the primary researcher made efforts to

be aware of the questions that were being asked to participants and to not intentionally frame conversations as either entirely positive or negative until the participant refers to it.

Finally, participatory action research relies on the involvement of willing participants and at times, such as the COVID19 pandemic and UK furlough period, it was very difficult to find willing participants due to their other working commitments or temporary furlough from the CSO. To minimise the impacts of this on the findings of this investigation, activities like the validation with literature and quantification of process quality were planned for period of time where participant engagement was likely to be limited, where this could be planned in advance.

3.11) Research Quality

The consideration of research quality is essential to enhance the overall credibility and repeatability of an investigation's outcomes, particularly where qualitative data is collected (Cope, 2014). Lincoln and Guba (1985) proposed that the criteria of research quality can be considered as credibility, dependability, confirmability and transferability and this was further built upon with authenticity in 1994 (Lincoln and Guba, 1994). The following section will detail the understanding of each of these categories from literature and propose considerations that were taken into account as a part of this investigation. Following this, 3.11.6 will detail a number of other methods presented in literature that can be used to enhance credibility and trustworthiness within a research context.

3.11.1) Research Credibility

Credibility refers to the truth of the data or participants views and the accuracy of the interpretations that are made by the researcher thereafter (Polit and Beck, 2012). To support this, literature proposed that insights should be verified with research participants after they have been collected to assess their accuracy before they are applied to the research questions being considered; this validation method proposed is referred to as member checking. Sandelowski (1986) proposed that a qualitative study is considered to be credible if the descriptions of human experience are immediately recognised by individuals that share the same experiences. This proposal was supported in this research due to the selection of a single case study methodology whereby the primary researcher was engaged with a particular population consistently through the investigation and thus information could be presented back to participants to validate whether the conclusions drawn accurately represent the data collected.

3.11.2) Research Dependability

Dependability refers to the consistency of data over similar conditions (Polit and Beck, 2012; Tobin and Begley, 2004), and is considered to be achieved if another researcher concurs with the suitability of decision steps taken at each stage of the research process. This is further detailed by Koch (2006) who suggests that a study could be considered dependable if the findings are replicated with similar participants, in similar conditions and using the same research process. Opportunities were present within literature, such as Carlgren, Elmquist and Rauth (2016A), to explore the decision-making process that other researchers presented in their similar published work and thus this research could be constructed to follow similar decisions made by other researchers. Finally, a journal was kept during the research process that detailed the decision steps taken by the researcher so that they could be accurately assessed in the final thesis; extracts are presented in appendices 9 and 10.

3.11.3) Research Confirmability

Confirmability represents the researcher's ability to demonstrate that the data represents the participant's responses and not the researcher's biases or viewpoints. (Polit and Beck, 2012). Considering this, methodological literature presented techniques to improve the confirmability of research. For instance, when reporting qualitative research, confirmability can be expressed by providing quotes from participants that directly reflect on the emerging themes identified in data analysis. This can also be demonstrated by describing how conclusions and interpretations were established and putting extra emphasis that the conclusions found have been derived directly from the data collected. In this research, anonymised quotes will be presented alongside the data analysis in the findings chapter (4) and, where applicable, the derivation of conclusions will be shown to the reader.

3.11.4) Research Transferability

Transferability refers to the applicability of the findings to other settings or groups (Polit and Beck, 2012 and Houghton et al, 2013) which can be achieved within qualitative studies if the results found have meaning to individuals not involved in the study and readers can associate the results found with their own experiences. To support this, researchers need to be able to provide sufficient information with regards to the participants, samples and research context the investigation has been conducted within to enable the readers of the investigation to assess the transferability of the findings. However, Sandelowski (1986) raised that this is only really relevant if the aims of the research were initially intended to be generalised to a larger population, and thus can be irrelevant in some cases. In the case of

this research, transferability was considered within the contextual restrictions of the CSO and the research population that was present therein as these restrictions would have significant implications on the findings of the research conducted. Therefore, by presenting all of the key characteristics of this case study to the reader, this will then provide an understanding of the overall transferability to other cases.

3.11.5) Research Authenticity

The concept of research authenticity refers to the extent to which the researcher expresses the feelings and emotions of the participants experiences in a faithful manner (Polit and Beck, 2012). To achieve this, readers should be presented with a range of quotes made by participants during data collection that can aid in the understanding of the experiences that have been found. Similarly to 3.11.3, quotes will be provided where applicable that express the range of thoughts that participants have towards topics of interest.

3.11.6) Further Enhancing Credibility and Trustworthiness

Cope (2014) proposed that the use of triangulation, where multiple methods of data collection are used to draw conclusions, is effective in improving the overall research quality due to the minimisation of bias or error. From this understanding, where possible other methods of data collection within the research have been conducted, or comparison is drawn between the primary data identified in this investigation and literature, to ensure that a suitable level of triangulation has been conducted.

3.12) Project Scope

The CSO for this investigation is a FTSE 250 LEO with over 4000 staff, has locations situated globally and an annual revenue of over £500 million in 2020. Therefore, this proposes the argument that the CSO is a suitable representative of an LEO in the case of this investigation. For the anonymity of the organisation, specific company information has been redacted from the findings and methodology sections of this research.

The pre-implementation investigation (section 3.10.2) identified that the implementation of DT and SE as a merged design process to replace the existing major design process was not possible (section 4.1). Therefore, change management solutions were created that utilised and considered the core components of DT and SE identified in literature, and presented again in table 10 for succinctness, so that the solutions created were conclusively based in DT and SE. The solutions created in this investigation should meet all of the core elements in table 10 to definitively be DT and SE solutions.

Table 10 - Comparing the Core Values of DT and SE

Core Elements of SE (Micaelli et al, 2013)	Core Elements of DT (Carlgren, Elmquist and Rauth 2016A)
Abstraction – requirements are created to generate an understanding of system rather than solution.	**User Focus –** the development of a solution always has the end user in mind.
Decomposability – systems are composed of many smaller elements.	**Visualisation –** or more accurately the visual representation of concepts in designs.
Pluralism – the system can be designed in many different ways and structure should be created that allows this knowledge transfer.	**Problem Framing –** Identifying problem and solution spaces and acting on them.
Alignment – SE is for the product and for the overall design process.	**Diversity –** collaboration of diverse teams in the design process.
Incremental Improvement – learning from mistakes is key.	**Experimentation –** the bias towards testing and trying things out in an iterative fashion.

A further comparison is drawn when mapping SE processes, through the use of the System Development Lifecycle model (SDLC), and DT processes, through the Stanford Design Schools depiction of DT (Darrin and Devereux, 2017). This comparison was utilised to develop an applied understanding of the uses of DT and SE where a complete design process was not possible. This direct comparison of process is faithfully re-created in table 11 (Darrin and Devereux, 2017).

Table 11 - Mapping DT and SE Processes (Darrin and Devereux, 2017; p.3)
Used with permission of the Institute of Electrical and Electronic Engineers

Phases of SDLC	Traditional SDLC Objectives	DT Principles
Understand the Need	Study user needs and objectives. Ensure there is a valid need. Assess if there is a viable approach. Document initial needs or capabilities, and operational requirements.	Empathise; work to fully understand the experience of the user, through observation, interaction and immersion in their experiences. Define; Process and synthesize the findings from your empathy work; form a user point of view.
Explore Concepts	Examine multiple alternatives; identify at least one that is feasible. Develop functional and performance requirements.	Ideate; Explore and generate a wide variety of diverse possible solutions.
Define Selected Concepts	Down select to a preferred solution. Develop conceptual design. Critical prototyping. Identify risks. Establish Functional Baseline.	Prototype; Transform your ideas into a physical form – experience and interact with them and, in the process, learn and develop more empathy.
Preliminary Design	Retire critical risks. Complete preliminary design. Hold Product Design Review (PDR)	Test; Try out high resolution products and use observations and feedback, refine prototypes, learn more about the user, and refine your original point of view.
Detailed Design	Complete detailed design. Hold Critical Design Review (CDR). Establish physical baseline. Document everything.	
Integration and Test	Complete the detailed design. Hold CDR. Establish As-Built baseline. Document everything.	
Production, Sustainment, Disposal	Establish production baseline. Document everything.	

The consideration of these core elements of DT and SE has two uses in this investigation. First, comparisons between created solutions to this series of core elements of DT and SE can be evaluated in chapter 5 to show that the solutions created are DT and SE solutions. Furthermore, if the CSD demonstrates each of the core elements of DT and SE proposed, then the CSD can be proposed to have adopted DT and SE.

At the conception of this investigation projects within the CSD had an estimated time to market of a number of years which meant that there was very little opportunity for project outcomes to be measured within this research. Instead opportunities were identified in smaller projects, and as outputs to implemented solutions rather than entire projects, to identify the value of DT and SE within the CSD.

3.13) Self Reflection

Polit and Beck (2012) propose that reflexivity is another issue to consider when discussing research quality; defined in this instance as the awareness that a researcher has towards their values, background and previous experiences related to an investigation's research questions and how these could affect the research process and its eventual outcomes. This is proposed to be managed through the researcher's self-awareness of their own ontology and epistemology and the maintenance of a reflective journal that details the thoughts and feelings from each decision point to identify subjectivity. This is something that therefore was conducted alongside this investigation. This proposed journaling technique also provides an audit trail as to the researcher's decisions and assumptions at any point in the research process.

The primary researcher's selection of ontology and epistemology reflects on their own beliefs as to the constitution of an organisation; there is an inherent objective aspect (such as assets, resources and locations) and an inherent subjective aspect (such as the perception of the organisation from its employees or customers) (Cope, 2014). This fundamentally changed the selection of methodology utilised as this perspective formed the framework for the research undertaken. If the ontological and epistemological standpoints favoured a more objective approach, the use of qualitative and interview data would not have been appropriate to answer the research questions proposed. Similarly if they favoured a more subjective approach, then the gathering of quantitative organisational data may not have been appropriate. Readers that engage with this work through different standpoints are asked to consider the applicability of the findings generated toward their own goals.

When this research was initially conceived, the primary researcher had little experience in applying design processes within organisations and very little experience working in a change management environment. As the abilities and knowledge of the primary researcher improved over the course of this research, through structured training, self-development plans, supervision and teaching, this highlighted key limitations in the change management approach undertaken to that point and opportunities to adapt the initially proposed

methodology to better apply within the CSO. For example, the initial approach to enacting change considered Lewin (1947) and Burnes (2017) proposition closely and aimed to generate an open discussion regarding planned change and its implications within the CSD. Later approaches considered Bass (1985) and Kotter's (1996) change management framework, or the Lean Six Sigma DMAIC (Uluskan, 2016). This, and similar other changes in methodology, were directly affected by the development of the primary researcher as an agent of change throughout this research.

3.14) Implications of External Influences

Six months into the conception of this investigation, a number of external factors became significant that may have impacted the findings of the methodology selected. This included; the introduction of COVID19, the UK furlough period and a divisional restructure within the CSD. Arguments are presented within the Discussions chapter of the thesis as to what these impacts may have been and how this influenced the overall generalisability and applicability of this research to other LEOs. The direct impact of this is presented in green in the timeline shown, figure 31.

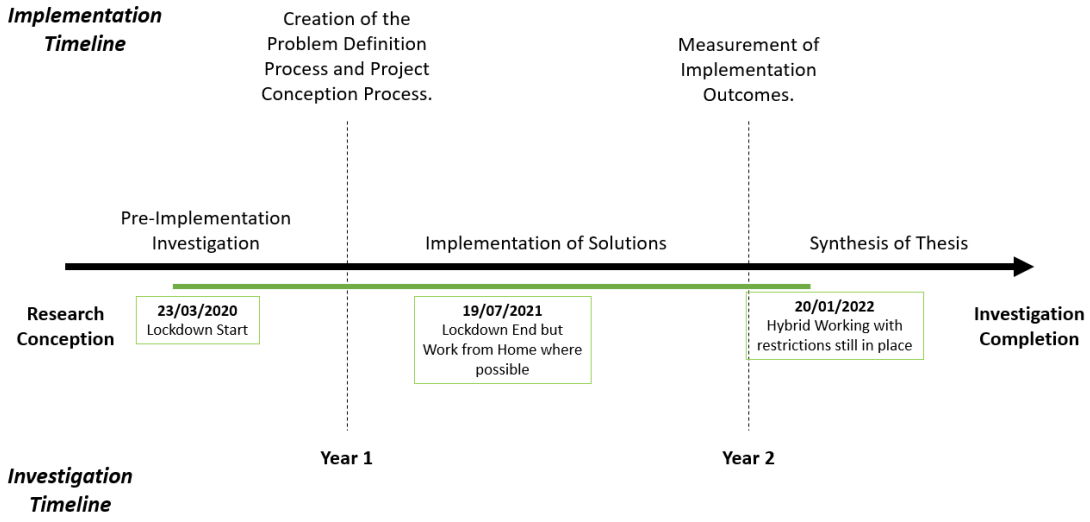

Figure 31 – Identifying the Impacts of External Influences on This Investigation

Importantly, all research methods conducted in this investigation were conducted remotely due to the changing restrictions that were in place.

3.15) Summary

Chapter 3 presented the methodology that was utilised in this investigation, and in the answering of the research questions;

1) **How can Design Thinking (DT) and Systems Engineering (SE) be combined and implemented in a Large Engineering Organisation (LEO)?**

Which can be split into;

1A) What are the optimal locations for DT and SE to be implemented in an LEO?

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

1C) What procedures support the implementation of DT and SE within an LEO?

1D) Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?

The overarching methodological choices can be summarised as the following;

- Research Philosophy: Critical Realism
- Research Approach: Inductive
- Research Purpose: Exploratory
- Research Type: Mixed Methods
- Research Strategy: Participatory Action Research Case Study
- Data Collection Techniques: Interviews, Questionnaires and Failure-Based Learning
- Data Analysis: Thematic Coding

Furthermore, this chapter also placed an emphasis on understanding research ethics and any regulations regarding the collection and manipulation of personal data. The ethical considerations identified led to several ethics focussed documents, a sample of which that are presented in appendices 1-4.

Section 3.10 outlined the main study of this investigation. Data analysis was proposed to be considered through thematic coding, with a particular emphasis on critical discourse analysis, as the ability to generate an understanding of a participant's perspective is critical in identifying; the optimal locations to implementation, attributes to implementation, procedures that support the implementation and outcomes that evidence the value of implementation of DT and SE within an LEO. Sections 3.10.2 through to 3.10.6 propose the methodological structure of this investigation and outline where specific research activities can aid in answering each research question. This is mapped in figure 32.

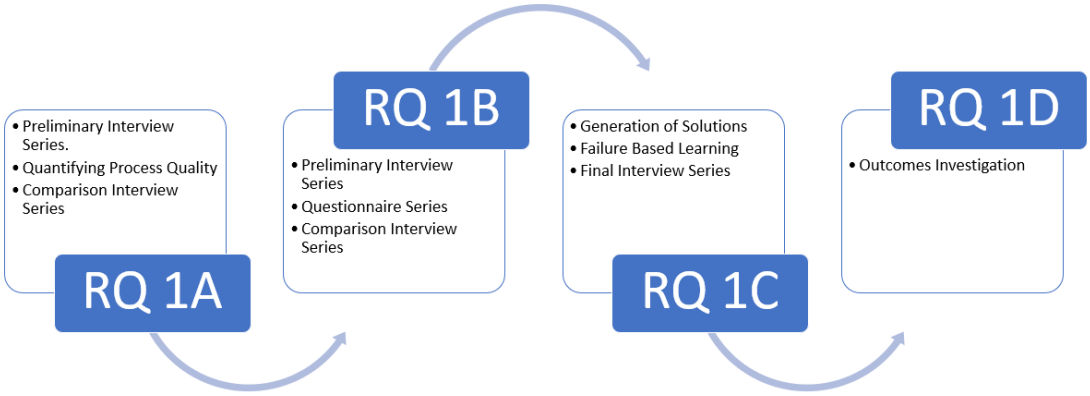

Figure 32 - Mapping Research Questions against Thesis Chapters

Section 3.11 considered best practise in literature regarding research quality and identified credibility, dependability, conformability, transferability and authenticity as vital to establishing quality research in this investigation. Next, section 3.12 considered this investigation's scope, due to its work within a CSD in industry. Due to the restrictions identified, the core elements of DT and SE were defined in literature and comparisons were drawn to the system development lifecycle process in order to identify where DT and SE could be implemented. These restrictions also identified that as project within the CSD had a proposed length of time of a number of years, it was unlikely that measurable outcomes could be achieved at project conclusion and so considerations must be made for alternative assessments. This chapter also included a brief self-reflection that identified the primary researcher as a relatively inexperienced agent of change and proposed that this may have hindered this investigation during its conception and in early change management activities. Finally, chapter 3 included a discourse on the implications of external influences that were present during this investigation, which included collecting all research data remotely due to the COVID19 pandemic.

4.0) Findings

This chapter aims to explain the findings of the methodology previously discussed in chapter 3 and answer the research questions initially proposed in chapter 1. First the pre-implementation findings are outlined to build an understanding of the CSD and present perceptions on the CSD's attributes to implementation. Following this the co-created solutions are considered and solution failures are discussed. The next section outlines the findings of methods post-implementation that were undertaken to assess the suitability of each solution. This chapter concludes by outlining a comparison taken with two other internal divisions to allow the reader to assess the generalisability of this work to another organisation or case. To reiterate, the primary research question is;

1) **How can Design Thinking (DT) and Systems Engineering (SE) be combined and implemented in a Large Engineering Organisation (LEO)?**

Which can be split into;

1A) What are the optimal locations for DT and SE to be implemented in an LEO?

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

1C) What procedures support the implementation of DT and SE within an LEO?

1D) Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?

The research question 1Aregarding optimal locations for implementation aim to be answered in the preliminary interview series (4.1.1), quantifying process quality (4.1.3) and the comparison interview series conducted in 4.6. Considering the research question 1B identifying the attributes that affect implementation, this is answered in the preliminary interview series (4.1.1), the questionnaire series (4.1.4) and the comparison interview series (4.6). The research question 1C considering the procedures that support the implementation of DT and SE is considered in the methodologies undertaken to generate solutions (4.2), in the failures that were found in process implementation (4.4) and in the final interview series (4.5.3). Finally, when considering the outcomes that can prove the value of DT and SE in implementation, the reader should be directed to all the post implementation methods presented (4.5).

This chapter follows the structure outlined in figure 33.

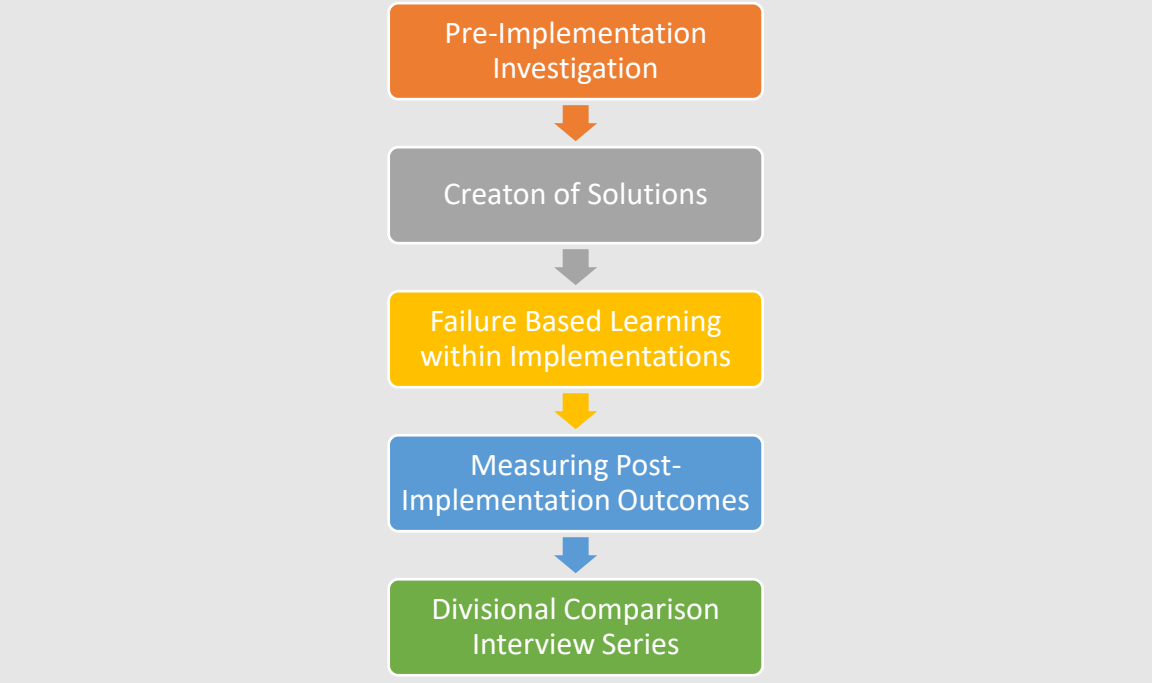

Figure 33 - Findings Chapter Overview

4.1) Pre-Implementation Investigation

This section will consider all of the research methods conducted prior to the development and attempted implementation of DT and SE within an LEO. Where applicable, comparisons have been conducted to literature and aspects of the investigation completed post this pre-implementation stage.

4.1.1) Preliminary Interview Series

To reiterate section 3.10.1.1, interviews were conducted with members of the CSD that were 30 minutes in length and primarily focussed on asking questions that aimed to explore their perceptions to divisional activities and attitudes. The semi-structured interview plan is available to view in appendix 6. As discussed in the methodology, semi structured interviews were selected so that points of interest could be investigated in more depth to generate a stronger understanding of the case study conditions. Transcription and coding were completed before the next interview were conducted to identify theoretical saturation of data in the analysis process. A total of 17 participants were interviewed using a semi structured interview method, with a sample taken across engineering design, project management, representative customer facing roles and across differing levels of seniority.

Thematic analysis presented the attributes in table 12, where themes have been recorded as a percentage of the number of times mentioned in interviews undertaken, i.e. if the value is 100% then a theme was mentioned in every interview, 50% would mean it was mentioned

in half of the interviews undertaken and so on. Therefore table 12 is not an indication of how well or how poorly each theme is perceived to be. It is also important to note that the topic of conversation in each interview was different and questions were adapted to suit each participant's level of experience with the content at hand.

Table 12 – Attributes to Implementation Raised in Interview

Theme	Percentage of Interviews Mentioned	Definition and Scope
Communication	100	How the division communicates information both internally and externally, to include communication processes, techniques and habits.
Organisational Culture	100	The influence of organisational culture on the processes and outcomes of projects, to include effects due to the beliefs and behaviours of its employees.
Established Process	100	The current design processes for all aspects of the division, to include the full design lifecycle from requirements generation to product development and manufacture.
Organisational Structure/Hierarchy	83	The influence of the organisational structure and hierarchy on divisional outcomes, to include the existing power dynamics and structure of the division.
Resistance to Change	75	Resistance to the implementation of new processes, tools and techniques, to include tangible and intangible resistances that could not be otherwise defined during analysis.
Individual Mindsets and Skillsets	67	The influence of individuality and diversity between and within teams in the division, to include individual's capabilities and their mindsets
Project and Business Metrics	58	The division's ability to measure the outputs that have been produced accurately, to include all metrics and KPIs
Education Resources	25	The division's ability to learn new things and the processes that are in place to support this, to include how education material is created and utilised.
Implementing Innovation	25	The division's ability to develop innovative solutions and implement them
Remote Design	8	The division's ability to operate as a globally distributed organisation, to include all hybrid and remote working.

It should be noted that there is likely overlap between each of the attributes identified in the above table, especially when considering the attribute resistance to change against attributes like organisational culture or implementing innovation, where the concepts being compared are intangible and perceived differently by participants. The impact and significance of this is discussed in 5.1.

A discussion on the attributes identified is presented in the rest of section 4.1.1. The subsections that follow within 4.1.1 will aim to each outline one attribute to implementation and present the quotes taken from interview to support each suggested attribute.

4.1.1.1) Communication

The attribute communication can be defined as a combination of internal communication and external communication, with internal communication referring to information processing activities within the organisation and external communication referring to information processing activities between the organisation and other entities.

Perceptions towards internal communication and the perceived channels present with the CSD were negative. For instance, when asked about the communication of market need due to the size of the organisation one participant proposed that this was completed at a higher level but that this was not necessarily communicated.

> *"…from what I hear it sounds like salespeople and people kind of higher up do go out and engage with customers and get feedback from them, but I don't feel that it always necessarily filters down, like the information that might be good to the design teams." [PI002]*

This lack of internal communication would inhibit the implementation of both SE and DT due to the contradiction with the core elements of these processes outlined in section 3.12. SE would be inhibited due to the lack of a traceable communication channel that ensures that engineers are presented with accurate requirements whereas DT would be inhibited as there is a clear disconnect, or lack of user focus, between the individuals and teams that complete design activities and the end users themselves.

However, interviews highlighted that customer interaction within the division was limited in the majority of cases and explored the relationship between the CSD and its external customers.

"In my previous experiences there was very limited communication with customers and doing that customer research. Unless we were designing something for a particular point where that product would be designed for that purpose, to one customer application." [PI003]

Proposed reasons for this communication strategy included a lack of contacts within the targeted market, the reported business strategy to engage with customers that might not necessarily be considering the CSD technologies and the relative youth of the division. Furthermore, when talking about customer interactions there is a perception that points raised are taken at face value rather than using tools and techniques to investigate the meaning behind them in more depth.

"There's been too much of a feeling that we pre-empt what our customer base requires and don't necessarily dig deep enough into the true customer requirements to find out what it is that they really need." [PI005]

This perception is unsurprising as other presented interview data proposed that market research was not always conducted and thus there may not be a particular process or level of experience when conducting this analysis. This could be due to the value that is placed on customer requirements in the division as interview data also proposed that customer requirements are often not used in projects.

"…you don't really have any customer requirements [in projects] because there aren't any which means then that the evolution of the scope is purely from a technical background…" [PI003]

Another concern raised discussed a lack of communication leading to duplications of work across the division. This data point is a significant piece of contextual information as it presents the idea that bodies of work would be required to focus on internal communication to support the implementation of any process in its entirety.

"…Communication within teams isn't very good either… And there was one occasion when, there were three groups of people working on essentially the same problem, but completely separately and it's just that they didn't realise… So obviously teams don't communicate very well either." [PI011]

Given the scope of this research, this presents an opportunity to implement DT and SE techniques specifically to resolve this problem.

4.1.1.2) Organisational Culture

The attribute organisational culture can be characterised by any cultural aspect of the CSD that may influence the implementation of DT and SE within the CSD. Interviewees discussing organisational culture proposed that the individuals being affected by the change needed to understand the value of any proposed activities. Interview findings showed that this is especially true of smaller projects, projects that are perceived to have short timescales, or projects that incorporate additions or amendments to existing work as process is otherwise perceived to extend project timeframes.

> *"I could see it not being implemented on projects where you've got multiple individuals who don't see the value. And I can also see not being used on, like you say, some smaller projects where they've got very, very tight timescale as they almost know who the end user is and what their requirements are? I guess the other the other situation is if you've if you've already got a product, but you want to make an addition to that product, so you've noticed that you've got something that's gone wrong." [PI001]*

Furthermore, one interviewee proposed that for change management to be successful, with regards to SE specifically, that the entirety of a project team needs to be bought into the change process as necessary, not just see its value.

Interviewees also responded that there is a cultural drive to achieve innovative solutions to problems and that this drive to achieve technological innovation should come as a surprise to potential customers once they have been completed.

> *"We're more interested in producing a technology that no one's even heard of. And, you know, they call it disruptive innovation. So in order to be disruptive, you almost need the element of surprise." [PI001]*

Interviewees also reported the influences of more senior members of the organisation as being prevalent in the concept generation and development of new ideas but proposed that on occasion these are presented to project personnel too late in the design process to be able to be utilised effectively.

"But quite often [senior management] will come up with these ideas and they'll get implemented sort of too late in the process... Which is great, you know, if we've got the time to do that, but sometimes the timescales would suggest we haven't got time, we've just got to commit to this. Drive it to the market." [PI001]

This influence is especially interesting because this was presented as a cultural factor of the case study division, where participants themselves identified that this was something that occurred culturally aside from any chosen process or procedure that might be in place within the CSD.

The organisational culture present within the CSD favours processes and techniques that are shown to clearly move towards the creation of a final product. Interviewees proposed that this was especially important when considering the generation of hardware.

"We will always want to have some physical hardware and [senior management] want to see it and use that" [PI001]

This inclination proposed that activities that create material such as low fidelity prototyping could be shown to actively progress projects may be easily accepted by the division. However, interviewees proposed that although there was a cultural drive to "put material on desks [PI005]" this normally tended to be high fidelity prototyping and thus led to cost and time issues if this required changing later.

"Cheap prototyping. I don't feel that that happens. We go expensive straight away. And then maybe that becomes an issue because its costly." [PI011]

This was proposed to be due to the CSD's expectations of completing high fidelity prototyping to satisfy stakeholder needs. This may not be the case throughout the CSO however as one interviewee proposed that due to the nature of each division within the case study company and the products that are sold therein, there are discrepancies between each division's processes to accommodate for vastly different markets and product lines.

"I think different divisions, even though everyone follows the same process, different divisions have slightly different ways of doing things." [PI002]

This difference proposes that the implementation of solutions as a part of this body of research would not need to be considerate of other division's methods and processes when considering the CSD only, as these are likely to differ. This suggests that there is an opportunity internally to interview members of the team from other divisions to identify whether the solutions proposed may be generalisable to other cases and provide a discussion on the overall applicability of the work conducted to other organisations with differing product and service capabilities.

Interviewees proposed that the organisational culture present within the CSD impacts on every other activity that is completed as a part of a project. For instance, there is a cultural expectation that the customer does not know what it wants until it has been provided to them and this value impacts factors such as the structure of existing process and emphasis, or lack thereof on internal communication.

> *"I think from my experience we have the attitude that the customer doesn't know what it wants until we've provided it… I think the issue is that project evolve from an idea… and they are allowed to bubble under the surface for often actually years until, on their own with no project management and no scope, no engagement or very little engagement with marketing and then when it's perhaps in a place where they think it's good enough they give it to marketing. They sort of hand it over to them and say, this is what I can do, now go and find me a customer for it or go and find me a market that would want it." [PI003]*

This quote would therefore suggest that the understanding and consideration of the CSD's culture is critical to the success of any proposed implementation; if the organisational culture present does not accept the changes made these are likely to revert to previous procedures, if implementation is successful in the first place.

Another cultural phenomenon identified through interview was individual's perceptions to accountability.

> *"…the accountability is not there to say, okay if I spend three days doing that then that's going to impact my work by three days and then I really am late, and I absolutely cannot be late. There's just sort of the attitude of, oh I'll just tell them that it'll be three days late because I'm giving you a hand." [PI003]*

This cultural limitation therefore provides a possibility that change management activities could be difficult if an appropriate understanding of actions and deliverables is not agreed with key stakeholders and thus, accountability must be built into the change management process.

The CSD is also proposed to place an emphasis on the individuality of its staff and allow them to make decisions on whether they believe that new process implementation is valuable to their operations. This closely resembles the concept of a hero culture presented in section 2.5.1 and further provides evidence of figure 11 (page 38); which links senior management, organisational culture, process quality and the emphasis on heroes.

> *"I think one of the things is that there is a lot of agency and licensing given to engineers to deviate from the defined process. So the simple issuing of a process is very different to the commitment to following. Staying within the process, iterating the process and improving the process rather than to go "this doesn't work for me at this point in time so therefore I'm going to go and forget about all of that and just go and do my own thing". So I think understanding that and mitigating that to some degree if you're trying to introduce something that's dependant on people following process." [PI004]*

This emphasis also links back to a prior finding regarding organisational culture, that all individuals affected by change need to be convinced of the value of the activities or processes being implemented for this change to be successful. This could indicate that a number of different messages need to be conveyed to individuals in different roles so that value can be explicitly identified, and the chances of rejection minimised. In some cases, interviewees proposed that generated products were often not completed before they were released to customers.

> "I mean *we, fairly consciously, at board level made the decision with the [redacted] to ram it out of the door kinda before it was finished, well actually it was definitely before it was finished. We built four prototype [products] that were intended to be used at [redacted] for test purposes and two of those ended up in subsids and one of them ended up with a customer. And that therefore meant that there was a [redacted] lot of unfinished work to be done." [PI006]*

This quote was referred to as another cultural phenomena, where the cultural drive to complete projects and get products to market quickly was perceived to impact on the completion rate of design processes and projects as a whole. This point again raises the issue the stakeholders involved in the change management activities proposed within this research must perceive that there is no significant impact to the time to market of projects that adopt DT and SE techniques or else risk implementation failure.

Interviewees proposed that there is a cultural pressure that is applied to achieve short time to market and low cost in design that impacts the design of any product.

> "But we *have tight timescales on almost any project because we want to make money as fast as possible really." [PI008]*

Interestingly this pressure reflects on Bessant, Öberg & Trifilova (2014), section 2.8, who proposed that this is normal of large engineering organisations and that it is a symptom of organisational exploitation, or incremental innovation as opposed to transformational innovation. Ultimately this presents the possibility that implementation of any design process will have to require a measure of cultural change as all involved stakeholders would be asked to consider projects as a number of sequential design activities.

Interviewees proposed that one of the key difficulties with designing for an emerging market is that often customer-based requirements are liable to change as they realise that a particular functionality is possible or required.

> *"…were now six months in and we've just been given a whole list of requirements from our key customers saying that we won't buy any of these machines without any of these things in them, and these are things that we've not even considered." [PI005]*

However by placing and understanding and emphasis on user problems rather than user proposed solutions, there is an opportunity to create products and functionality that resolve user needs without this change needing to take place. In some cases, the changes made within projects can lead to different issues as proposed in the interview quote below.

> *"People are changing their mind about what they want and they can't stick to it, they even wrote down and signed up to what the thing should be and it's changed since then. We can't just make a decision and stick with it. And then there's time scales put on these things and people*

don't accept that when you change what it is the timescales have to move, which makes our life quite hard." [PI009]

This response suggests that there is a lack of, but a need for, a change management procedure and an understanding that changing the requirements being worked to impacts the design time and impacts the overall project time to market. Since the research conducted utilised change management it was likely that these cultural issues would become more apparent.

4.1.1.3) Established Process

The attribute traditional process is characterised by any points raised that consider the current processes or ways of doing things that are in the CSD and aims to discuss how these may assist or resist the implementation of DT and SE within the CSD. As raised previously the use of process, among other things, is heavily linked to the organisational culture that is present within the CSD. Therefore, where this has not been explored already, this relationship will be detailed and may reflect on similar ideas and concepts.

Interviewees proposed that the traditional process in place within the division is normally focussed more on the development of new technology rather than the development of a saleable product that is suitable for a particular market.

"We want to ensure that there's an end user, there is a good market foundation for the products before we go spending money on hardware. Conventionally, we've been able to do that with some smaller products at [the CSO]. But now that [the CSD is] going a lot bigger and it's this more complex, we want to ensure that once we've built that hardware, once we've invested that capital and cash into the projects, that we're going to be able to sell them." [PI001]

This point is in contrast to the proposition made regarding the implementation of DT and SE, where emphasis must be placed on the development of a product or service that resolves a particular customer or market need. Therefore, this aspect of traditional process should be considered to be one of the key attributes to the implementation of DT and SE in the CSD.

One of the key areas raised with regards to traditional process considers the generation and manipulation of requirements. In the CSD requirements were proposed to not be completed or to be completed unsuitably for a particular product or project.

> "The *way that [the CSO] has done requirements in the past is not particularly great. I don't know if you've seen the document but people just kind of fill in what they think that they know and what they think that should be in there. It's not necessarily what stakeholders have actually said." [PI002]*

This mentality towards requirements would present a considerable issue around the implementation of a requirements-based solution as current process would need to be overcome and perceptions to the concept of requirements changed to deliver positive value. Importantly, stakeholders would need to be educated about the reasoning behind generating requirements and presented with the tools and techniques to do this accurately if this were to be successful.

When queried, participants reported that traditional process in the CSD were reported to have very few requirements as the division places a value on technology drivers as opposed to market requirements.

> *"So the scope, the requirements, certainly you don't really have any customer requirements because there aren't any which means then that the evolution of the scope is purely from a technical background, and they don't see the value in following a documented or systems approach because it's all in their head anyway." [PI003]*

Arguably, this perception could stem from the reported perception that "the customer doesn't know what it wants until we've provided it," as this viewpoint would naturally place a low value on customer interactions and lead to few interactions occurring between the CSD and its market. Since DT and SE focus more on customer need, and the accurate understanding and communication of those needs throughout the design process, this characteristic would need to be overcome as a part of the implementation of solutions.

The concept of innovation is perceived to be important within the CSD and activities progress within projects with the aim of ensuring that project outcomes are innovative within a given market. However, interviewees propose that innovation often occurs too late in the design process and this drive leads to the accumulation of significant cost and time delays within projects as designs change and created hardware is modified or removed.

> *"But quite often [senior management] will come up with these ideas and they'll get implemented sort of too late in the process. So we always*

have to go backwards to implement that again… which is great, you know, if we've got the time to do that, but sometimes the timescales would suggest we haven't got time, we've just got to commit to this. Drive it to the market." [PI001]

These late design changes would therefore present another fundamental aspect of the division that would need to be considered in the generation of solutions and was one of the key points that led to the quantification of the case studies process quality in 4.1.3. This is proposed to again relate to an understanding of the core problem, as interviewees proposed that in some cases baseline requirements are not captured and this allows scope creep to develop as there is no generated specification on what cannot change or identification of core problem statements.

"I think if w*e want to hit timescales and try to reduce development costs, we need to ensure that we've got upfront captured documented baseline requirements that everyone's agreed on to avoid scope creep later on in the projects." [PI001]*

Therefore, according to this interview passage, by focussing on the accurate generation and documentation of the initial business case within the CSD, which itself would ideally be a combination of problem statements and requirements, this would mitigate costs associated with late changes in projects due to a drive to achieve innovation.

At project conception, interviewees reported that there is often a poor definition of scope and that this can lead to a poor understanding of how long something takes to complete in its entirety.

"I think we really poorly define how long a task is going to take because we haven't really thought about the scope, you probably hear this all the time." [PI003]

Definition of scope is another important factor that would affect the implementation DT and SE in a LEO as the ability to define project scope is essential to analysing and defining risk within SE activities and ensuring that project expectations are met.

4.1.1.4) Organisational Structure/Hierarchy

The attribute organisational structure and hierarchy refers to the divisional management of its own personnel and the influences that are present due to this management and the

presence of the power dynamics in the CSD. As mentioned previously in 4.1.1.2, there is a cultural drive to achieve and create models and hardware very early on in the design process and this is proposed to be driven explicitly by more senior members of the organisation.

> *"[Senior management] will always want to have some physical hardware." [PI001]*

The proposition that projects within the CSD want to develop hardware is important to identify when considering the later generation of solutions. For instance, incorporating the early development of hardware could assist in the implementation of a solution as it would align with the identified cultural value. Alternatively, if a generated solution does not incorporate the early generation of hardware, or actively proposes that the early generation of hardware is not possible, then the solution may not be easily accepted without an element of cultural change.

Interviewees reported that customer engagement is often done by sales individuals and more senior members of the organisation but information from this communication does not necessarily get communicated to design engineers.

> *"Sales people and people, kind of higher up, do go out and engage with customers and get feedback from them but I don't feel that it always necessarily filters down, like the information that might be good to the design teams" [PI002]*

However, since no real reasoning was given as to why this communication strategy was the case this could also be interpreted as another area of implementation; the communication of customer need amongst the rest of the division. This point was extended to the design process in general as interviewees proposed that "there is very little directive coming through the executive in relation to the design process" [PI004].

Another characteristic proposed by interviewees related to organisational structure and hierarchy is that there is no one whose responsibility is focussed entirely on the quality and effectiveness of process.

> *"We don't have anyone whose explicit board responsibility is the efficiency and the quality and the effectiveness of the tools that we use and I think maybe some of these arguments would be easier if there was*

someone who was concerned with that who had significant board responsibility." [PI006]

Therefore, the onus of process-based change would likely need to be on the researcher rather than any individual within the division and the effective management of stakeholders would be essential where there was no structure for this in place already.

When discussing organisational change, interviewees proposed that fundamentally change would be required to come from more senior management as this would be critical to the successful implementation of change.

"Getting [*redacted], [redacted] and [redacted] more bought into it all. Because I think certainly with [redacted] and [redacted] you would get the grumble, makes things slower. [redacted] I think ought to be more receptive but at least getting them to get it would be a huge step forward." [PI006]*

As participants proposed that senior management is involved in the day-to-day operations of the CSD, this change is proposed to be especially important.

"Obviously [senior management] have opinions on everything. The senior management is very involved in [the CSO]." [PI007]

Therefore, considerations must be made to acknowledge the influences of senior management as an attribute to change. Senior management were also perceived as being the key people to convince when conducting organisational change work as they would otherwise present a significant barrier to implementation.

"I would like the senior management to have this as a core aspect of what we need to do in our projects in order to save time. I think that it's the senior management that need to have their minds changed. I think that if you asked anyone on the ground about your work then they would be thrilled by the idea and they would implement it but it's always the first thing that gets shut down. We need to change the attitudes to it really." [PI008]

This involvement suggests that early research efforts should be focussed on understanding the needs and responsibilities of senior personnel and employing effective stakeholder management to incorporate messages that are compatible with these core beliefs.

Some interviewees went on to propose that there is no clear organisational structure within the division that explains the delegation of power within the division and this lack of clarity makes it difficult to enact change management projects.

> "But how *is that delegated, power down through the organisation. Who is responsible for software, hardware, firmware, electronics… I certainly don't have a remit to go and stand up in front of 30 people across the organisation and say this is the way it happens." [PI010]*

When considering prior points regarding the need to identify and convince relevant senior management of the value of an implementation, this lack of structure potentially would make the implementation of a process difficult as it may be difficult to identify who a relevant senior stakeholder may be. This would be especially true in the circumstances where there is an authority figure present for a particular field of expertise, but it is not necessarily clear who that individual may be with regards to the levels of seniority in the division.

Finally, organisational structure is mentioned to be especially disorganised when it comes to project teams where the onus is often placed on individuals to manage their own workload and present their own ideas on personal strategy.

> *"What you end up finding is that people take ownership and actually get it, but they're driving it from an individual strategy rather than from a company wide strategy. [PI012]*

This cultural emphasis on key individuals that complete particular activities is something that was also reflected and discussed about in the organisational culture section of this interview series (4.1.1.2) as interviewees expressed that the value was placed on people rather than process. This also reflects on section 2.5.1 and adds additional credence to the proposal that the CSD follows the proposal set out in figure 11 (page 38).

4.1.1.5) Resistance to Change

Resistance to change can be categorised as any attitude or influence present within the CSD that may manifest in a way to counter proposed change activities. In particular, this attribute also aims to consider previous change management through the perceptions of interviewees and understand what was done well and what would need to be changed in future to be successful. For example, when one participant was asked about successful previous change projects within the company, they replied that:

"I think for change to work … the whole of the project team needs to be bought into the process" [PI001]

This involvement should therefore be considered in any change management activities that are proposed within the CSD. Similarly, individuals proposed that "engineers want to see where some of these processes could make their life easier [PI010]" and that failing to do so would lead to a failed implementation.

Due to the cultural onus on individuals taking responsibility for their own tools, techniques and processes, interviewees reported that there may be difficulty in enabling stakeholders to adopt proposed DT and SE solutions in their entirety.

"I think that the first thing that might be an issue would be [the CSO's] culture. I think people, not everyone, but a lot of people can be quite set in their ways and when a process changes and it's been like that for a while, I think that some people struggle to adapt. So I feel like maybe if more steps were added in, some people might skip some of them maybe." [PI002]

This point is a clear example of the CSD's organisational pluralism (2.5.2) which means that resistance to change must also occur on an individual or small group level. In some cases this pluralism leads to other change management as individuals can drive their own change initiatives that differentiate from the division's processes and other activities that may be ongoing.

"…there are very few projects which do implement SE but over the last 18 months to two years is something that we felt that we had to do because of the complexity of the products and being able to bring all of those different technologies so that it works as a system as opposed to just one device." [PI001]

On the other hand, there is a similar onus on individuals to choose not to adopt process if they do not believe that this is something that is suitable for their own role. This reliance on individuals as opposed to process reflects back on the discussions presented in section 2.5.1 when considering the emphasis on heroes over process.

"There is a lot of agency and licensing given to engineers to deviate from the defined process. So the simple issuing of a process is very different to

the commitment to following. Staying within the process, iterating the process and improving the process rather than to go "this doesn't work for me at this point in time so therefore I'm going to go and forget about all of that and just go and do my own thing". [PI004]

Where interviewees had previous knowledge of DT and SE there were reported concerns around the resistance that may be found through preconceptions to each design process; the most notable of which being that there was a perception that the implementation of process would increase the overall time to market and still not remove the issues that were present in design.

"…predominantly the preconception that approaching things from a more systems or design thinking point of view will prolong the length of time that it will take us to get something into the marketplace… I think there is a preconception that there is diminishing return on investment for some of that upfront work. In other words, you could put huge amounts of effort in and still get to the marketplace and discover new things at that moment in time." [PI004]

Interviewees also proposed that to enact successful change projects, senior management need to not only be supportive of the proposed activities but also understand exactly what is asked for with regards to the commitment of resources.

"So there is a leadership element here in terms of senior management with senior management needing to understand what commitment is required to achieve the results from anything that you might propose." [PI004]

Change management activities therefore will be communicated clearly and the scope of any solutions proposed will be considered in depth before completing any work. Another issue that interviewees raised that could lead to the prevention of a solutions implementation was the argument that things have been the same for a long period of time and the organisational has been successful thus far.

"The first question that you get hit with is why are you doing something differently? You know, we've always done it like this and were a successful company that's been around for forty something years" [PI005]

This argument is an issue that would need to be directly combatted during the implementation of any solution generated in this research. With specific regards to SE, interviewees proposed that there are process-specific issues to consider as per the quote below.

> *"That's why it's difficult to implement, because you've got people doing things and there's no hardware to show for it, there's no test results, there's nothing from the systems development process to show for that work but its work that's been done to stop you from having to do work later on effectively. It'll stop you having to redo work and correct yourself and it ultimately costs you time and money that you don't have." [PI005]*

Therefore, the creation of solutions will need to ensure that each stage of the process leads to clear value adding materials that can be disseminated to other members of the organisation. Further quotes from interview suggest that this particular issue is linked to senior management as proposed in section 4.1.1.4.

> *"…senior management, the board, like to see stuff happening and things being made." [PI006]*

As mentioned previously, another issue that could characterise resistance to change is the perception that process slows things down. This is something that would also need to be incorporated into any and all change management activities that are undergone within the CSD.

> *"There is a widespread thought in [the CSO] that process slows things down… Some people see process as something where you have to jump through certain hoops, and you therefore have to spend more time doing things so that the same output can come out." [PI008]*

This resistance could be especially difficult in this case as the implementation of DT and SE incorporate outputs that would be novel within the CSO. Ultimately, this resistance to process could be proposed to represent a possible barrier to implementation as quotes indicate that time is treated valuably within projects.

> "It's a*lways the first thing that gets shut down; we need to shorten timescales so stop doing requirements because we don't need them. We need to change the attitudes to it really." [PI008]*

Interviewees also raised that the most significant change required in the CSD was not a process change but a fundamental cultural change so that individuals can see the value of process.

> *"I think even more important than a process being put in place is a culture change… Lots of people try and put processes in place and not many of them stick because there are too many outside pressures like timescales or money and they just get pushed by the wayside. We really need to give them a chance to really prove their worth. If we can have a culture change that demonstrates why it is so important to do those things then I think that would come a long way." [PI008]*

This quote proposed that the process-based changes created would need to be supported by a number of cultural change considerations that would support the long-term adoption and retention of the solutions created.

4.1.1.6) Individual Mindsets and Skillsets

The preliminary interview series highlighted that individuals within the CSD had mixed understandings and attitudes to DT and SE and their expectations of industry in general. The attribute individual mindsets and skillsets aims to discuss these differences and understand how this could affect process implementation.

First, interviewees commonly proposed that "SE is just requirements management. [PI008]" This suggests that there is a preconception towards SE, likely due to the previous attempt to implement SE, that SE is perceived to be useful in one particular domain. Since an emphasis is not placed on the generation and understanding of requirements within divisional design projects, this preconception would likely prevent particular stakeholders from engaging with process-based change activities if the value of SE is not communicated clearly. However, interviewees supportive of SE also proposed that there were expected long term benefits to adopting a SE approach.

> *"The new technology that we're currently developing in, has taken 6 years longer than it should have had it been thought about in a system approach." [PI003]*

Supportive interviewees suggestions include time to market, overall project cost and the ability to understand and deliver market need. One of the core themes identified in interview with regards to individual mindset and skillsets was the idea that there is a "right person" for a particular problem and where this problem could not be resolved in one area there would be an individual elsewhere that might have a solution.

> "I think w*e operate on this very traditional approach of build, test, iterate etc. And it kind of, it's even more so than that it's identify a problem, solve a problem. And if I identify a problem but I can't solve it then I escalate to somebody else that can solve the problem and so forth" [PI004]*

This point is likely due to the hero culture perceptions that were raised in this interview series (section 2.5.1), as an emphasis is placed on qualified and capable individuals rather than a particular process or narrative. Therefore, the adoption of process would need to understand and incorporate the individual stakeholder abilities and responsibilities. Furthermore, the divisional culture encourages individuals to deviate from the defined company process if they do not believe that this is suitable for their needs. In many cases, interviewees proposed that generating this commitment to follow process would be significantly more difficult than the creation and implementation of the process itself.

> "There is a lot *of agency and license given to engineers to deviate from the defined process. So the simple issuing of a process is very different to the commitment to following." [PI004]*

One characteristic raised in interviews proposed that since the organisation had grown rapidly from its foundations, there was a lack of understanding of why the skillsets and mindsets that were adopted at organisational conception were not still delivering the same results after the organisation's expansion in terms of number of employees and number of locations globally.

> *"When you are a small organisation dealing with niche markets where our directors traditionally formed hugely strong relationships with our customers, so probably they had an awful lot of that insight, but they were talking about it but in a small company you don't think of it as a separate activity, it's just doing what you are doing in running your business. The problem is when there's four or five thousand strong, how*

do you capture that and disseminate that meaningfully to people… it's not disagreeing with things but what we're really saying is that the model by which he achieved those things doesn't work because of the scale up to this level." [PI004]

Fundamentally, this characteristic presents the argument that one of the key activities in the implementation of DT and SE needs to be the development of proof that the way things were done previously is no longer suitable for the organisation. From this basis, further proofs would need to be created to argue that the implementation of a DT and SE process would lead to improved outcomes overall.

Another characteristic identified in interview was the shift between a solution focussed and a problem focussed mindset within the organisation. Some interviewees reported that they had been aiming to consider daily challenges using this problem-focussed approach and had found that this was beneficial.

"If I'd been thinking in the traditional old sense then I would have written down a requirement of no [innovative feature]. Can't have it. But actually what we did is said why not… So if I hadn't asked that clarification question, I would have taken myself out of a position where I could do massive innovation, I would have completely written it off." [PI005]

However, this point proposes the idea that there may still be a number of people that just consider a solution focussed mindset and will take customer suggestions as verbatim, which ultimately leads to a failure to identify the true customer need. Mindsets could be developed through the educational materials delivered as a part of process implementation, as the collective shift towards a more problem focussed mindset may add more value to the requirements or problem statements generated and in turn lead to more scope for innovation for new products.

When asked about positive cases of requirements generation in other roles, participants reported that there were normally a core group of individuals whose main focus was on engaging with and understanding market needs.

"With experienced, capable capture requirements people it can be overcome and it has to be overcome. But it's a tough job and it requires

a lot of capability on the part of the requirements capture engineers," [PI006]

This quote also proposed that because there were no particular individuals within the CSD whose role it was to engage directly with customers to generate requirements, this was not suitable at the time. Therefore, individuals in customer facing roles may need to become more experienced in requirements capture so that this information can be utilised within the organisation.

Attitudes towards SE extended further, in that interviewee perception suggested that the entirety of a project team must be bought into, educated in and see the value of SE for it to be successful.

"Systems engineering is a set of rules that are applied to the whole project and whole project team from the start to the end of a project that everyone needs to incorporate as an additional strand into their thinking." [PI010]

Therefore attempts to engage the entirety of a project team are considered in the change management process adopted, as it would suggest that all interested parties must be educated on how to incorporate SE into their regular activities.

4.1.1.7) Project and Business Metrics

The project and business metrics attribute aims to discuss the perceptions towards divisional metrics and metrics implementation. Importantly, in cases where formalised metrics were not utilised, this attribute also considered the values that interviewees presented as important and these are discussed.

Interviewees reported that although some individuals argue that they measure performance, there is no common metric or platform between teams within the division to effectively evaluate these metrics.

"I think that individual areas would say that they measure their performance but having a common platform to compare and contrast against across the organisation is definitely lacking." [PI004]

Interviewees also argued that "largely, you get emotive responses to things rather than real metrics. [PI004]" These points suggests that there may be an opportunity within the division to implement a series of metrics that focusses on establishing a measurable commonality so

that projects and design activities can be assessed effectively. Considerations around metrics would also be essential when considering the change management literature proposed in section 2.6 as literature proposed that change is more easily adopted when participants are being rewarded through the use of metrics. Furthermore, this suggests that divisional control, through the use of metrics and process, is not valued highly within the CSD and thus, proposed implementations must be aware that individual concern around control may not support change. This is especially important as interviewees describe a lack of response of being able to improve or change as time goes on due to organisational culture.

> *"[The development of metrics] does require an attitude that says I can do this better." [PI004]*

One interviewee proposed that the development of a metrics solution would enforce how success within the organisation was viewed and perceived to be measured.

> *"Well how do you measure success?" And therefore how do designers focus on what it is that they should be thinking about and trying to achieve because there is this very clear disconnect between the sense of technical achievement of things and the sense of business success." [PI004]*

For instance, if success were to be measured solely from a commercial standpoint, metrics could include time to market or overall cost of a project whereas a purely technical viewpoint of success could incorporate metrics like number of requirements or prototypes generated. Regardless, a metrics implementation should be developed alongside the DT and SE process-based solutions proposed as metrics are an essential tool to facilitate change management. It should be noted though that since success can be interpreted differently between individuals within the CSD, this can lead to issues in the acceptance of a metrics solution. As one interviewee noted, "There is no such thing as an organisational goal, only individuals have goals. [PI009]"

When asked about the kind of metrics that they would like to see within the CSD, some interviewees proposed that metrics should not only be used to identify what the division does want to be doing but also what it does not want to be doing. The below quote expresses one interviewee's thoughts on several metrics that they believe might be suitable for the CSD and the value of using metrics to remove obstacles.

"So it's not really a case of what I would like to see, it's a case of what I wouldn't like to see. I don't want to see mistakes and rework and I do want to see [the CSO] being seen as the number one go to solution for [industry specific] applications at the very least in particular areas of expertise and particular industries where the strengths of our system are particularly apparent… in two years time I would like to see us putting out systems that have a much lower failure rate. I'd like to see a much higher machine sales number per month as a ratio of service visits." [PI005]

These particular metrics incorporate more of a technical viewpoint, but it is important to consider that they would not be suitable for all fields of expertise and levels of seniority. Therefore a further exploration of the values present within the CSD must be undertaken before project level metrics are identified. As raised previously, interviewees raised a particular requirement to develop ways of presenting outputs to the division in the initial stages of design as individuals in senior positions like to see progress within projects at all times.

"People like to see output. People you know, senior management, the board, like to see stuff happening and things being made. And certainly we would be wise to anticipate questions about, you're only going to make the design process slower." [PI006]

Therefore the use of metrics at this early project stage, if supported by senior management, could overcome this particular attribute to implementation and enable support for process within the division. Interviewees did identify that one of the metrics most commonly used in the division were measures of time, most notably the metric of time to market and so considerations should include this in some format.

"Time is the biggest pressure in [the CSO]. Particularly in the last nine months, we've been really pressured on time scales massively." [PI008]

In some cases, interviewees proposed that there may not be suitable ways to measure the effectiveness or impact of a particular team without an exact side by side comparison which is not often possible.

"You would never know how useful we are unless you run two projects alongside, one without us and one with us." [PI011]

This perception could present a barrier to the overall adoption of a metrics implementation as if individuals within teams do not believe that a particular solution is delivering value for them, then they may be inclined to reject the solution entirely.

Finally, as the CSD's market can be referred to as emerging, there are competing metrics present between this market and the more traditional market that should be taken into account. Interviewees identified that project personnel;

> *"… benchmark it against two levels. One, when [they] benchmark it against the other competitor's equipment, [they] can't get the same productivity and therefore [industry accepted metric] which is key. But also, [they're] competing on a cost base that's competing with the more conventional, [traditional market] that we're up against." [PI012]*

Therefore it is important to select and utilise metrics in this case that can accurately reflect on these comparisons between more traditional and emerging markets.

4.1.1.8) Educational Resources

The attribute education resources aimed to understand how interviewees learnt about new phenomena at the time of the interview and present an argument for the suitability of change management resources that could be used to support implementation.

When asked about current organisational attempts to educate individuals of new subjects, interviewees suggested the idea of workshops but made it clear that these need to be tailored to demonstrate the value added by adopting proposed processes or activities to particular groups of people.

> "We seem to *respond quite well to workshops so having the workshops and, you know, engineers, they don't just want to be killed by PowerPoint actually being able to see where some of these processes could make their life easier." [PI001]*

Interviewees proposed that normally education resources are created by particular champions of organisational change or heroes within the organisation that are knowledgeable about a subject.

> *"So she had to give me a bit of background for what I should be doing in order to do it myself." [PI008]*

When contextualised within the hero culture defined previously and the onus placed on individuals to use process when they believe it necessary, this onus suggests that the researcher will likely need to create target audience specific materials that aim to demonstrate where they might use the proposed solution to create value.

However, interviewees also proposed that there are instances where change occurs within the division and individuals must teach themselves about particular ideas or phenomena.

> *"I became aware when I moved into [the CSD] that we had or were making a SE team so I did a little bit of background reading into what it was." [PI009]*

This point suggests that when implementation of a solution might occur, there is some scope to not educate all employees in everything regarding that particular implementation as so long as they are bought into the concept of the introduced material, they may teach themselves any additional content that might be necessary.

4.1.1.9) Implementing Innovation

Innovation is raised often among interviewees in the CSD as one of the critical driving forces for divisional products. However, interviewees reported mixed perceptions to the concept of innovation and the innovativeness of process. The attribute implementing innovation aims to characterise the CSD's ability to finalise and release innovative products and understand what effect this may have on the implementation of DT and SE. Interviewees raised that innovation is encouraged and aimed for often within the organisation.

> *"We ought to explore different, you know, different technologies without fully understanding where they're going to be used in the marketplace." [PI001]*

However compared to the foundations of the organisation where the market for its initial products was underdeveloped, the CSD is aiming to achieve innovation within a saturated market which is considerably more difficult. This means that the development of new features and technologies is considerably more difficult and requires a greater emphasis on the concept of innovation.

> *"If you look at where [the emerging market] come from, there's lots of competitors out there. If you look at where we came from years ago, when [redacted] kicked off the [first organisational product], you know it*

was the only, it was the only thing out there. So I think it's we're just having to adapt now." [PI001]

Interviewees went on to suggest that the ideas and concepts generated within the CSD are innovative but not enough time is spent innovating within particular project problem spaces. This is something that could be expanded on in the solutions generated.

"It feels like we are innovative in some ways but not in others. Like I think when a new project is being started, I feel like someone comes up with a design which is jumped on and everyone goes ahead with that whereas I feel that there is a bit more room for innovation there, to come up with more concepts and kind of narrow these down rather than taking one and developing it" [PI002]

The overall perception to innovation within the CSD is very mixed however with some participants commenting that;

"I don't think we are innovative." [PI001]

Whereas others provide the argument that innovation is an inherent part of the work that is done.

"The products *that we have developed and are selling are innovative and they have USPs (unique selling points), and they are, functionally have some really good features and good market" [PI005]*

Interestingly, this perception to innovation can be interpreted to be related to the development of the technology drive within the division and the associated time to market.

"Are we *innovative enough? We are certainly innovative enough in terms of the ideas and the technologies that we come up with, evaluate and do initial development on. Are we innovative enough in terms of the actual technologies that we actually see all the way through and get out to customers? Less so on that score, I think. Takes us too [redacted] long to get stuff through the door." [PI006]*

This therefore suggests that to achieve innovative outcomes within the CSD, time to market should be mitigated as much as possible and individuals should be allowed to investigate technology drivers as a part of the formation of projects. This context suggests that,

compared with the literature found in section 2.7.5, innovation and the concept of innovation is reported but is less likely be a significant attribute to implementation than proposed in literature.

4.1.1.10) Remote Design

The attribute remote design is characterised by data points that comment on the ability for individuals to work remotely within an organisation and any perceptions that they may have around remote design impacting on the implementation of new design process.

Participants commented infrequently on the effectiveness of remote design and its potential impact as an attribute to implementation of DT and SE but did raise that the introduction of COVID and the shift to remote working in the three months prior to one particular interview had made communication more difficult and placed an increased emphasis on the time to market of a new product launch.

> *"I think that COVID hasn't helped us. I think that things were starting to change but I think that being away from the office and having accrued the cost that COVID has cost us means that getting revenue in quicker is now more important. I mean it's a perfectly valid situation to be in, we need to make money, COVID has cost us money, so getting products to the market faster will generate revenue sooner." [PI008]*

The theme, remote design, was not considered in later investigation as it was believed that it had been mentioned too infrequently in interview to be a key theme for this research. However it was raised a number of times in the proceeding questionnaire meaning that this could be considered in future work.

4.1.1.11) Summary of Pre-Implementation Interview Series

To conclude, the pre-implementation interview series aimed to identify perceptions to the research question;

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

This interview series identified and characterised a total of 10 attributes to implementation that were perceived to affect the implementation of DT and SE within an LEO, summarised in table 12 (section 4.1.1). These are considered in further sections to assess the accuracy and generalisability of these attributes to the implementation of DT and SE within an LEO.

4.1.2) Validation with Literature

The attributes found thus far were compared with the comprehensive literature review to determine where any similarities or differences in data might be present. This was done to assess the generalisability of these perceptions, as the presence of similarities may suggest that the data gathered fits within the current knowledge base around the implementation of DT and SE in an LEO whereas differences would propose that something more novel was being investigated. This section will directly compare the attributes to implementation generated in this investigation against findings that were presented in literature.

Communication was mentioned in every interview conducted as a part of the previous interview series and suggests that establishing effective communication channels that support the flow of information is just as great a barrier as communicating externally to the organisation. This is not something that is focused on heavily within literature, but successful implementation in the CSD was perceived to be linked heavily to both internal and external communication methods.

Although many cultural similarities can be drawn between primary research and literature, this case study is interestingly, culturally very accepting of risk in the pursuit of innovative outcomes which contradicts the findings of (Carlgren, Elmquist and Rauth, 2016A) that suggests that this would be one of the more significant issues in the implementation of DT. However, this may present the opposite problem and become a significant barrier in the adoption of SE; as one of the main purposes of this is to de-risk projects through the collection of requirements. Furthermore, the CSD has been identified to be both pluralist and hero driven in nature and, whilst this has not been discussed specifically in DT and SE literature, this has been identified in change management to be significant when considering implementation.

Specific areas of established process were perceived as negative attributes to the implementation of DT and SE as a part of this case study; early problem and scope definition, fixation on high fidelity prototyping and failure to identify and learn from lessons learned were mentioned as key issues. This therefore is very similar to literature, which highlighted that traditional process can be a barrier to process implementation (Carlgren, Elmquist and Rauth, 2016) and highlights specific areas that the early generation of solutions could achieve.

The theory of existing power dynamics being a barrier to the implementation of DT and SE in this case study is expanded to include all relations to organisational structure and

hierarchy. In particular the organisational structure was found to be unsupportive of the use of process and identified that where this was not valued prior to implementation, it would negatively impact the implementation of process-based solutions. Overall, this interview series is supportive of the theory that the existing power structure will aim to retain the status quo but, in this case, a greater emphasis is placed on individuals' overall perceptions of control, or lack thereof during the current design process.

The data regarding resistance to change concurs with the literature review conducted and participants that raised this were often able to discuss change initiatives that had occurred previously from "top down" and "bottom up" perspectives. Within these specific conversations, change initiatives that had been perceived to have started at the more senior levels within the organisation were perceived to be more successful than initiatives that started at a grassroots level.

Primary research has identified that both individual mindsets and individual skillsets are contributing factors to the implementation of DT and SE within this case study. Since research suggests that the adoption of supportive mindsets towards both design processes are critical, this therefore supports the proposal to conduct this investigation considering the attributes to both implementation of DT and SE as influencing entities on the outcomes of this work.

To paraphrase one participant; "there is no such thing as an organisational goal, only individual goals" [PI009]. This emphasis highlights one of the key considerations that needed to be made within this case study, that the implementation of both project- and business-level metrics must support the individuals that are using them in their day-to-day activities. This understanding builds on from the comprehensive literature review conducted, which states that there are very few metrics for design activities, and suggests that metrics can, and should, be created to suit particular needs within particular cases as only in that way can all the other characteristics of an organisation be captured.

Literature discusses the implementation and education of tools whereas insights from this investigation have identified that the greatest barrier with regards to education would be due to finite resources to create educational material and the engagement that will be had once this is created. An individual's interest to be involved with a particular initiative is perceived to be a relatively difficult process within the CSO as individuals tend to be focussed on their short-term deliverables.

The reported success of the division in implementing innovation differs significantly between changing levels of seniority. More senior employees present the argument that the division and organisation overall are innovative but that sometimes technology drivers are considered too heavily within projects. On the other hand, less senior employees argue that the division struggles to be innovative within the AM market space as the focus on innovation and innovative technologies prevents the meeting of market expectation and thus the division cannot consider itself to be innovative.

Although remote design is raised as a significant barrier in literature, this was not perceived to be a significant issue with respect to this case study. This may be due to the global distribution of personnel as although teams are based in various areas around the world, the design specific teams work in close proximity to each other and often on one specific site.

To conclude, although minor differences were identified between each of the attributes to implementation from interview and the attributes present in existing literature, these differences are minor and could be due to a range of organisational or circumstantial differences in the LEO considered in research. These differences are considered further in the discussions chapter (section 5.1.2). Ultimately, these attributes were found to be validated with literature and considered in further stages of this investigation. Please note that from this stage onwards, the attributes to implementation follow the naming convention found in literature, outlined in 3.10.2.1 and summarised in Appendix 11, in an attempt to avoid confusion within the thesis.

4.1.3) Quantifying Process Quality

Interviews from the preliminary interview series indicated that there may be a need to specifically consider the costs due to significant change management within the design stages of projects as this was thought to be a key issue in the division. This would also serve as a measure of the CSD process quality, and thus support the exploration of the CSO culture prior to the conception of any change management activities. Using a combination of the organisation's accounting software, project management documentation and discourse with key project stakeholders the following values were found for late project changes in the division. First, all data was taken from the CSD accounts for all available projects and tabulated against when changes were made. Next, project management documentation was consulted and used to identify where late scope change had occurred, which then proposed that changes in the accounting software at a given time were due to this late scope change. Importantly, this included both material costs and personnel costs. Finally, where this was

not clear or could not be defined accurately, discourse was undertaken with key project stakeholders to identify what changes may have taken place and ascertain its viability for this quantitative investigation. Where any uncertainty was still present as to the cause of an increase in project costs, this was not included in this dataset. It is important to note that increases in project cost and time were only considered in this case if project management documentation, or in discourse where this was not available, proved that it was due to late scope change. The figures provided are an average of all projects within the CSD. For cost these were;

- Total cost due to late changes in projects: £14.5 million
- Average cost per year due to changes: £1.3 million
- Cost as a percentage of total project cost: 72%.
- Cost as a percentage of total project cost, conservatively: 31%.

Similarly, the values found for time were;

- Total time cost due to late changes in projects: 129 project months
- Average time cost per project: 21.6 project months
- Time cost as a percentage of total project time: 85%.
- Average time cost per project, conservatively: 9.6 project months.
- Time cost as a percentage of total project time, conservatively: 52%.

This preliminary investigation led to a clear understanding that late changes in design projects due to poor initial problem definition or late scope correction are to blame for significant cost and time losses, as shown in project management documentation. The scale of this issue appears to be anomalous to the CSD as the comparative, more established, divisions interviewed have defined processes that they follow to mitigate these effects as presented in section 4.6.

4.1.4) Questionnaire Series

To reiterate section 3.10.1.3, the aim of the questionnaire was to give participants an additional opportunity to identify any further points that they believed were attributes to implementation given the short nature of the initial interview series. It also allowed the attributes identified thus far to be quantified, and perceptions towards the significance of each attribute to be explored.

The questionnaire conducted used the software Qualtrics and aimed to remove methodological issues in conducting 30-minute semi-structured interviews in the preliminary

investigation by presenting participants with a questionnaire that they can complete in their own time. 20% of the CSD (17 participants) completed the questionnaire and representatives were sought from each area of expertise within the company to ensure that theoretical data saturation was achieved.

To ensure that all questions in the questionnaire had little ambiguity, the attributes to implementation identified in the preliminary interview series were split into a number of statements that explained each theme in an adequate amount of detail. These were tested for their accuracy and suitability with a small focus group of four participants and have been listed below in table 13. The last two columns aim to identify what the greatest strengths and threats are to the organisation; whereby participants were asked to rank each statement from 1 (highest agreement) to 11 (lowest agreement).

Table 13 - Preliminary Questionnaire Outcomes

Statement	Mean Strength Rating (/11)	Mean Threat Rating (/11)
There are opportunities for the division to learn from project issues	**3.2**	**3.3**
There is scope in projects to implement innovative ideas	**3.3**	8.2
All individuals in teams are working together towards a common goal	5.9	4.5
The organisational structure/hierarchy positively affects my work	6.3	8.8
The organisational culture positively affects my work	6	8
There is strong communication with customers externally to the company	**5.2**	**3.9**
There is sufficient support to learn new methods of working	6.6	7.2
There are metrics in place that accurately measure project outputs	8.5	4.8
There is strong communication amongst internal teams in [the CSD]	7.6	**3.4**
The current product implementation process positively affects all aspects of my work	7.7	6.8
There is no resistance to new methods of working	5.7	7.1

The data displayed in table 13 presents a number of findings. First, the three greatest strengths present within the CSD are;

- That opportunities are present for the division to learn from project issues,
- That there is scope within projects to implement innovative ideas

- And that that there is strong communication with customers externally to the company.

However, the value found when considering the external communication statement was around five which implies that the agreement around this theme is not strong. On the other hand, the three greatest threats to the CSD are;

- That opportunities are present for the division to learn from project issues,
- That there is strong communication among internal teams within the CSD
- And that there is strong communication with customers externally to the company.

Since the values found for these themes were relatively low this indicates a strong agreement that these themes, amongst other low values themes, are the greatest threats present within the division. Interestingly, the statement regarding external communication is present in the top three of both categories which likely is a quantitative measure of the dichotomy of perspective found in the initial interview series. The data from this questionnaire can also be presented graphically. Figure 34 shows the greatest strengths in the division and figure 35 shows the greatest threats to the division, with the error bars demonstrating the standard deviation for each theme.

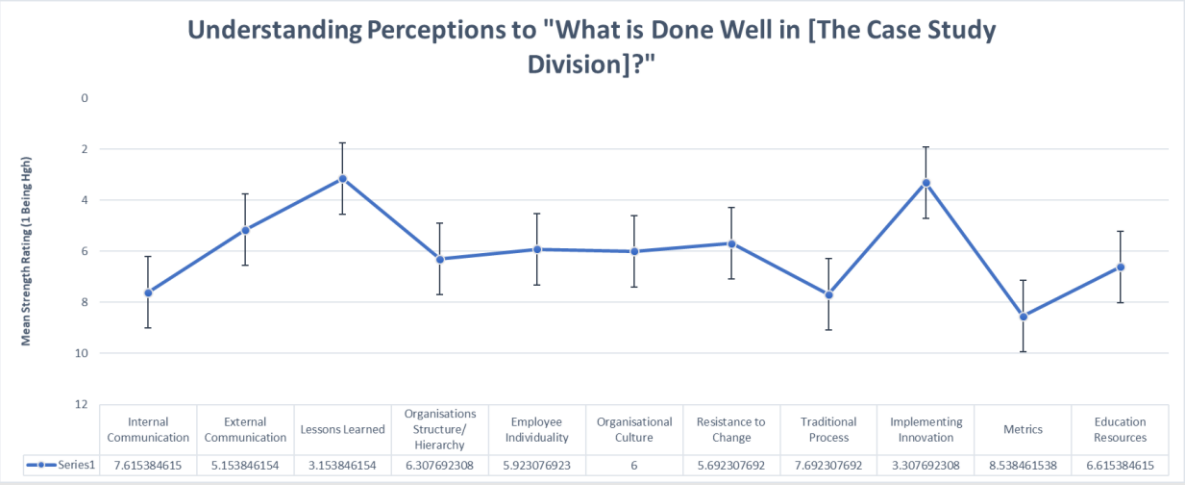

Figure 34 - Strengths found in the CSD

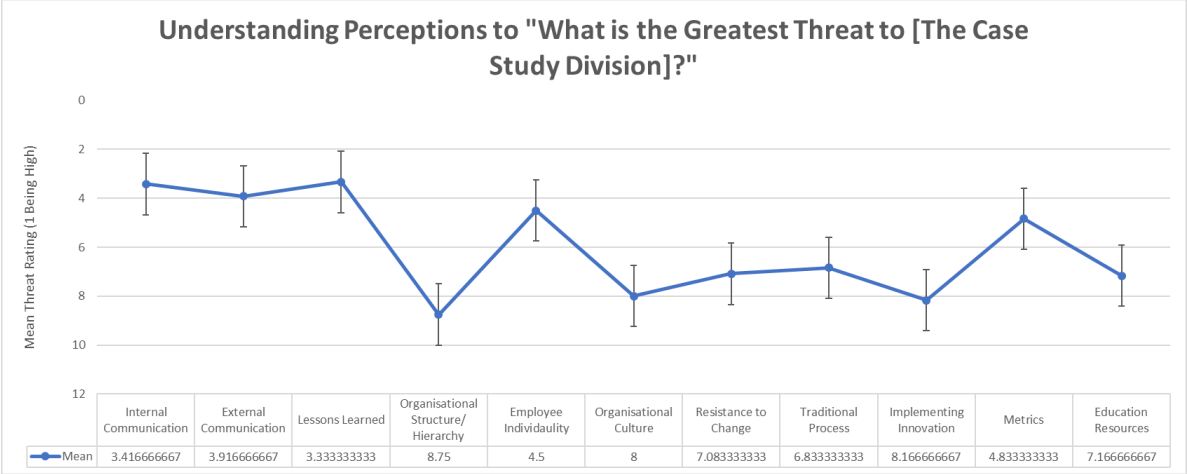

Figure 35 - Threats found in the CSD

To summarise, this questionnaire was critical to ensuring that viewpoints were captured across the division on the previously identified themes of interest and that these same individuals were given an opportunity to identify any other issues that they believed were relevant. The questionnaire sample also included individuals that had not been involved in the interview series, as this allowed greater divisional representation in the pre-implementation data. This data was also used to plan the initial implementation of the solutions created, as resolving something that is widely perceived to be a strong threat would likely be supported when compared with solutions that focus on working on improving a theme that is perceived to currently be a strength anyway. This questionnaire series further answers the research question **(1B) What are the attributes affecting the implementation of DT and SE in an LEO?**

4.1.5) Post Questionnaire Interviews

Post questionnaire interviews were conducted with the intent to understand why participants had allocated certain values to particular themes within the questionnaire and to mitigate any impacts of reification. 29% of the questionnaire sample (5 participants) took part in this investigation. These were semi-structured interviews that reflected on the themes that participants had identified as being their personal perceptions on the greatest threats to the division as understanding all relevant contextual information around this would aid in the successful implementation of later solutions. As such, discussion often centred around an in-depth view of a small number of the themes identified. This investigation, therefore, aims to generate data that should be considered alongside the outcomes of the preliminary interview series; in the identification and contextualisation of attributes to implementation and in the identification of suitable areas of implementation.

4.1.5.1) Communication

Exploring perceptions to communication led to a more in-depth understanding of the inter, intra and external communication issues that are present within the CSD and its teams. Considering first the communication perceptions regarding working within teams, individuals are not perceived to communicate effectively between one another. One participant commented on the introduction of remote working in the organisation, stating that;

> *"Communication was poor when remote working was introduced but it was not strong to begin with." [QF003]*

This data point presents an argument that suggests that although the preliminary interview series was conducted shortly after the introduction of remote working, findings from this investigation that suggested that communication was poor likely had a basis when organisational employees were working in one location. Interview data within the organisation proposed that the issues related to communication, internally and externally, have been exacerbated by COVID19 and the relatively recent organisational restructure, but these are not the causes for poor communication. Further, participants suggested that improvements could be made through the "…documentation or capture of individual specific work," as the divisional hero culture present meant that when an individual within a team left the organisation, they took with them the understanding that they had around their particular role.

'Communication' was a frequently raised issue; where 'communication internally to teams' was raised by 40% (2 participants) of the post questionnaire interview sample, 'communication between teams' and 'communication as an organisation' was raised by all interviewees. Working collaboratively between teams was suggested to benefit from clearer communication, with particular emphasis placed on the communication channels that were utilised as a part of design work. Participants reported that;

> *"There is a lot of opportunity for poor communication" [QF004]*

This quote and subsequent relevant interview data suggests that there may be opportunities for process implementation that focusses entirely on communication as a theme of interest. When queried further, participants reported that significant design decisions were not communicated in a suitable way and that the transfer of information from one base to another was often not documented or controlled which led to miscommunication.

One participant discussed communication externally to the division and suggested that relationships with external companies are not common but are positive when they are employed within design projects. This, potentially, suggested another avenue of investigation within this research; to identify and understand why external relationships are only used within some projects, so that DT techniques can be used more suitably.

One of the other critical themes discussed around the theme of communication was focussed on the concept of strategy and the understanding, use and discussion of particular strategies when making design decisions. For instance, participants raised that the use of goal setting within the division, the reasoning behind selected goals and how this is communicated as being of particular issue. The below quote was taken when one participant was asked about changes that they would like to see in design projects.

> *"We need to be considerate of whether we are all working towards a common goal… Also why are we trying to achieve particular goals?"*
> *[QF001]*

This expansion on the theme of communication internally to the division presented a variety of potential solutions that could be generated using DT and SE within the scope of this research.

4.1.5.2) Resistance to Change

When the attribute resistance to change was investigated further, interviewees proposed that toolsets, mindsets and documentation from phenomena long established within the division were pushing employees away from accepting change. Furthermore, when discussing where change might be applied, interviewees proposed that attempts to implement new methods and processes were often restricted to smaller projects, or simply not applied to the larger divisional projects.

When asked about a successful change management experience, interviewees often identified the recent divisional restructure, that had occurred very shortly after the conception of this research and made a number of individuals redundant, as an example of where change had been successful but had been enacted poorly. The change itself was perceived to be poorly communicated, with particular emphasis placed on the poor communication of why the change was happening and the delays in communicating the new proposed outcomes. When investigated further, interviewees proposed that had this

information been available before the change had taken place they would have been more accepting and understanding of the change management activity.

4.1.5.3) Established Process

The existing processes within the division were raised in the preliminary interview series, and quantified in the questionnaire, as perceived points of issue within the CSD. Notably, interviewees in this interview series raised that the existing process is not sufficient simply because it is not followed. Interviewee's proposed that;

> *"…so, yeah, the way that we do technical work and the processes that we have don't work for us…so they're not normally followed." [QF006]*

Some participants went on to raise that because the organisation shared one design process across a number of divisions that designed very different products, this generalised process was therefore not in-depth enough to be able to resolve the complex CSD problems. One participant also raised that the review process for new projects found difficulty in managing business case, suggesting that new technologies or machines were at times created based on a poor business case and that more time should be spent cultivating opportunities.

4.1.5.4) Metrics

Metrics were also highlighted as a key topic of interest, with participants commenting that across projects;

> *"…measurements are not undertaken within [the CSD] to measure one success criteria consistently." [QF006]*

In some interviews, participants suggested that very few metrics were considered throughout the existing design process that was present within the division and that those that were often fell into the category of either cost or time. Finally, participants raised that;

> *"…there are no clear criteria when it comes to how successful a project is." [QF005]*

Collectively, and due to the change management methods aiming to be employed within this research, these points suggest that the consideration of a metrics implementation may be novel within the division.

4.1.5.5) Lessons Learned

Similarly to the metrics findings, interviewees reported that there were no end of project reviews for design work done within the division and thus, no opportunities for any lessons

learned work to be completed. This was not perceived to be a positive thing however as participants reported that;

"…lessons learned is vital to the future success of the [CSD]" [QF006]

When questioned further, participants pointed to the company culture as being one of the most critical reasons for this learning to take place suggesting that if individuals leave the organisation, then they take their knowledge and understanding of projects with them which in turn can lead to repeated mistakes in future work.

4.1.5.6) Organisational Culture

Finally, participants expanded on the theme of culture and the discussions around how company culture affected design and business activities. For instance, projects within the CSD are reported as not often including project contingency which in turn affects the workload present on employees and prevents them from engaging with innovation or change management activities; this is reportedly due to a cultural drive to demonstrate value adding material within teams and to complete projects quickly that add value to the division. The culture is referred to as *"old fashioned"* and *"people focussed"* which *"…fails where people or teams are inexperienced."* This directly suggests that the divisional culture is more akin to a hero culture than a process culture (outlined in section 2.5.1). A final point made by interviewees suggested that;

"good engineers are promoted to management but that does not make them good managers." [QF007]

This strategy, coupled with few reported opportunities for training and development, is perceived to be a strong cultural issue within the organisation and something that would need to be considered in the development of any educational material or in any change management that affected the divisional culture. This also reflects, interestingly, on the Peter Principle (Peter and Hull, 1994) which supports the argument for the accuracy of this point.

4.1.5.7) Summary of Post Questionnaire Interview Series

The post questionnaire interview series aimed to further contextualise the attributes to implementation identified in section 4.1.1 and validated in section 4.1.2 so that all perceptions towards the attributes affecting the implementation of DT and SE in the CSD can be identified. Since no new attributes were raised in either the questionnaire or the post questionnaire interview series, the ten attributes to implementation already defined are considered as valid in later stages of this investigation.

4.1.6) Conclusions of the Pre-Implementation Investigation

To conclude, the pre-implementation investigation contained a number of research methods that aimed to understand the divisional attitudes, and potential attributes to implementation, of DT and SE and the issues that are present within the division that could be affected by the implementation of DT and SE. The preliminary interview series found a total of ten themes from taken from interview data that characterised the divisional issues and attributes to implementation that may be present within the CSD, presented in table 14 for ease.

Table 14 - Identified Attributes to Implementation of DT and SE within an LEO

Theme	Explanation
Communication	How the division communicates information both internally and externally
Organisational Culture	The influence of organisational culture on the processes and outcomes of projects
Traditional Process	The current design processes for all aspects of the division, to include product development
Organisational Structure/Hierarchy	The influence of the organisational structure and hierarchy on divisional outcomes
Resistance to Change	Resistance to the implementation of new processes, tools and techniques
Individual Mindsets and Skillsets	The influence of individuality and diversity between and within teams in the division
Project and Business Metrics	The division's ability to measure the outputs that have been produced accurately
Education Resources	The division's ability to learn new things and the processes that are in place to support this
Implementing Innovation	The division's ability to come up with innovative solutions and implement them
Remote Design	The division's ability to operate as a globally distributed organisation

Although slight differences were found, these were then validated successfully against literature and a comparison created between the context that was present within the primary data against discussions made in literature material. These attributes, therefore, were considered in later stages of this investigation.

The questionnaire conducted found that the greatest divisional strengths were;

- That opportunities are present for the division to learn from project issues,
- That there is scope within projects to implement innovative ideas

- And that that there is strong communication with customers externally to the company.

The questionnaire conducted also identified that the greatest divisional threats were;

- That opportunities are present for the division to learn from project issues,
- That there is strong communication among internal teams within the CSD
- And that there is strong communication with customers externally to the company.

Finally, a quantitative analysis of the division's current process quality found significant losses in overall project cost and time to market that were attributed to late changes in design. On average, the costs identified as a percentage of project cost was 72% and the time to market overrun on average was 85% of initially planned timeframes. This data identified that resolving the CSD's process quality issues would result in significant improvements to projects.

Reflecting on the totality of the pre-implementation investigation, the CSD be identified to have a pluralist culture due to the variance in perception between differing levels of seniority and differing fields of expertise (Fox, 1976). The concept of a unitarist culture would propose that the values and beliefs that were reported through the investigative methods conducted in the pre-implementation investigation would be the same, which is not true, and the concept of a radical culture would propose that these same values and beliefs would be significant and opposing between higher levels of seniority and lower levels of seniority. This was also not the case as the perspectives presented in interview often differed between individuals of similar seniority and similarities could be identified between individuals of higher and lower levels of seniority. Therefore, this would be something key to consider in the development of solutions and the bespoke nature of each implementation as the differing cultures present would need to be accounted for (Prajoho, 2005).

Similarly, the culture can also be ascertained to be an uncertainty culture due to the poor process quality, and so poor process adherence, within the CSD (Crosby, 1979). This is also reflected in the interview data collected, which displays a lack of certainty around project success, leadership, strategy and communication. If the CSD were a certainty culture, all of the points made would point to the existing process being fit for purpose, adopted and followed at all times and more certainty would be present within the interview responses given. Therefore, the CSD can be identified to be an uncertainty, pluralist culture based on

the literature within section 2.5. This is important to consider in the remaining research methods, and in the implementation of solutions in this CSD.

4.2) Creation of Solutions

Once the preliminary investigation had been conducted, a suitable contextual understanding of the CSD had been developed from which DT and SE solutions could be generated. It is important to note that the division had recently implemented a new design process and that interview participants had explicitly mentioned that this investigation's implementations could not contradict this newly implemented process. Therefore, DT and SE were considered through their core components found in section 3.12. This section will detail the co-creation methods, reasoning used for each solution and its link to the core components of DT and SE. Section 4.2.5 concludes by detailing the application of change management process to each solution and outlining areas of success.

At a high level, the solutions created were;

- Solution 1 – A pre-design process, process that placed an emphasis on investigating and understanding the problem before any attempts were made to design a solution.
- Solution 2 – A communications process, that aimed to use to DT and SE concepts to enable a stronger communication flow between customer facing, engineering design and enterprise roles; which in turn supports the later implementation of DT and SE.
- Solution 3 – A low fidelity metrics solution, that aimed to resolve challenges around late changes to scope by aiding project teams to test early and learn from failures.
- Solution 4 – A suite of DT and SE metrics, that would support the later change management work undertaken as affected parties would be supported by metrics that reflect the DT and SE activities that they are undertaking.

4.2.1) Solution 1 – Project Conception Process

Initial interviews identified that scope creep and poor problem definition were significant challenges in the CSD due to the rapidly changing market requirements of the CSD industry and the traditional design process that was present in the CSD. This was reflected in the results of the quantitative investigation into the costs of late scope change in the division; poor problem definition coupled with an acceptance of major scope creep as part of the design process would lead to late scope change and accrue relevant costs and time delays. This was also supported by the outputs of the initial interview data, where participants state

that solutions should be focussed on this pre-project stage as this would generate the greatest design process impact with the smallest amount of resources (reflecting on Baxter, 1995) and due to the other process-based solutions that were ongoing in the division.

For the first implementation, titled Project Conception Process (PCP), the creation of this process utilised change management procedures outlined by Lewin (1947) and Burnes (2017). As such co-creation was used as an organisational change method and included input from all fields of expertise in the division. A total of 14 individuals took part in this process across a period of three months, with meetings scheduled around the ongoing turbulence in the division due to COVID19. Co-creation at this pre-project stage of the design process led to the generation of a number of process objectives that were to be achieved by its preceding implementation, these were;

1. To improve communication with customers by identifying relevant stakeholders early to assist in problem definition.
2. To improve internal communication through effective use of documentation and development of logical arguments.
3. To mitigate project conception if there is insufficient commercial viability.
4. To identify relevant project Lessons Learned so that projects will not suffer from the same issues as previously identified.
5. To formulate problem level requirements to enable a margin for innovation whilst ensuring that scope is clearly defined. These requirements place an argument for why the project is progressing in a certain way, considering customer need.
6. To utilise low fidelity prototyping to ensure that costs in early project stages are minimised whilst still gathering the same depth of relevant data.
7. To increase the emphasis on scope definition to ensures that cost and time over-runs are kept to a minimum.
8. To identify literature-based metrics that allow for a creative understanding of what the problem is and how engineering productivity is measured.

These objectives also required a series of co-created outcomes to be generated that would ensure that each of the objectives had been satisfactorily completed to suit the organisation, seen in section 4.5. Once this had been identified, conversation was directed towards the specific details of how this process might work and what review stages would be important to ensure that each project started using this process would remain on track. These conversations however were driven with a DT and SE outlook depending on the particular

point that was being raised. For instance, conversations around process structure, review stages or requirements considered the multiple V model approach from SE (outlined in section 2.2). On the other hand, conversations around understanding the particular problem that the project is aiming to resolve or in investigating user needs is fundamentally driven by DT as this has a core user-driven focus. The previous process is documented in figure 36 and the proposed process can be seen in figure 37. This will be discussed briefly below.

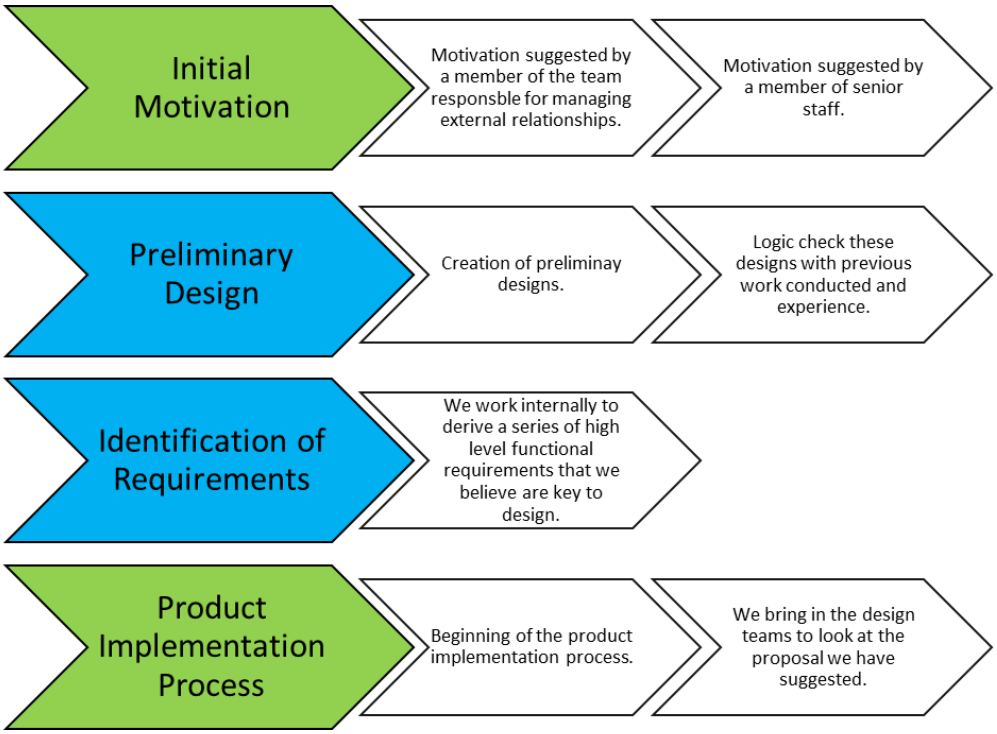

Figure 36 - Previous Project Conception Process

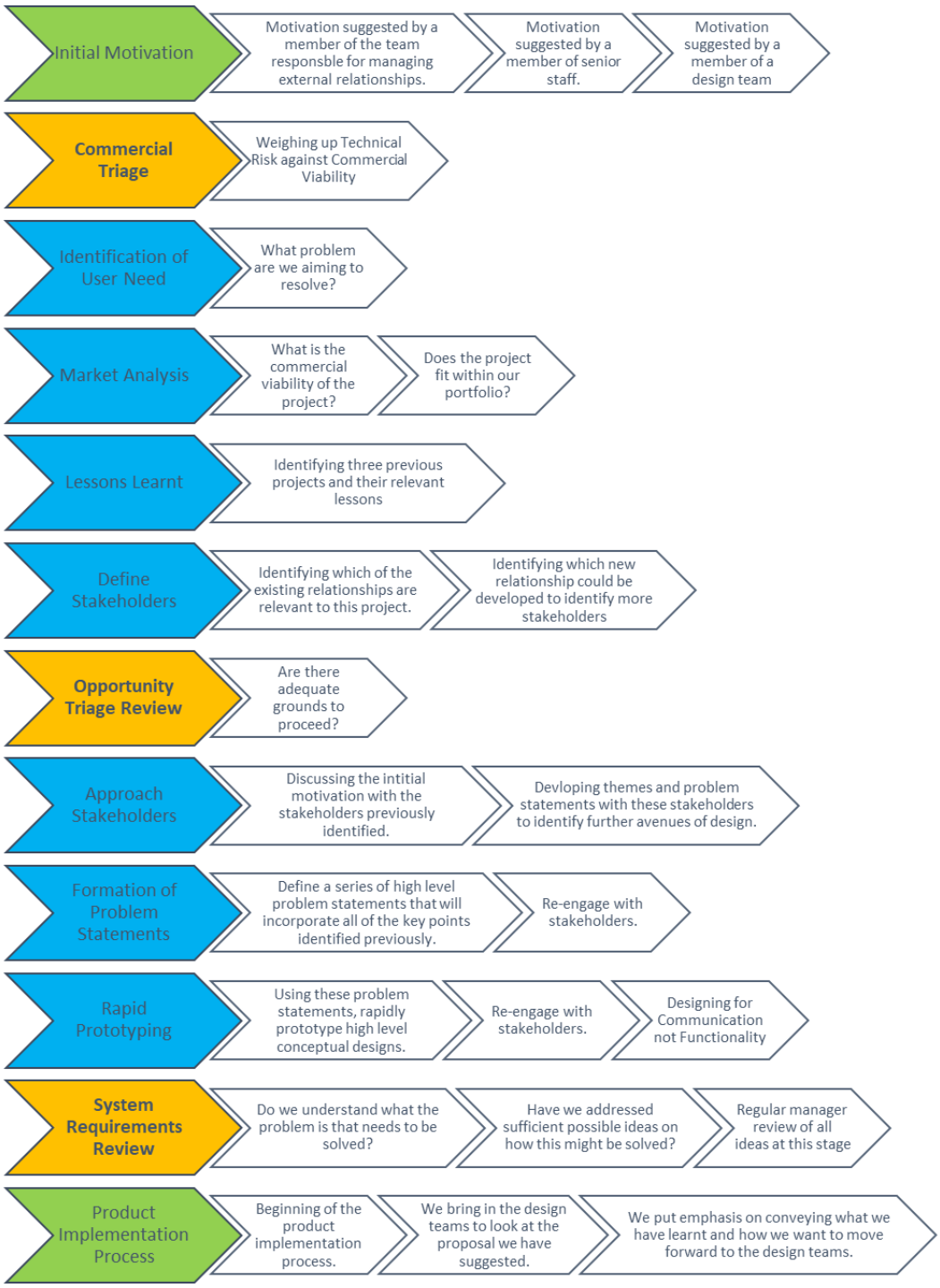

Figure 37 – Proposed Project Conception Process

At the highest level, the proposed PCP can be discussed through the use of its review gates. Once an initial project motivation had been identified this was then considered by weighing its commercial viability against its technical risk, referred to in this instance as commercial triage. This allowed reviewers to bring in perspectives from individuals engaged with other aspects of the division's target markets and thus develop a rapid understanding of the scale at which a project based on this may be viable. Fundamentally, if the commercial viability

was considered too low or the technical risk too great then the project was prevented from progressing further. The motivation was however recorded in a database that allowed individuals to return to it if anything changed in the future and thus provided a level of traceability.

Once the initial commercial triage was completed, the following body of work would lead to an opportunity triage review. At this stage, a level of research had been conducted to identify whether the initial motivation was correct and to understand the division's capacity to achieve this project. This included research into the market that the CSD were aiming to engage with, identification of who the key stakeholders for the project may be and the capacity of the division to complete this project within a reasonable timeframe. A number of documents would be completed for this review stage to support the accurate representation of projects and the traceability of thinking. Importantly, the introduction of these documents aimed to capture customer needs in a preliminary market assessment, a number of proposed next steps, identification of previous lessons-learned points and details of any contactable parties.

For projects that progress past the review stage, co-creation activities conducted with stakeholders outlined, it was important to engage or re-engage with external stakeholders and develop a better understanding of the problem that is being challenged by a particular project. DT techniques are employed in all parts of the process from here until the next review stage, as implementations considering user need, rather than solution-focussed requirements, and rapid prototyping were considered key to challenging some of the cultural issues that had been raised in previously conducted research methods. The final review stage in the PCP reflected back on this point and identified whether the project proposed is fully understood in terms of the problem that was aiming to be addressed and to ensure that early design considerations were discussed with key stakeholders, which may eventually lead to key clients.

As the aims for this process were generated using co-creation, it was important to use co-creation to also identify metrics that key stakeholders perceive as suitable measures of success. For this process implementation, metrics were identified for each review stage to ensure that desirable activities were being achieved. For the opportunity triage review, the identified metrics were the use of, and number of, personas and the number of lessons learned points that have been raised. At this stage very minimal data had been gathered but it was important to demonstrate that there was an understanding of the business case that

a project may have. Furthermore, at this point very little resources had been allocated to the project and this was perceived to be important to reflect in the metrics at this stage. The system requirements review metrics include; the number of problem statements identified, the number of prototypes created, the number of customers interacted with, perceived cost pressures and perceived time pressures. Although these metrics were not created during co-creation activities, as they were present in literature, they were decided upon during co-creation sessions. The system requirements review occurred just prior to the beginning of the existing product development process and so a much greater quantity and quality of information is required to ensure that projects were suitable for the division. The metrics proposed could contribute to the understanding of the outcomes that are perceived as valuable within the CSD.

This solution was to be implemented at the same time as a number of workshops that talked through the process, the fundamentals of DT and SE and the importance of conducting each of the stages in turn with their proposed documentation. These workshops were conducted with external facing roles, design teams, project management and engineering management where applicable and appropriate. Later, a series of videos were created that aimed to support the implementation of this solution.

4.2.2) Solution 2 – Problem Definition Process

Communication was one of the key attributes to implementation that was raised in the interview and questionnaire investigations conducted; both internally to the division and the company as a whole. This was exemplified internally when investigating the division's concerns around process quality and the interview data that suggested that internal communication was perceived to be liable for aspects of this issue. This therefore formed the basis of the second proposed divisional solution; to co-create and develop an information management system that used DT and SE principles to ensure that information is disseminated fluidly throughout the division and to ensure that this information is accurate. This was named the Problem Definition Process (PDP) and followed a similar co-creation methodology to the PCP (section 4.2.1). The creation of this process therefore was conducted considering Lewin (1947) and Burnes (2017) change management methodology. Co-creation in this case utilised eight interviews before the creation of this process, seven during the process development and eight after the process had been completed to ensure that process objectives were being achieved.

Within the existing process, some initial conversations around market need were developed and raised in collective meetings and then brought to the attention of members of the CSD's management group if they are seen as having commercial value. This process had several key objectives that built from this understanding and aimed to deliver value; these were:

- To reduce overall time to market due to the emphasis on generating accurate user needs and requirements and so removing the need for later scope correction.
- To improve cross team communication by centralising key divisional data on one accessible platform.
- To provide requirements traceability throughout the initial process of forming projects or work packages so that future project teams understand the reasoning behind completing such work as a part of the divisional portfolio.
- To place an increased emphasis on customer needs, as opposed to customer solutions, which will lead to more scope for innovation and innovative products.
- To ensure that requirement capture and storage is done effectively so that no data is lost when compared with a multiple meeting structure.
- To reduce overall project risk for any projects or work packages that are developed from the outcomes of this process by placing an emphasis on fully understanding the design space that is relevant to a particular user need.
- To generate an increased scope for divisional agility due to the early gathering and documentation of user need, leading to less defined constraints at concept selection.
- To support the division with a divisional Lessons Learned Database so that no two projects are making the same mistakes.

The use of co-creation as a research tool led to the process outlined in figure 39 which can be split into four sections for ease of communication. For comparison the existing process within the CSD is presented visually in figure 38.

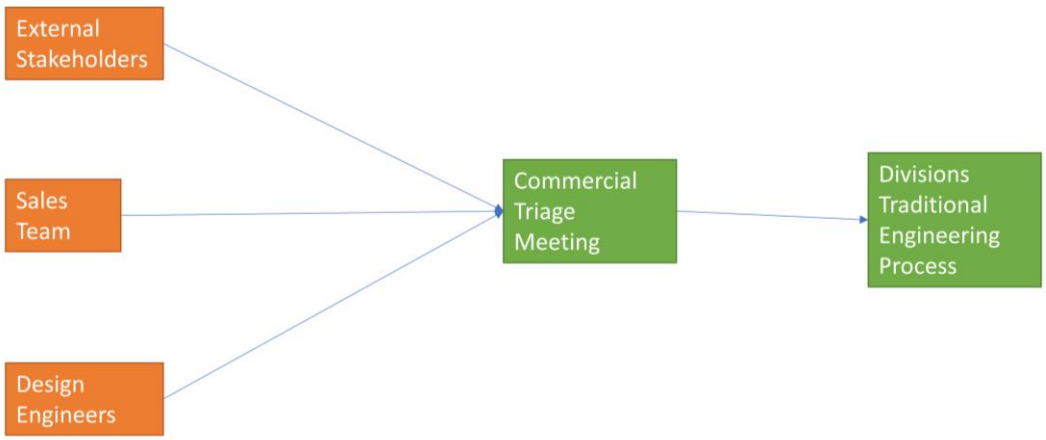

Figure 38 – Established Communication Overview

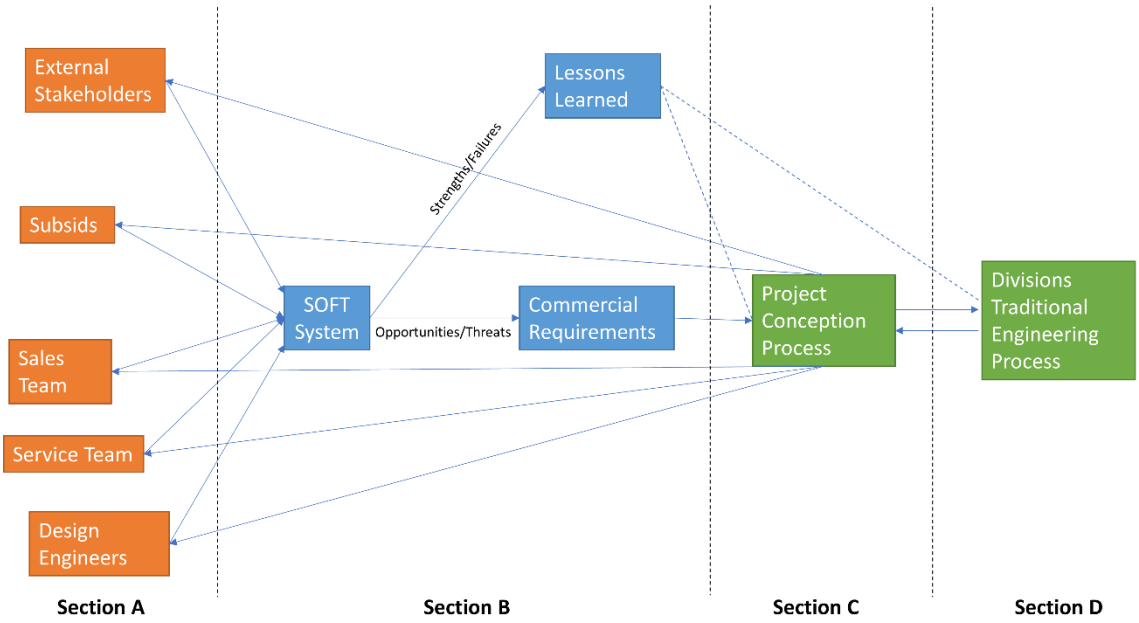

Figure 39 - Problem Definition Process Overview

Section A identified all of the customer facing roles that are present in the division, the vast majority of which took part in requirements generation before the formation of this research project. Therefore, the key objectives at section A were to shift the focus from defining a solution to documenting a need, and to introduce DT techniques as methods of generating this accurately. The tools that were proposed in co-creation initially were empathy mapping, customer journey mapping, persona generation, formal natural language, problem

statement validation with stakeholders, why analysis, mind mapping, assumption testing, product visualisation and storytelling.

Section B aimed to communicate the documentation and manipulation of incoming divisional data into a number of databases. The CSO traditionally used a SOFT approach (strengths, opportunities, failures and threats respectively) and so this was adopted as a familiar tool for these databases. All data points reported would be added to a SOFT system database that would split the points into their aforementioned SOFT categories and place opportunities and threats (as these were actionable points) into a commercial requirements database and strengths and failures (as these were points that could no longer be interacted with) into the lessons learned database. The lessons learned database was used here as a reflection point. The points that are positioned in the commercial requirements database moved forward into section C. Although there were a number of suitable candidates for this information management and communication system, the Atlassian suite of Confluence and Jira was eventually selected as it allowed the data gathered at this pre-project stage of the design process to be integrated with other Atlassian project implementations that had begun at that time; and thus, allowing complete project traceability. For added context, Jira is a project management software that helps project teams track project issues through to completion; Confluence is a collaboration software that aids in the sharing of project-based knowledge and Atlassian is the company responsible for the creation of the aforementioned software. It would also mean that this implementation would not fall foul of the cultural bias shown by interviewees towards SharePoint sites (in that these were seen negatively due to oversaturation) and that a level of transparency could be maintained between the individuals that were involved in each step of the process, the individual that raised the point initially and any other interested parties.

Section C represents the PCP discussed previously (section 4.2.1); one of the fundamental reasonings for the PCP to struggle initially was because there was no clear information flow throughout the pre-project stage of the CSD design process. Therefore, section C in this diagram represents the previously co-created DT and SE solution and all the documents created as a part of this are uploaded to Confluence and Jira to maintain this element of traceability.

Section D concludes this problem definition process and one of several things could happen depending on the point in question, its scope and perceived value to the division. If the user need was investigated and found to be valuable to the division and could be completed in a

relevant timeframe alongside other aspects of the divisional portfolio but fits outside the scope of all existing projects, then a new project may be formed to act on this. If the need falls under the same conditions but also falls within the scope of an existing project, then that project would be consulted in an attempt to alter its scope to include the need. In some cases, user needs that would form smaller projects can be introduced instead as part of the portfolio of non-project specific research and developmental work (R&D) where resources would be dedicated to it as a part of that portfolio. Finally, if a user need was not found to have adequate commercial value or couldn't be completed without impacting the costs and timeframes of existing projects significantly, it could be rejected or postponed based on these merits.

Similarly to the PCP, the metrics used to measure the efficiency of the PDP were generated using co-creation activities based on the perceived value that needs to be obtained at each stage. For instance, at the end of Section A, where the aim was to generate as many SOFT points as possible so that an understanding of customer needs can be generated, the metrics chosen were SOFT quantity and the subjective value of the DT methods that are employed at this stage. Similarly, in Section B, where it was important to understand the value of the database system used, the perceived value of the commercial triage and lessons learned database were measured through interviews and questionnaires. Section C reflected back on the PCP that was discussed previously which had its own metrics attached at each stage. Finally, Section D was measured using; a comparison of outputs from pre and post implementation, perception of risk reduction, perception of requirements confidence, perception of improvement of communication, perception of long-term strategy and perception of understanding of customer need. Again, these present perceptions as to outcomes that change participants may view as valuable.

Interview data reported that there was a need to consider a cultural change element to the implementation of the proposed process and activities therein. Therefore, communication around and about the change was encouraged and efforts were put in place to ensure that concerns were raised and resolved quickly. This implementation was supported by workshops that aimed to educate customer facing staff, design teams, project managers and engineering managers and encourage a mindset shift to one that supports the inclusion of DT and SE. A series of short workshops were also created for business management staff to aid in the understanding of the importance of market drivers and resolution of customer need alongside a technological drive for innovation.

4.2.3) Solution 3 – Low Fidelity Prototyping

The established CSD prototyping process focussed on high fidelity representations of an actual product, which led to significant increases in overall project cost for testing that is not necessarily required. This is especially true when high fidelity prototyping is done early in the design process, as was discussed in the interview series conducted, whereby changes in project scope whilst generating requirements may invalidate parts, subsystems or the system itself.

Therefore, the proposed solution aimed to implement a prototyping structure that uses low fidelity prototypes, and DT prototyping techniques, and structured test plans in a meaningful way to test components of a proposed design. Due to the perceived need for more knowledge in this field, the proposed solution would utilise SE to include the generation of test plan and test programme documentation and identify a number of methods for educating employees so they can learn the rationale behind choosing what these low fidelity prototypes might be. This body of work would be conducted as a joint venture between the primary researcher, and a number of other teams across the CSO that have previously encouraged the use of low fidelity prototyping. The prototyping solution was created using this methodology as this was perceived to support its engagement with stakeholders and generate accountability in the division, as is suggested to be important in the Lewin (1947) and Burnes (2017) change management process.

This prototyping solution was attempted to be implemented through the use of workshops at all levels within the organisation. Figure 40 shows the final prototyping solution that was proposed within the division.

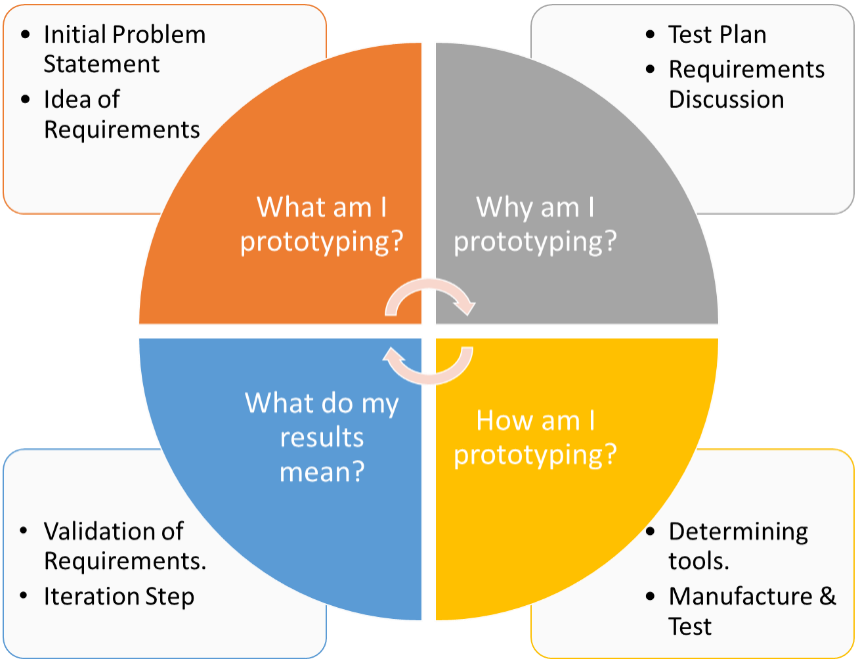

Figure 40 - Outline of Prototyping Proposal

Importantly, due to the proposed value of prototyping within early stages of a design process (such as section 4.2.1), later stages of design to test features or functionality, and in research and development work this prototyping work package was proposed to be suitable for implementation across a range of scenarios within the CSD.

The prototyping solution stakeholders identified a series of measurements that were perceived to be important within this implementation. These included the use of test plan and test programme documentation, the fidelity of the prototyping work found in each project and in the uptake of rapid prototype manufacturing techniques through the relevant internal team.

4.2.4) Solution 4 – Business Level Metrics for Design

Finally, the previously conducted interview and questionnaire series highlighted that there was an opportunity for the implementation of new divisional metrics for design. Since the implementation of metrics is key to the successful implementation of DT and SE (Royalty and Roth, 2016), this opportunity was used to identify and implement metrics that are supportive of the core values of either process. It is important to consider that this implementation was already being led by a senior member of the management team in the organisation and so key contributions were made from the primary researcher in terms of organisational change process and the metrics themselves. Where there may be ambiguity in the work conducted, this will be explicitly stated.

A total of 65 metrics were identified in literature that would support the implementation of DT and SE across the fields of engineering hardware design, software design and business management. Of these identified metrics, a total of 25 were proposed by change participants to be suitable for the CSD's activities based on the CSD's ability to measure and document them. These metrics were all reported to the senior member of the organisation for consideration as a part of the overall metrics portfolio that was being developed. Through stakeholders detailed analysis of the metrics that were measured at the time, it quickly became apparent that the ease of implementation of metrics would vary greatly, from metrics that would rely on data that is already gathered through to metrics that would require significant organisational or software-based change to achieve. Due to this, stakeholders decided to rank each metrics into categories based on its perceived value, ease of data collection and likelihood of successful implementation. This would therefore ensure that overall failure of the metrics implementation was easily identifiable, if any one of the "must have" metrics were not implemented then this implementation as a whole would not be successful. This implementation was developed with a group consisting of key decision-making personnel within each division to ensure that the differences between each division were taken into account as a part of the metrics chosen.

The success of this metrics implementation was proposed to be measured quantitatively. The perception of overall value, project control and risk reduction were proposed by senior stakeholders to be investigated through the use of a questionnaire as this implementation would likely reach a significant number of individuals in the organisation and values for these metrics could be quantified before and after implementation. It was proposed that the percentage of employees that had adopted these metrics could be identified at three months from the final date of implementation through existing metric measurements that are undertaken divisionally at regular intervals in the organisation.

4.2.5) Summary of Creation and Implementation of Solutions

To summarise, this investigation created a total of four solutions to be implemented within the CSD. These were a pre-process solution, a communication solution, a low fidelity prototyping solution and a metrics solution. The pre-implementation process considered the problem space, and aimed to ensure that the problem was fully understood before solutions were generated. The communications solution aimed to utilise DT and SE principles to resolve project related communications, and in turn support DT and SE activities. The prototyping solution aimed to implement design thinking and systems engineering prototyping methods to assist in early-stage innovation and resolution of early solution

challenges. Finally the metrics solution aimed to establish the use of DT and SE metrics in order to support DT and SE implementation. These were proposed to be optimally located within the CSD and attempts to implement them are considered in section 4.3.

4.3) Implementation of Created Solutions

This section considers change management methodological changes that were made in attempts to implement the solutions outlined in section 4.2 in response to attitudes and results that were found post the initial creation of solutions within the CSD.

As highlighted in the creation of each solution, solutions were initially created using the change management methodology proposed by Lewin (1947) and Burnes (2017) and the initial implementation of all processes followed this. Due to poor process implementation at 14 months post investigation conception (December 2021), which was six months post the creation of initial solutions, the approach to change management was changed to Bass (1985) and Kotter (1996). This meant that employees within the division were now viewed as barriers to the adoption of DT and SE as opposed to active participants, and stakeholder management was conducted to identify individuals influence and perceptions towards the solutions created. This change management activity led to the identification of specific divisional heroes that could adopt the solutions created and aid in the further progression of implementation for the Project Conception Process, Problem Definition Process and the proposed metrics implementation. The low fidelity prototyping solution failed to identify an influential, supportive individual, or progress through the use of the Bass (1985) and Kotter (1996) change management methodology, at 12 months from process creation and so the Lean Six Sigma change management process (Uluskan, 2016) was considered.

Overall, the solutions created experienced some success when implemented within the CSD. The Project Conception Process was implemented within the CSD but challenges were identified in implementing all proposed activities and in implementing the process within high value projects. The Problem Definition Process was implemented in its entirety but challenges were identified in generating adoption across the CSD. The low fidelity prototyping solution and the metrics solution failed to be implemented. The failures identified are specifically detailed in section 4.4 as these were analysed through failure-based learning.

4.4) Failure Based Learning from Implementations

Despite the emphasis on early investigation work to identify the DT and SE solutions that would be valid for this investigation, a number of solutions experienced partial success when compared with their proposed outcomes. Where failures occurred, these were investigated through interviews with key stakeholders and through the self-reflection journal completed by the primary researcher with the aim of identifying why a particular solution might have been partially successful. It should be noted that partial success was found within the solutions created and thus, this section does not propose that all solutions within the CSD failed but highlights the key failure-based learning so that the research questions can be tested against an applied dataset. To further emphasise, section 4.4 will consider how the primary researcher utilised failure based learning as a tool within this investigation to better understanding the challenges that were found when implementing each of these solutions.

4.4.1) Learning within Prototyping Solution

At the time of the initial investigation, a major new project was being undertaken that planned to utilise high fidelity prototyping very early in the overall design of the product. This was perceived to play a significant role in the initial drive to create a low fidelity prototyping implementation. When this project began creating a high-fidelity prototype, the overall perception towards low fidelity prototyping was reported to be negative as a successful implementation was proposed to waste the time and resources now used. This solution was therefore postponed until internal communication was released that indicated that a new product launch was being considered. At this time, the new project team were receiving explicit communication from project leaders that the project needed to be completed quickly and with minimal prototyping support. Furthermore, the interest and perception that low fidelity prototyping would resolve key cost and time issues had waned, a sentiment that was expressed especially clearly by key stakeholders within the new project in the final interview series. These factors were perceived to lead to the failure to fully implement the low fidelity prototyping package in the second instance and no alternative opportunities to implement this work were identified during this investigation.

4.4.2) Learning within Metrics Solution

The stakeholder perception of the initial proposed metrics implementation was that it was ambitious considering the limited range and number of metrics that were present within the organisation at the time. During the course of implementation, key stakeholders identified that there was no structure to support the recording or data collection of many of the metrics

proposed. Focus for this implementation therefore shifted from the metrics themselves to the facilitation of metric capture, manipulation, storage and output. Due to the constraints imposed by senior management on this proposed solution, where more senior individuals wanted cost and time data to be generated quickly, this ultimately led to the failure to implement any of the proposed DT or SE metrics that were outlined within literature.

4.4.3) Learning within Education Materials and Solution Engagement

Despite the initial drive to achieve suitable problem definition and a considerable number of attempts on the part of the primary researcher, workshops were not positively received within the organisation. Workshops were created for each of the solutions outlined in section 4.2, for the values of DT and SE and for DT and SE activities. Of the 22 workshops created over the course of the PhD (this does not include workshops with a planned length of less than 30 minutes), only four were conducted with more than five participants or at least 75% of their target audience whichever being smaller. Shorter workshops of less than 10 minutes were proposed by key internal stakeholders to teach individuals topics quickly as a part of their morning meetings and, of the three conducted, there was no attendance to this attempt at generating educational resource. Finally, a series of short videos were created that aimed to allow individuals to access education materials on a handful of the core topics of interest at that time, in their own time, with the intent to expand to other topics as they resolved particular stakeholder need. These materials were not viewed on the platform they were hosted on. Unfortunately, this demonstrated a failure to properly educate stakeholders within the CSO which directly impacted the implementation of DT and SE in this case study due to the importance of educational material identified in literature (section 2.2.1 and section 2.3.1). This also demonstrated a further function of the onus placed on pluralism and heroes (identified in section 4.1.1.2) as participants were enabled to choose whether to engage with the educational material proposed. In this instance, failure-based learning identified that the hero, cultural factor must be overcome to generate consistent engagement with educational materials and change management activities.

4.4.4) Summary of Failure Based Learning

The consideration of failure-based learning throughout section 4.4 is vital to answering the research questions considered as it allows for an investigation into an applied set of circumstances as opposed to consideration of perception or reflection data. This investigation considers each of the component research questions.

Previous to this investigation, a number of optimal locations for implementation were identified through the co-creation of solutions done in section 4.2. This investigation proposes that of the four solutions generated, the prototyping and low fidelity work package created were not optimally located within the CSD as they were not implemented within the CSD. However, due to their partial success, the Project Conception Process and Problem Definition Process can still be perceived to be optimally located as the implementation findings were similar to those from the co-creation activities.

The attributes to the implementation of DT and SE were identified and validated in the pre-implementation investigation (section 4.1). The consideration of failure-based learning does not contradict any of the attributes previously identified but instead presents implementation data to support whether the attributes in question are valid. This is discussed further in section 5.4.

The change management methodology proposed in section 4.3 outlined a number of changes that were made in efforts to further the implementation of generated solutions. By considering failure-based learning, this section points to where failures in these change methodologies took place. A further discussion is presented in section 5.4.

Finally by reflecting on the objectives of each solution generated in 4.2, solutions that have failed may identify areas where the value of DT and SE is not perceived to be present. Reasons for this perception vary and are included in section 5.4.

4.5) Measuring Implementation Outcomes

The solutions successfully created and implemented within the CSO were measured against the initial objectives created and the attributes to implementation identified in previous investigation. This section will aim to discuss efforts made to outline and measure selected metrics, and in doing so answer the following research questions;

1C) What procedures support the implementation of DT and SE within an LEO?

1D) Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?

4.5.1) Measuring Communication between Customer Facing and Design Focus

One of the objectives for the problem definition process (outlined as solution 2) aimed to improve communication between the customer facing roles in the organisation and the design teams, as poor communication was proposed to be one of the key reasons for failure

within an organisation (Kasser and Schermerhorn, 1994). A comparative metric between the number of valid information points before implementation could be compared to the number of valid information points received after implementation to determine whether the implementation had been effective. Previous to this implementation, the organisation utilised SOFT reports that would regularly be conducted by customer facing roles to inform the strategy and management team of any strengths, opportunities, failures or threats that might be relevant to the division. As this proposed solution was aiming to build from this structure, a comparison was made from data collected using these documents in the year prior to that collected as a part of this process (figure 41). This figure has displayed average values in percentage change across 1 month, 1.5 month and 2 month averages as variations on a smaller scale were significant.

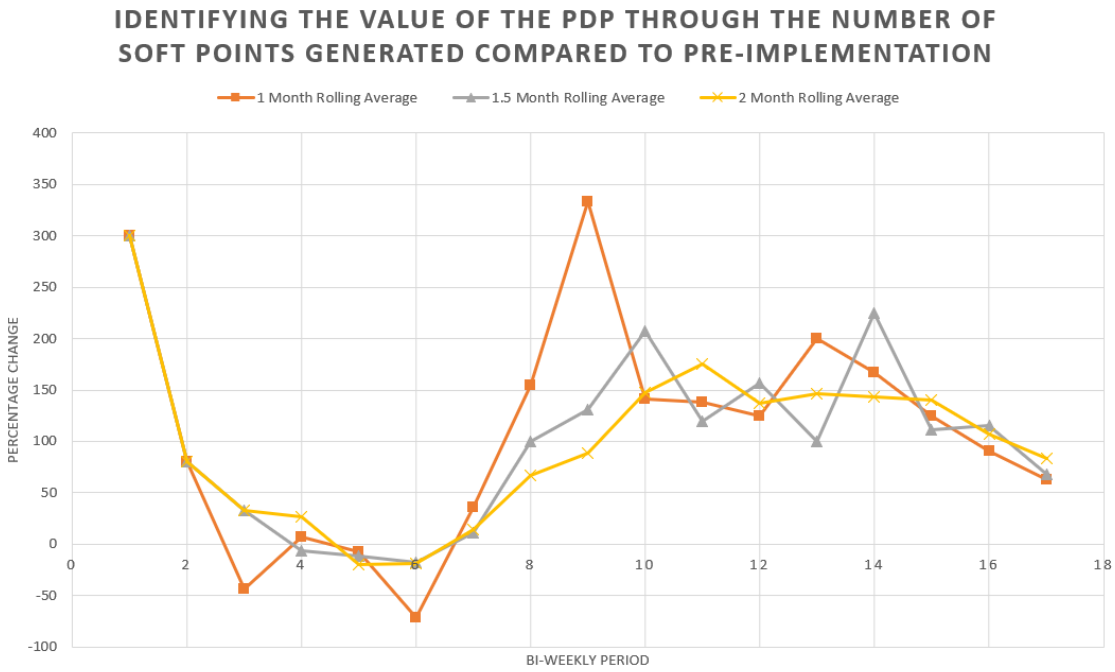

Figure 41 - Percentage Change in Communication Post Implementation

Figure 41 shows that once the process had been established at around 7 bi-weekly periods (or 14 weeks) from conception then consistent positive change was found which peaked at around 175% increase on the two months rolling average. Furthermore, these averages were sustained as a positive increase in number of data points over the next 20-week period suggesting that this had been a successful, sustained improvement in the communication channel between customer facing roles and the organisation's design teams.

4.5.2) Project Case Studies

Since there was very little opportunity for outcomes to be measured within this research, as divisional projects at that time had an estimated time to market of a number of years, a small, internal project was conducted using DT and SE techniques that aimed to resolve a particular documentation need that was present within the CSD. This documentation need was raised in the preliminary interview series but was not incorporated into any of the solutions created in section 4.2 as it was proposed to be a single, discreet body of work.

DT style interviews were conducted with a total of ten participants that aimed to identify the aspects of the particular documentation that were required to resolve this proposed problem. Emphasis was placed on aiming to understand interviewees perceptions as to why they required sections or chapters as this investigation was aiming to focus on its respective problem space. Once this data was collected, root cause analysis was conducted with the case study participants to explore what the underlying meaning was behind initial responses.

Once root cause analysis had been conducted, the generated requirements were constructed using formal natural language and reported back to the project participants to verify that the outcomes of the root cause analysis accurately reflect the user needs. At this stage, a total of 92 different requirements were verified and could be thematically structured under nine different headings to form a document specification. Examples of these included;

- Must have clear instructions about the manual handling characteristics for each machine.
- Must include a checklist of tools that will be used at the start of the document for easy access.
- Should clearly identify and label components in the schematic diagrams

This specification was then used to outline how the initially proposed documentation need could be resolved and was incorporated into the existing projects within the division. Creation and use of the documentation had an upfront cost of around £13,500 based on the requirements and estimates made as to personnel wages to complete the document to the specification generated. However, the overall improvement to the users' role was proposed to be 20% more efficient than previous solution. This is a significant finding, as without the application of DT and SE to understand the user needs and to identify the documentation solution in the first place, emphasis may not have been placed on this area and the project may not have been conceived at all.

4.5.3) Final Interview Series

Once attempts had been made to implement the solutions previously outlined, an investigation was conducted to reflect on the changes that had occurred within the organisation and understand how the attributes to implementation had changed. This investigation also utilised a semi-structured interview series to investigate its aims as the solutions created and proposed had co-created metrics and it was the change in these that was important. Each of the following sections within 4.5.3 relates to one of the proposed objectives, and corresponding metrics, identified earlier in the creation of each process (section 4.2.1, 4.2.2, 4.2.3 and 4.2.4). This interview series therefore was aiming to identify the outcomes of the implementation of solutions and explore how the attributes to implementation affected or may have changed over the course of this investigation.

4.5.3.1) Internal Communication

Participants universally reported that internal communication had improved since the conception of this investigation, but half of the participants expressed concerns relating to issues that they still perceived to be present. For instance, one participant reported concerns regarding the;

"…communication of business strategy and … decisions." [CI002]

This emphasis is opposed to the technology drivers that are, traditionally, focussed on more prevalently within the CSD. Interviewees proposed that communication is seen, in some cases, as being essential to replace poor or missing documentation.

Solution 2 was suggested to be important in creating the positively perceived change with regards to internal communication, especially with regards to opening a channel between the division's customer facing roles and the division's design and management teams. However, this was not perceived to be a conclusive solution to the entirety of this specific issue as participants raised that;

"[People] are listening … but what happens to these suggestions after [the researcher] reports them onwards?" [CI003]

This concern was coupled with the reported perception that participants were becoming disillusioned with the implementation of solution 2 as it was not resolving this internal, pre-process need. This suggested that further work could be done that focusses on the transparency of information and decision making within the division to explain and ensure that involved stakeholders perceived the value of the work that was being done. Failure to

do so could impact on the long-term implementation of this work, as the proposed disillusionment may lead to rejection.

When interviewed, some participants made comparisons to previous places of employment and identified that communication within their roles might be better than other organisations.

> *"[Communication] is better than most companies I have worked with… People are very friendly." [CI004]*

This point could be presumed to identify that internal communication within the CSD was stronger than in other organisations; however without significantly more data to support this claim, this cannot be concluded. One participant proposed that the advent of COVID had improved the communication that individuals and teams have between themselves as more of an emphasis was required to be placed on the effective communication of information.

> *"I think that COVID has probably improved internal communication to some extent. You know you can't replace face-to-face communication… but I think we've become better at putting more detailed emails and we probably have more regular communication because we know that we can't do it face-to-face in the office." [CI008]*

However, the interview sample more commonly reported the alternative, that with the introduction of remote working it had become harder to clarify issues and generate opportunities for innovation.

> *"When you're out of the office, there is a lower touch time with people around you. I suppose it's also the opportunity you get… when you can just grab someone who's in front of you and go oh, by the way, what about this?" [CI001]*

When specifically asked about the implementations created and implemented as a part of the body of research, participants reported positive changes to their perception of internal communication when compared with pre-project conception.

> *"I think that [the communication process] had affected how our communication has changed. We're probably not significantly better than we are were two years ago, that bearing in mind we've reached a sort of comparable level is sort of an indicator that the system does*

work because were doing it with a much-reduced workforce and so actually, I think as a tool, it's been significantly more efficient than previous communication methods." [CI009]

The interviewees mention of efficiency in process can also be interpreted as a strong indicator that this interviewee culturally accepts that there is a value in developing process over more unstructured approaches. The concepts of process and structure were considered when discussing external communication.

"So I would say that the approach we take is a more structured approach to that communication with the subsidies to get that kind of market feedback in detail has definitely helped on that point." [CI009]

Interviewees also reported positive changes regarding the concept of reviews and review stages, which links to the concept of metrics, as this prevented potentially high risk or low reward projects from being initiated.

"And I think it is also tied in with the idea that we didn't really evaluate things from a commercial point before we started doing them." [CI009]

The key objectives for each solution created through the co-creation process was conducted, in part, so that participants were being listened to and therefore more likely to support the generated solutions. One of the key objectives behind the implementation of solution 2 was to "ensure that requirement capture and storage is done effectively so that no data is lost when compared with a multiple meeting structure". This had a secondary effect in practice, as interview data proposed that this structure also allowed customer facing roles to be provided regular feedback on the ideas raised through this process and thus lead to more support for change.

"We get the information in, and I think the feedback loop actually works pretty well, the communication back [to customer facing roles]. From what I'm hearing, we are getting good engagement and its good for the teams that feel like they're being listened to." [CI009]

However, when asked about the implementations presented, participants also proposed that the focus on improving communication had now gone too far and that this was now starting to hinder the CSD.

> *"I can see how we've tried to improve communication but we've possibly tried to improve communication too much now. So what we're trying to do is to create an open, cohesive culture by telling everyone everything but all that means is that because [senior management] don't know all of the answers and we end up with everyone having partial information which then gets spread around as rumour." [CI010]*

Although this was not an intended effect, this concept of communication being too prevalent is something that may need to be taken into consideration in further research as the negative perceptions to this may present longer term implications on the success of the managed change.

4.5.3.2) External Communication

Participants commented that there was a stronger understanding of customer needs compared to project conception but perceived that nothing was being done with this market analysis due to the cultural focus on developing technology drivers. This therefore presented a significant barrier to the longer-term adoption of the implementation of DT and SE as the value proposed in the creation of the solutions used in this investigation was not being fully realised. This also supports the suggestion that to implement a DT and SE process, a level of cultural change must be achieved.

Another point raised was that although efforts were being placed on better understanding customer need, the resources required to effectively engage with customers about products or new projects was still missing. This limited the success of the implementations conducted as customer facing roles were prevented, in some cases, from engaging with customer using the proposed solutions and thus offering an opportunity to regress back to previous processes. This again would suggest that a change in culture and mindset was critical to the long-term implementation of new process. However, due to the non-uniformity between project resources this would also suggest that the attribute individual mindset and skillsets was important as individuals from different projects were supportive of the proposed change management activities in different ways and thus led to different outcomes.

When asked about the solutions created and their perceptions regarding external communication, participants reported that communication externally to the organisation has improved in both frequency and quality.

"Communication has increased and is better. It still feels a little bit like it's in process rather than a finished product from my point of view." [CI006]

In particular, some participants proposed that communication had improved on an individual level between customer facing roles within the CSD and the division's customers and identified that this had a direct impact on the design of new products.

"I think that individual's communication is very good to the customer… That communication I find really interesting as it opens your eyes to different aspects as well as known problems that we've got. You can see things getting better and the things that need to be improved." [CI006]

Participants that were supportive of requirements generation in the CSD proposed that the development of communication methods within the organisation were vital in the development of new product design.

"I think that we communicate with [customers] a little better… We can pick up the phone and arrange a call with very minimal effort now. The information that we've managed to get from our key accounts for the [new project development] partners is invaluable." [CI008]

Emphasis was placed on this value during the co-creation and implementation processes undertaken within the CSD and although this participant perceived that change had been improved 'a little', this provided strong evidence to suggest that that further investigation and evaluation of communication methods could lead to positive outcomes.

Overall, most participants proposed that they believed that the CSD did now understand what the market wants. However, perceptions towards the division's understanding of market needs are mixed amongst all fields of expertise.

"I don't think we've got a fundamental misunderstanding of what the market wants us to do. I think we likely have enough conversations with customers to understand roughly what the market wants us to do. Yeah, fundamentally it's not like I think we're misreading the market and going out to complete the wrong things." [CI009]

When this information is collected, participants proposed that there are issues with the dissemination of market information to other areas of the division.

"Customers are giving feedback. I think that's very important and I've heard that other people are very keen on this as well. The problem is it doesn't filter down to us, those requirements, I have noticed… There's no indication that this problem is being worked on or that there is a problem so filtering down to us would be good." [CI012]

Therefore, reflecting on the preliminary interview series, this meant that the implementations completed have not successfully resolved the previously raised issue of internal information dissemination.

4.5.3.3) Long Term Strategy

Perceptions to the long-term strategy communicated by the divisional leads was reported as mixed. The technical engineering strategy, which focused on design activities aiming to achieve a particular use case or develop particular technologies, was reported to be greatly improved and overall reported as positive. This would suggest that activities that aimed at better communicating why something was being developed were positively received.

However the sales strategy, which aims to identify and engage with customers in a particular way; service strategy, which aims to maintain customer machines and generate revenue; and the business strategy, which dictates the overall focus of the CSD within a market, were reported by interviewees as being 'low confidence'. In the case of the sales strategy, this dictated the ways in which internal staff members communicated externally and thus low confidence in this field indicated that although DT and SE tools had been implemented to better understand user need, these are not reflected in the overall sales strategy. The service strategy was not engaged with directly by any implementations conducted but would have been indirectly impacted by the implementations that encourage an understanding of scope and engagement with customers over a product lifecycle. Therefore, concerns here may indicate that where successful implementation may have taken place at the beginning of the CSD design process, these attitudes and considerations may not be carried through to project completion. Finally, the business strategy would have been impacted by activities that aimed to investigate user groups and particular markets as insights generated therein would affect the business decisions that need to be made for future projects. However, since the time to market for a product within the CSD considers years rather than months, it may be possible that influences from these implementations were not yet able to be implemented by divisional management.

In some cases, participants considered long term strategy not only as the development of new products and services but also in terms of the strategy of generating and training individuals and resources for future projects.

> *"I think that [the long-term strategy] is good… We're already looking at integrating new engineers and apprentices." [CF004]*

There were a few instances (18%, four participants) where participants believed in the long-term strategy and also believed in the division's capacity to execute on this proposed strategy. One of the key issues with this was proposed to be due to the rapid change in focus when considering product development.

> *"In many ways, there's too many false starts. It was the [redacted] machine when I started which was quickly internally rubbished. Then it was the [redacted] which was quickly rubbished and now we have the [redacted] which I rate as a machine but unfortunately its now also rubbished within the business as well." [CI003]*

This concept was similarly proposed in participants that did not have confidence in the long-term strategy.

> *"I think other people would say that we change direction, make strategic changes and sort of top-level changes and these have been too frequent for people to gain confidence in the strategy. The timing and scale of the changes doesn't convey a clear view and clear vision… I think it's just come down to that lack of unifying vision that's actually driving decisions." [CI009]*

There were many other reasons and suggestions for why interview participants were still not confident in the long-term strategy after process implementation. One of which considered the clarity of the strategy that senior members of the division were communicating to other individuals within the organisation.

> *"I think that I would start with the strategy, it's not a clear, coherent strategy that everyone can buy into." [CF007]*

A similar point raised considered more recent change within the division and made comment to suggest that they believed that the current divisional strategy is not supportive of the data recently collected within the organisation in the form of requirements.

> *"Being brutally honest, I am not confident [in the long-term strategy] … We worked with customers, we work with partners, we've got these requirements on board. We're not focussing on the project that we've just collected requirements for where we know customers really want value." [CI008]*

The same participant raised that the long-term strategy was inherently linked to the idea of risk acceptance within the division and that the current strategy chosen, although known, was simply too great a risk for a division with products of the size and scale prevalent within the CSD.

> *"[Senior employees] want to launch a product to customers where they don't realise that they want this technology and [they] want to take the world by surprise… But the stakes are too high. If we get this wrong its millions at stake rather than [other divisions' projects] which are tens of thousands of pounds lost." [CI008]*

4.5.3.4) Cost and Timeframe Predictions

Individuals within the CSD raised that "Cost and time to market are more accurate than they were… [before implementation]". This was one of the key concerns raised pre-implementation and the main focus of the Project Conception Process as quantitative data presented in 4.1.3 identified that this was a significant divisional issue. However, this was not perceived to be completely resolved as change was still occurring within projects late in the design process that was leading to significant changes after process implementation.

When asked for suggestions on how to develop this, interviewees reported that the introduction of a change management process would be vital to driving improvements within the division's operations as it was reported that individuals involved in project-based change management did not necessarily see what the impacts of late project change might be. This reflects on the failure found in this research to implement suitable education materials throughout the company due to poor engagement. Had a solution been identified to this problem, there was a possibility that cultural change could have been enacted and this issue mitigated.

When considering the timeframes proposed, participants suggested that there were some improvements although these were minimal.

"[Timeframes] are still a bit of an afterthought but its less of an afterthought than is used to be." [CI010]

When participants were asked about their confidence around the suitability of the new timeframe values proposed, the vast majority (75%, 16 participants) responded negatively with a consensus that the new product timeframes were likely to change over the course of the project development.

"A lot of people are comfortable that the timeframes that we have for the [new machine development] are not what they are going to end up being." [CI004]

When these participants were asked why they believed that this might be, the majority identified that the divisions tendency to enable change at later stages within projects and be more reactive to changes in technology and the market as the primary issues. Individuals of higher seniority supported this argument and stated that the proposed timeframes would be accurate if these late changes did not occur.

"We might say we want to deliver this product in this timeframe but its typically reactive. We say, so if the organisation needs to do, we need this change in the organisation in order to deliver that, which is not necessarily the wrong way of working. It's just that its purely reactive." [CI001]

However participants did propose that change had occurred, and that conversations were present within the CSD to place a better emphasis on the planning and managing of project timeframes.

"[There is an emphasis on better timeframe analysis] so that we can present accurate plans to senior management and allow them to make the right decisions when it comes to cost." [CI008]

This also extended to a more individual level whereby some participants proposed that they have taken personal steps to develop their own abilities.

"So yeah, definitely, timescales and financial management is something that I've improved on a lot over the last two years." [CI008]

Interestingly, some participants reported that it was hard to evaluate improvements with regards to project cost and timeframes as these were not perceived to be key project drivers or issues that are commented on within their teams.

> *"[Cost and timeframes] are just not often the drivers of projects or they don't often surface as issues. There's certainly more awareness of timeframes and cost but have we actually done better at hitting those time costs over the last two years compared with the previous period. We probably don't." [CI009]*

In the cases where participants remark on the awareness that the company has with regards to cost and timeframes, these were always positive and suggested that where changes were not perceived to have taken place within the relatively long timeframe projects that were undertaken within the division, there was an added emphasis and awareness of this moving forward.

> *"There's maybe slightly better awareness of how well we are performing against timelines and I think that probably project costs like direct costs, like material costs and capital costs, we were in a slightly better position compared with before anyway." [CI009]*

Participants also proposed that the lack of change with regards to timeframes and overall project cost are likely due to the lack of metrics or standardisation within a project, and so making it very difficult to evaluate how long a project should take, or how much a project should cost.

> *"It's very hard to evaluate [project timeframes]" [CI002]*

Finally, where success has been found in suitably predicting the cost and timeframes required within a project, there was a dichotomy between the values that are proposed by project managers and those that are requested by the more senior members of staff within the division.

> *"The [recent product release] was pretty much on budget and it wasn't that far off timescales. [The project managers] timescales were fairly accurate but what the division asked for was a bit unrealistic." [CI010]*

This had potential implications for the process quality investigation conducted in section 4.1.3; as although the project management and accounting data was completed by project

management, this highlighted non project personnel as having significant impact on the overall planning of CSD projects.

4.5.3.5) Requirements Generation and Understanding

The understanding and use of requirements in a small number of projects was perceived to be good and in these cases requirements were considered to be more accurate than before implementation. This reflected positively on all implementations conducted as the generation and communication of market need is critical throughout. However, the projects that are perceived to have poor or no requirements were also perceived to have incomplete or poor understanding of business case.

When asked for suggestions for improvement, interviewees went on to identify a balance between the level of detail of requirements, and the ease of communication and manipulation of requirements suitable to the products and services being offered by the CSD as vital for future products.

> *"[Projects] have been getting as many requirements down as possible but [project personnel] aren't looking at them... We need to make it clear what the key messages are for the [new product]" [CI007]*

Implementations conducted thus far had not focussed on this and had aimed predominantly at generating as great an understanding of the market need as possible. Overall the generation of requirements was seen by participants as 'invaluable', and interviewees proposed a number of occasions where project requirements were disseminated to design engineers to support the design and development of new projects within the organisation.

> *"The information that we've managed to get from our key accounts for the [new project development] partners is invaluable… It's nice to see that those requirements are now being set down and disseminated to the design teams because one thing is collecting up a database of requirements from your customers but the important bit is how you use it." [CI008]*

The creation, application and manipulation of requirements was briefly discussed within the CSD as being considered in more depth for the current and future machine development.

> *"Hopefully now we have a master set of requirements that we can tailor to each new machine that comes along. We didn't have that before;*

each group had their own requirements… There was no real collection of requirements for the main purpose of the machine." [CI011]

Perceptions and commitment to generated requirements were reported to be unsupportive to the implementation of a requirements-based process within the CSD.

"So the problem that I've got is that we've spent probably 12 to 18 months on requirements, capturing requirements, dissemination to project teams, working with key accounts, working with partners and now were being told that potentially we might allow a machine that has a very different architecture to the specification." [CI008]

Therefore, although requirements could be generated within the CSD as a part of the implementations created, the perception of value of requirements had not been implemented successfully and was not present within the organisation prior to implementation. Ultimately this meant that the attempt to implement process should have also considered more of an investigation and consideration of organisational culture when creating the proposed solutions. However this point can be explored further, as other interviewees proposed that this was evidence of where the CSD's drive for innovation was prioritised over a more structured requirements generation process.

"We're not focussing on the project that we've just collected requirements for where we know customers really want value. Were now going for, were not prioritising a product that hasn't had a structured SE approach and that is more about internal innovation." [CI008]

In some cases, individuals within the CSD worked on the generation of requirements outside of the solutions that had been created as a part of this body of work. In particular, participants reported instances of using MOSCOW requirements generation with the intent to get individuals within the case study to commit to particular courses of action.

"I was quite keen to use MOSCOW analysis so that you can work out what we're definitely going to do against what we are fully committed to do." [CI008]

This process allows project teams to identify the value placed against requirements; including what must be done for project success, any requirements set through laws or

legislation and any additional requirements that could be met to further achieve project goals.

4.5.3.6) Risks

As a division, the development of new products or technologies is reportedly comfortable with the concept of project risk and efforts made in implementing activities to reduce this were often not successful.

Interestingly, people in more senior roles within the organisation perceive that individuals within the division should be happier accepting more risk whereas people in less senior roles perceive that the risk that was accepted at the time was unnecessary. Individuals who perceived that risk was unnecessary also often proposed that internal communication was poor and reported lower confidence in the overall divisional strategy meaning that risk acceptance may be linked to other divisional factors.

When asked about risk, some participants proposed that the acceptance of risk within the CSD remained too high. Some participants went on to comment;

> *"If we get it wrong, we lose millions basically, and that could jeopardise the division in general." [CI001]*

Some participants propose that this is due, in part, to product complexity and the complexity of products that was present among other divisions.

> *"When we think about risk, I've mentioned that [other organisational products] cost a lot less but our projects are considerably more complex than something that we might make somewhere else in the organisation." [CI005]*

To conclude this section on risk, one participant remarked the following.

> *"So I think where we are now starting to recognise that sometimes things can go really well and sometimes they can go really badly, and you need to plan for that middle ground that takes those risks into account that you're planning for." [CI008]*

Initially, the preliminary interview series conducted found that the CSD as a whole was very risk accepting. However, this interview series found that the response to risk was much more balanced with participants commenting in favour of both risk aversion and risk acceptance. Interestingly, participants that commented in favour of risk aversion were less likely to

comment positively on the existing organisational culture whereas those who were in favour of risk acceptance, were.

4.5.3.7) Lessons Learned

The introduction of lessons learned within the organisation was perceived to be positive and interviewees commented that the development and engagement with these resources will lead to perceived long-term benefits. This suggests that communication here has been improved. Lessons learned work was found in interview to have been conducted in a number of other areas.

> *"There are a number of different projects going on at the moment that think about lessons learnt and how we take away from things done previously." [CI011]*

One participant proposed a lessons learned process that had been adopted outside of the scope of the research work being conducted.

> *"[In one previous project] we had a meeting where everyone was invited…and everyone could anonymously write in post it notes for things that are good, things that are terrible and things that could be improved… We said, what could we do better next time? And then we've had actions come out of them... The plan is that when we go to start any other project we review that basic checklist. We're going to be using it now when we start a new gate." [CI010]*

This acceptance proposes that the value of failure-based learning is known within the CSD, which was also found in the preliminary interview series, but to the extent that individuals within the CSD develop their own lessons learned methodologies.

However, in some cases participants reported that the CSD "are not necessarily fixing our problems or learning our lessons." This proposes that although success has been found when developing and delivering failure-based learning, this perception of value does not extend throughout the division itself, and that some individuals were not engaging with the lessons learned work.

4.5.3.8) Innovation

Perceptions towards the capability of the division to be innovative are mixed but interestingly, when compared with the other measured metrics that are found to be mixed,

perceptions are not linked to seniority. Instead perceptions to innovation are mixed among all levels of seniority within the CSD. When queried, individuals reporting that the case study is innovative also proposed that the division's cultural drive for innovation needed to be more balanced with obtaining the basic needs required for particular markets. On the other hand, individuals that perceived that the CSD was being not innovative propose that the design work ongoing in the division was still trying to catch up with the divisional competitors already in the market and as such, the innovation is trying to achieve something that has already been done. One participant that reported the division to be not innovative proposed that current attempts to improve this metric were a "waste of time" due to the influences of the organisation's culture.

The concept of innovation is a critical driver of projects and new product development within the CSD and is perceived by divisional employees as one of the strongest aspects of divisional process.

> *"The focus now is less on budget and less on time and more about making sure, to be better rather than cheap. We always have been innovative. I think innovation is our driver and that is the one thing that matters above anything else." [CI001]*

When asked for their perceptions of change on how the division works with innovation between the pre-implementation and post-implementation phases of the body of research conducted, participants reported that change has occurred when considering how innovation is used in the design and development of new products.

> *"In the last two years, we changed how we approached innovation… I think maybe we've been a little bit more focussed on the sort of innovative outcomes and thinking about how what we do from an R&D point of view will actually impact the product and drive commercial value." [CI009]*

Participants did not comment specifically on whether their perceptions on the innovativeness of the division had changed at all due to the implementations themselves or any action therein. However the development of this innovative emphasis was perceived to be positive within the division.

> *"Innovation is emphasised in lots of different projects and it has paid off to be honest." [CI006]*

This positively reflects on the solutions implemented (and their emphasis on innovation) and further supports the argument that being able to innovate is critical to the CSD's culture.

4.5.3.9) Resource Allocation

The resolution of resource allocation was perceived to be critical to the long-term success of the business and efforts to resolve these have highlighted a dichotomy of opinion between more senior and less senior members of the organisation. More senior roles perceived that the resources available within roles at the time were sufficient and that prioritisation needed to occur where other individuals were not content, whereas less senior roles proposed that there were simply not enough resources to complete work to the required standard and that this could lead to issues in future machine design. Ultimately blame was placed on the recent restructuring that had occurred in the division and the change in resources between before and afterwards.

> *"You might put [organisational issues] down to the reduction of headcount. I mean, obviously, that definitely affects our ability." [CI009]*

This interview series also raised that resource allocation concerns also include a lack of documentation to support particular functions or roles which in some cases was perceived to impact the relationships between individuals and divisional customers. This concern was perceived to be related to the lack of resource available in the division's marketing function and unrelated to the implementations that had been conducted.

4.5.3.10) Individual Mindsets and Skillsets

When discussing individual mindsets and skillsets and their impact on the design and change management activities that had occurred as a part of this body of research, participants indicated that they were much more aware of the need for particular mindsets and skillsets when following a prescribed design process or completing particular activities.

> *"If someone comes into the company and doesn't have an [established] skillset then they are going to have a steep learning curve… It's about getting the right individuals." [CI004]*

Participants did comment on the culture that was present within the CSO when discussing issues relating to individual mindsets and skillsets and outlined that with the emphasis being placed so heavily on the individual rather than any defined process, which meant that any circumstance where individuals are not available within projects, can be incredibly disruptive.

"We're so focussed on individuals, you know, this individual can do this or this individual has this skillset. And this is an issue when we actually lose those people, we have these massive gaping voids." [CI010]

This point can also extend to individuals understanding of a topic however, as participants raised that if responsibility is placed on an employee, but they don't necessarily have the experience or skillsets to complete that responsibility, then further issues can arise.

"What we seem to be working with here at times, not all the time, but especially with new features and new technologies, is people that might not necessarily know everything there is to know about it or where it's going, to try to use it and it tends to crumble a bit under the strain of, we've asked that one person to know everything there is about that part and they don't necessarily have that experience yet." [CI012]

4.5.3.11) Organisational Culture

Participants raised that organisational culture was considered to be one of the most significant negative attributes to the implementation of new process and overall one of greatest influences in the completion of projects within the CSD.

One of the issues raised by participants concerning organisational culture suggested that there was a strong cultural focus on the design aspects of organisational activities and a very weak focus on all other aspects of business.

"[The CSD] has three areas; one is the engineering which I have to say we are brilliant at and we excel in that particular area, then you've got your sales, marketing and strategy driven technology and the third leg is service and support. We have one massively strong area… but you don't have success because success is all three." [CI007]

When explored further, participants alluded to the idea that this concern could be due to the perceptions and focus on technology drivers as opposed to market drivers, and thus the value placed on developing new, innovative technology compared with understanding market needs.

"There is always a reason to change our minds and there is always another market to go into but if we keep chasing this then were never going to meet our targets." [CI003]

This is not proposing that SE and DT are incompatible with a focus on technology drivers, but the minimisation of value placed on market needs does contradict the user centred design approach taken by DT and the focus on understanding market requirements proposed by SE. Some participants stated that this focus on innovation as an aspect of the CSD's organisational culture extends further, proposing that individuals within roles that progress the development of technology drivers are viewed more positively than individuals whose roles progress any other aspect of the business. This tight focus conflicts with the idea of both DT and SE.

> *"We have this mentality that engineers are where the value is and anything beyond is redundant." [CI007]*

When reflecting on organisational culture's impact on the changes that have taken place within the division, participants reported that change has to be agreed on by all parties and suggests that stakeholder management would need to consider all relevant parties that were affected by change and not just the ones that were perceived to be key to its implementation.

> *"Every sort of level of hierarchy that we have can think that we need to change things but getting everyone to agree to change something is very hard." [CI004]*

Some participants proposed that there was a period of time during the course of the implementations conducted whereby process change was being made that benefitted projects and alluded to a number of positively viewed steps that were being taken.

> *"I think we were making significant strides in the right direction. [Project management] were in control of the project, we knew who the stakeholders were. We had it all quite clear. All the communication routes were quite clear and the culture was quite clear…We were engineering led and we were solution led but we were also keeping an eye on communication…We were doing loads of SE stuff that was all going quite well and now it feels like we've just sent it all back to the [redacted] days where were just chasing our tails and working out what the [senior management] want." [CI010]*

However this point emphasises the importance of creating and managing organisational change within the CSD, as success found at an early stage can easily be removed if the perception of value is not shared by all members of a project team

4.5.3.12) Established Process

When commenting on perceptions towards the process that was in place during the final interview series, participants raised that although process had been implemented that aimed to combat the initially proposed issues in the division there were still a number of cases whereby the implementation of DT and SE could be expanded.

> *"And they were saying, well you know, we work really well where there are no regulations…but when you start to put in regulations or health and safety we run into all sorts of problems that really could have been foreseen the earlier we thought about them." [CI007]*

For example, the early generation of requirements and efforts to implement systems level thinking early on in the proposed design processes implemented may have mitigated this issue had implementation in this area been more successful. This theory was especially prominent when considering markets like aerospace where proposed regulations would prevent the traditional methods that the CSO would employ as these relied on an element of surprise.

> *"If you look at aerospace, for example, they need that machine to operate in a very specific way because they spend so much money on certification and compliance that you need to work with those customers to develop the product over a long period of time. I think that if we were to launch into the market with a product and try to surprise them, the chances are it's probably going to be not good." [CI008]*

When participants were asked what they would like implemented to further combat the proposed divisional issues, participants raised that a change control process would be valuable to ensure that long term project development is not negatively affected by late design changes.

> *"For me, it would be a change control process, to say that if this change that's coming really is disruptive and its potentially a big project in jeopardy then we need to have a bit more justification for why we are*

changing something. There's never mention of a business case, it's always a mention of we think it's the right thing to do." [CI008]

Furthermore, this change control process would need to consider business cases which indicated that the influence of market drivers was considered to be valuable from their perspective.

"I think if we had a proper change management process where, you know, we could review the business case and work out what the impact is going to be on the company, on the division and on the customers we can weigh it all up and go, actually this isn't the right decision. The risk is too high." [CI008]

Ultimately participants raised that even when projects within the CSD were utilising DT and SE methods, the inability to come to a consensus across a number of core engineering values hampers the ability of project personnel to effectively action and deliver on proposed outcomes.

"Is time important? Is quality important? Is cost important? How much risk do we want to take until someone makes a decision or not? You've got fundamental differences between major stakeholders on what should be the priority." [CI010]

This dichotomy therefore suggests that although understanding and acknowledging the influences of the existing process are important in the implementation of DT and SE within an LEO, if all personnel are in disagreement about how to interpret the existing process, then fundamental differences will occur between each person's perceptions of what requires changing.

4.5.3.13) Organisational Hierarchy and Structure

When considering organisational hierarchy and structure, participants provided a range of opinions as to whether this was still an attribute that affected the implementation of DT and SE within the CSD. One participant proposed that;

"[Senior management] don't care how it's done, as long as they get the quality, they get the productivity." [CI011]

However this sentiment was not echoed by other participants, who placed a special emphasis on the SE aspects of work that had been conducted within the CSD.

"I don't think we'll keep doing SE much longer. I can personally see its benefits but I can also see from [senior management] point of view that they think it slows things down." [CI010]

When asked what the alternative proposition and way of working might be to either of the processes considered, participants responded with a much less structured approach. This point again reflects on the divisional culture to always strive to achieve innovation.

"In terms of the [senior management] and their top-level requirements, there's going to be a wall with the problem and their solution. They're going to sign it and then that gets pushed into the design teams to implement. It's not going to be from a SE perspective." [CI010]

Furthermore when asked about what would support any future implementation of process within the CSD, one participant commented on whether process was valid for the divisional issues in place at all.

"With a very complex product, we've got the sort of divisional structure and things and priorities that makes it difficult to put that kind of [process change] in place… You know, it's not like you have a minimum take off target or specific fuel economy or you want to achieve something because of EU regulations. So because of that its harder to bake in specific things at each design review." [CI012]

To conclude, the challenges present with regards to organisational hierarchy and structure were present both before and after the attempted implementation of all solutions created and still presents a significant barrier to the implementation of process within the CSD.

4.5.3.14) Summary of Final Interview Series

The final interview series aimed to understand and identify the outcomes of the implementation of generated solutions and assess how the attributes to implementation may have contributed or changed during the course of this investigation. This investigation also considered the objectives identified in the creation of solutions (section 4.2) to identify whether this value has been found within the CSD. The final interview series highlights a number of key findings that are relevant to the following research questions;

1A) What are the optimal locations for DT and SE to be implemented in an LEO?

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

A further discussion is presented in 5.5.3, that considers these findings within the scope of the existing literature, the CSO and the research questions.

4.5.4) Conclusions of Measuring Implementation Outcomes

To reiterate, section 4.5 aimed to identify and explain the findings that were generated when researching the outcomes of the implementations conducted within the CSD. First, communication within the early project stage had been improved and averages taken show that this improvement could be as significant as 175% when compared to values gathered one year prior (section 4.5.1). One project case study was documented and discussed to identify the proposed benefits of implementing a project-based DT and SE process across the span of an internal divisional project (section 4.5.2). A final interview series was conducted post implementations to identify where perceptions within the division had changed and to identify where solutions created could be expanded in scope to resolve further divisional concerns (section 4.5.3). These measures present the argument that although the implementation of DT and SE within a large engineering is possible, there are numerous themes that should be considered in the generation and implementation of solutions (discussed further in sections 5.1 and 5.5 and summarised in section 6.2).

4.6) Divisional Comparison Interview Series

The division comparison interview series aimed to assess the generalisability of the findings of this research when compared with divisions with differing structures and characteristics to the CSD. In particular, the divisional comparison interview series aimed to understand whether the complexity of engineering design and manufacturing was important between cases for the findings of this work to be applicable, as the culture and existing power dynamics were constant between cases. A total of 12 interviews were conducted within two other divisions (six interviews per division) of the CSO with an emphasis on aiming to identify what aspects of the work conducted could be transferable to other organisations in industry. To reiterate section 3.10.4, the main CSD creates high value, high complexity products in low quantities; comparison division 1 manufactures low value, low complexity products in high quantities and comparison division 2 manufactures medium value, medium complexity products in medium quantities. An attempt had been made to implement SE as a form of requirements generation within the CSD, but no other implementations of DT and SE have taken place outside the scope of this research.

4.6.1) Comparison Division 1

Comparison division 1 identified that the complexity in their products was with mass production, as opposed to product complexity, and so research is conducted at the conception of a new product to ensure that this complexity is adequately de-risked.

When participants were asked about their perceptions about the proposed solutions that had been implemented within the CSD, participants reported mixed viewpoints on this. However, all participants agreed that the current design process was not supportive of the product development ongoing within the division.

> *"I don't think that the way we design products is as good as it could be and I don't know why that is. I don't know if that's the influence of [senior management] because they're so involved in the design fields." [CO001]*

Some participants expressed support for the solutions that had been created and implemented (Project Conception Process and Problem Definition Process) as they were perceived to be supportive of the organisation's innate drive to innovate.

> *"Fundamentally people don't feel like we have no structure in place to be able to pick up a process or a new way of designing things; a new way of innovating." [CO005]*

This is especially true as these participants proposed that products developed within the division are sometimes not completed before they are released for customers which could be symptomatic of an unclear conclusion to a design process.

> *"What we do with most products is release them before they are stable. And so what happens is the research teams end up firefighting to support the products until it is nice and stable." [CO007]*

However, other participants perceived that process prevents innovation and that individuals working within an organisation are either inherently innovative or not. Therefore, the concept of innovation cannot be supported by a particular process or set of activities but is instead inherently known or not known by individuals.

> *"How would you write a procedure to be a great scientist or a great musician? You can't do that… Unfortunately, some people are looking for the procedure to make them innovative." [CO005]*

When asked how to improve innovation if not through the use of innovation driven processes, participants proposed that divisions should be broken down into much smaller groups that work much closer together so that innovation can be developed naturally.

"You've got to minimise the divisions and try to make people into more of a family unit [to be innovative]." [CO005]

When interview participants within comparison division 1 were specifically asked questions were asked whether they perceived the implementation of the Problem Definition Process, which aimed at improving the communication channels between fields of expertise and in doing so improve knowledge of customer need, they reported unanimously that this would not be suitable. This was due to the perception that the division would be hampered by forward planning and instead preferred to take an iterative design approach. One participant reported:

"Technology push drives all of our projects and this technology push is then marketed by teams" [CO002]

When asked about the idea of prototyping and testing, there were negative responses to the proposition that low fidelity prototyping could be suitable within the division. Low fidelity prototyping was reported to be "wildly inaccurate" by one participant, and instead a preference was reported for prototyping and testing on a rig. The proposed metrics solution was also suggested to be unsuitable due to the perceptions that there were no concerns regarding the metrics that were currently being measured. Overall, these proposed metrics were perceived to slow down the overall timeliness of design and new products.

Similarly to the final interview series, participants in this comparison interview series also proposed that the organisational hierarchy within the division affected previous attempts to implement process, specifically with regards to understanding the market needs through requirements.

"I do remember a time when the project manager did a list of market requirements but I do remember at the time there were people quite senior in the division who didn't believe in them." [CO005]

The most senior members of the organisation are the same between the main CSD, and comparison divisions one and two, meaning that influences from these individuals are likely to affect all employees within the organisation.

Attitudes to risk in this comparison division were very different when compared with the CSD. In this instance, the division was reported as more risk conscious where risk aversion was proposed to be more commonplace due to the age of the division and its established nature among its proposed market.

> *"[The division] is not always [risk accepting] no. I think it depends on the age of the division. I think it's like when you get older, when you are younger you take more risks because you've got less to lose. And as you get older you become more risk averse…" [CO007]*

However, participants emphasised that there had to be a balance between risk aversion and risk acceptance, particularly when developing and investigating new technologies.

> *"Risk aversion is important, but at some point you become too risk averse to accept taking on new challenging technologies." [CO005]*

When participants were asked why they believed this to be important, they reported that;

> *"…If someone turns up and they've got something, something that we do, but better and cheaper and more efficient then obviously we've not got a market anymore." [CO011]*

Ultimately this shows that attitudes to risk are still considerate of the organisational cultures focus on developing innovative technologies but that since the division is more established a greater emphasis is placed on balancing this risk acceptance with risk aversion.

Finally, participants within comparison division 1 proposed that there was a need to foster innovation rather than process. The common perception that SE considers projects in too great a level of detail and the relative alien nature of DT were highlighted as key reasons why these design processes could not be implemented within the division. When probed further, participants would either identify agile design methodologies or no design methodologies at all as suitable alternatives.

To conclude, comparison division 1 proposed very similar cultural discussions within the context of a much simpler product that is made in much greater volume. The interview series conducted within this comparison division found that although there was a significant difference in the products and manufacturing methods utilised, the main cultural drivers within the CSD were also present and so attitudes to the solutions created within this research were mixed, as found within the CSD.

4.6.2) Comparison Division 2

Individuals working within comparison division 2 identified that they have been established for a long time and thus have an established knowledge base when aiming to understand customer need and expectation. In comparison to the CSD where external communication is not emphasised, customer interaction is planned for as early in the design process as possible. Where customer need is not met, product variants can be created using module design alterations and this same process can aid in the development of new products. Requirements are perceived to be well defined, and the final design is perceived to be complete early in the product design process.

Interviews from within comparison interview 2 reported that individuals perceived that communication throughout the division overall was "good" but that the communication of the divisional strategy was poor.

> *"One of the big problems we've had in the last 12 months is we're not sure what's coming next… So I do think communication is important and you know, I've gotten pretty sick and tired every week where I sit down with my team and I say to them 'I don't know what we're doing'."*
> *[CO004]*

When the work conducted thus far in the CSD was discussed it was perceived that this was less relevant to their concerns and a bespoke solution would need to be created to resolve the communication of strategy needs.

Participants in more senior roles in this comparison division interview series also presented similar perceptions as participants from the CSD when asked about the innovativeness of their work; that the division itself is too risk averse and avoids innovative opportunities. In the case of the CSD this was a perception that was found at differing levels of seniority division whereas in the comparison division this was most applicable to more senior roles. One interview participant suggested that a possible fix for this would be to encourage more senior members of other divisions within the CSOs to work together to spread this mentality amongst the more junior members of each division as this would help them adopt the organisation's principles and ideologies.

When considering risk, participants expressed that they believe that risk and innovation are intrinsically linked and that attempts to reduce project-based risk will inevitably lead to poor innovation within project deliverables.

"I think we're pretty hot in terms of doing things like risk assessments for products and families and things like that. I get the impression at the moment that we are very risk averse and I think that's what's stifling new product evolution." [CO010]

When queried about what this would mean with regards to the application of the solutions created, participants reported that they were not considering the introduction of process as a valid solution but were instead trying to identify 'strategies' that might benefit them. When asked, these reported strategies (or tools in some cases) were not consistent amongst the interview sample; some reported wanting more time to make and test new ideas whereas others discussed the divisional strategy at a much higher level.

"…Were risk averse. We need to push further. We need to work out strategies so that we can innovate faster so that our products are better, then some way to take control of them to get them moving." [CO008]

Participants also raised that there is often divisional complaint (although none was raised with the interview sample selected) around resources and timeframes being of concern but that this was not a really an issue. Further exploration within the division could not identify any individuals that presented this perception which could present the notion that reported issues within the organisation as a whole are much more affected by extraneous variables than initially perceived.

Due to the relatively recent release and lack of new product development occurring at the time of the interview series participants reported that they had limited time working within the area of engineering design as they were spending much more time supporting the new product release. However, this had led to individuals within the team losing vital skills that they would require to move quickly when the next product was being designed.

"I want us to take a couple of hours every week to just brush up on CAD modelling skills or something else they might want to try or do a tutorial so that when we come to do a new product, I want them to hit the ground running." [CO004]

The particular interviewee CO004 quoted above went on to discuss the need for this skillset to be available and ready as more important than learning about the implementation of new

process and suggested that if there was limited time to complete the former then the latter was likely not possible.

4.6.3) Conclusion to Divisional Comparison Interview Series

Ultimately, both comparison interview series found very similar outcomes to the conclusions of the interview series completed within the CSD and as such, presented mixed perspectives towards the implementation of DT and SE as a function of one of the four solutions presented in section 4.2. A summary of the comparison is presented in table 15.

Table 15 - Summary of Comparison between CSD, Comparison Division 1 and Comparison Division 2

	Case Study Division	**Comparison Division 1**	**Comparison Division 2**
Production Requirements	Single to batch units.	Mass production.	Single to batch units.
Product Complexity	High with a high focus on innovating features.	Low as the product is known and simply constructed.	High with a high focus on innovating features.
Project Complexity	Creation of new features.	Production to required scale.	Creation of new features.
Time Period Established	New - Less than a decade.	Established - More than a decade.	Established - More than a decade.

This interview series therefore finds that organisations that have similar characteristics to the CSD and organisation described are highly generalisable when considering the results found from this research. Although aspects of the research here have been validated using literature, the generalisability of this work may be limited when applied to organisations that are significantly different in culture, structure, values and beliefs to the one outlined here. Alternatively, this may propose that aspects of this research are more generalisable to large engineering organisations as a whole than others, as discussed in chapter 5.

4.7) Summary of Findings

The findings chapter split the results found within this investigation into the structure proposed in figure 26, where the findings chapter is composed of a pre-implementation investigation, creation of solutions, failure within implementations, measuring implementation outcomes and the divisional comparison interview series. The pre-implementation investigation identified a total of 10 attributes to implementation that would be important to consider in the implementation of DT and SE in an LEO, which directly reflects on research question 1B, ‘What are the attributes affecting the implementation of DT and SE in an LEO?’. These were;

- Communication,
- Organisational Culture,
- Established Process,
- Organisational Structure and Hierarchy,
- Resistance to Change,
- Individual Mindsets and Skillsets,
- Project and Business Metrics,
- Educational Resources,
- Implementing Innovation
- And Remote Design.

These attributes were validated with literature and a follow up questionnaire and interview series were conducted to further contextualise the attributes to implementation identified. The pre-implementation investigation concluded with an investigation into the CSD's process quality that identified that late changes in the design process, due to poor process quality, were leading to significant cost and time overruns.

In section 4.2, a total of four DT and SE solutions were generated using co-creation techniques that aimed to remediate specific divisional concerns. Since each of the solutions was created through considerable user involvement, this section is proposed to identify perceptions to the optimal locations of implementation of DT and SE in an LEO. The first was the Project Conception Process that aimed to better manage and facilitate the early project stage. The second was the Problem Definition Process that aimed to establish a communication channel between customers and design teams. The third solution was the Low Fidelity Prototyping Package that aimed to encourage the shift from high fidelity to low fidelity prototyping work within process. The final solution generated was the Metrics solution, that aimed to establish a range of metrics that could evaluate DT and SE and the values proposed by the CSD.

The next section considers failure-based learning, where all of the challenges identified in implementation are analysed in order to evaluate the optimal locations of implementation identified in the generation of solutions and the attributes to implementation identified in the pre-implementation investigation. Section 4.4.1 considered failures to implement the low fidelity prototyping package, where the change in perception due to a change in divisional circumstance led to failure. Similarly 4.4.2 presented the failure to implement the metrics package outlined due to the influences of organisational culture, structure and

hierarchy. Finally, the failure to garner engagement with the educational materials generated is outlined and reasons for this were presented.

Section 4.5 presented the results from the implementation outcomes investigation, project case studies and the final interview series. First, changes in communication between the solutions implemented and the established process one year prior were compared to identify any improvement in the quantity of project-based points and found that this was significant. A short project case study was then presented to demonstrate one area of value to implementing DT and SE within the CSD. Following this, the final interview series was conducted with the aim to investigate the practical application of attributes to implementation in the CSD and to identify perceptions towards the outcomes that had been found that demonstrated DT and SE's value. The attributes to implementation were found to be valid during the course of implementation and the areas of low fidelity prototyping and metrics were not supported as optimal locations for implementation.

Finally, a comparison interview series was conducted with two other divisions within the CSO in section 4.6 that aimed to assess the generalisability of the results found. The first comparison division identified that the complexity in their division was with mass production, as opposed to product complexity, and found that although there was a significant difference in the products and manufacturing methods utilised, the perceptions raised were similar to the interview series conducted in the CSD. The second comparison division had similar product complexity but had been established for a longer period of time. In this case, participants reported that they had characteristics that differed from the CSD, such as their relative risk aversion, and proposed that the implementation of process was not suitable within their product development. Overall, there were mixed perceptions towards the implementation of the solutions created.

5.0) Discussion

There was significant value in the contextual information that was present within the organisation and how this influenced change management activities and their outcomes. This should be considered alongside the findings outlined in chapter 4 as critical in answering the research questions. To reiterate, the primary research question was;

1) **How can Design Thinking (DT) and Systems Engineering (SE) be combined and implemented in a Large Engineering Organisation (LEO)?**

Which can be split into;

1A) What are the optimal locations for DT and SE to be implemented in an LEO?

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

1C) What procedures support the implementation of DT and SE within an LEO?

1D) Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?

This chapter will discuss this context and present arguments as to what interactions may have taken place, the influences related to internal and external factors and how the use of change management methods may have led to particular successes or failures. First, discussions will be presented on the pre-implementation investigation work undertaken with a particular emphasis on why research methods were chosen to assess the validity of the data collected. Second, this chapter will highlight the solutions that were created and commentary will discuss links to existing literature and identify points of contention. Following this, the change management approach and methodology will be discussed and a number of external factors affecting the research are highlighted. The failures in implementation are then discussed as a function of their implications on the wider research and its findings conducted and these are linked back to the proposed attributes to implementation to extend and test this investigation. Next, this chapter presents a discussion on the outcomes of the post implementation work conducted and how the divisional comparison interview series realises the precise aspects of generalisability of this work to the rest of literature. This chapter concludes with a commentary on attempts to improve research quality.

Figure 42 - Discussions Chapter Structure

5.1) Pre-Implementation Investigation

This section considers the pre-implementation investigation and the outcomes that were presented therein. First, an overview of the pre-implementation investigation is considered, and discussion points are proposed around this investigation as a whole. Following this, each stage of the research methodology conducted is analysed and contextual information is presented alongside its findings to further answer this investigation's research questions.

Project conception and the early investigation techniques conducted within this research were undertaken during an abnormally turbulent period of time within the CSD that should be considered in the context of research findings. In particular, the division underwent an organisational restructure, the emergence of the COVID19 pandemic and the introduction of the UK furlough scheme within a short period, meaning that one could assume that this impacted the data found through this investigation. Conversations with key initial

stakeholders suggested that this was the case, whereby during the periods of time where the divisional headcount was low as employees were not working, the stakeholders perceived that the change management activities proposed were "additional" to their normal working responsibilities and thus avoided them. This is consistent with the findings of Carlgren, Elmquist and Rauth (2016B) who found that in times of high workload, design thinking may be avoided in favour of more 'essential' activities. This also led to significant issues in initial attempts to achieve outcomes within the CSD as the individuals that had been established as supportive of change were no longer present. Thus, an argument could be presented that the rapid turnover of contacts could have been partly responsible for the failures in implementation discussed in section 4.4 as consistent engagement with key change supporters is critical in establishing change (section 3.10.1).

The organisational complications that were present at project conception also had a significant impact on the investigative and change management work undertaken. For example, these complications ensured that there were multiple changes in the initial stages of the research of the industrial supervisor and thus competing visions as to what direction might result in the greatest output at project completion. Change management literature would propose that visions are important (Kotter, 1996) and that the effective communication of a singular change management vision is key to enacting organisational change projects. Therefore, these complications likely hampered the production of change early on in this research and impacted the credibility of the primary researcher in further change management endeavours within the CSD.

In addition, due to the relatively, anomalously, high turnover of individuals within the CSD during this time, great difficulty was found in identifying and establishing relationships with key divisional stakeholders that would support the change management work proposed. Again, the change management literature considered in section 3.10.1 would suggest that the identification and onboarding of key stakeholders within change management projects as vital to their success and therefore this period of employee instability would also have impacted the early project findings.

5.1.1) Preliminary Interviews Series

This section will aim to present the key discussions points relating to the preliminary interview series and present an account of the primary researcher's attempts to enhance the quality of the research conducted.

An argument could be made that a bias was introduced due to the use of selective sampling as there may be a possibility that not all of the points had been collected to answer the research questions. This was mitigated through the attributes to implementation, where the proceeding questionnaire and follow up interview series where individuals within the case study were presented with another two opportunities to raise further points. With regards to the concerns within their own division, existing participants and new participants were then asked to be a part of a co-creation period to detail how DT and SE could be applied to the CSD, and participants had another opportunity to again express these opinions.

In practice due to delays to the research as a result of COVID19, the UK government furlough process and the organisational restructure discussed previously, the preliminary interview series was conducted after the majority of the literature review and identification of attributes to implementation in literature. Although the primary researcher, aimed to be unbiased in their stance when inductively coding the data, proposed this would present an argument that some of the similarities found between literature and the preliminary interview series were due to this coding bias. If this coding bias was present that skewed data towards identifying similarities within the data gathered, then this would have prevented the exploration of new attributes to implementation but not affected the accuracy or validity of the attributes that were raised. To try to mitigate this, emphasis was placed within the coding conducted to naturally generate attributes rather than to place the data collected into a number of pre-allocated categories. Furthermore through the consideration of implementation failure within this research, the primary researcher proposes to discuss the perceived attributes to implementation within actual attempted implementations and thus argue a level of accuracy when considering what attributes affect the implementation of DT and SE within an LEO. Finally, the final interview series should serve as a further argument for the validity of the attributes identified at this early stage as perceptions towards what has or has not worked can be explored to understand its root cause.

Interestingly, data from the preliminary interview series revealed that when 67% (11 participants) of interviewees were asked about things that the CSD did well, the recordings taken identified that within a short time (mostly within 10 seconds) they raised issues that they perceive the case study does poorly. This was perhaps due to the divisional restructuring process that was ongoing within the division at research conception, that ultimately made a number of individuals within the organisation redundant and was reported through several negative comments in interview. If correct, this would be another data point that supports the creation of the eleventh attributes to implementation, Organisational Zeitgeist.

Finally, the data collected aimed to holistically consider the attributes to implementation in the CSD rather than only data points that are specifically related to design activities as this understanding was thought to better contextualise all aspects of the social phenomena present within the CSD. Due to this the data presented in section 4.1.1 may at times seem unrelated to the fields of engineering, design or design processes but is absolutely critical when aiming to contextualise these findings.

5.1.2) Validation with literature

Section 4.1.2 presents findings on how the attributes gathered may be similar or dissimilar to material proposed in literature but value can also be found in exploring why these differences may have occurred using contextual information regarding the CSD. This section will explore this further and contextualise the results found by directly comparing the attributes to implementation found against literature. For ease of reference, the attributes to implementation are listed below;

- Communication
- Organisational Culture
- Established Process
- Organisational Structure/Hierarchy
- Resistance to Change
- Individual Mindset and Skillsets
- Project and Business Metrics
- Educational Resources
- Implementing Innovation
- Remote Design

A much greater emphasis was placed within the CSD on points that consider the attribute to implementation 'communication' when compared overall with literature. However considering the clear concerns participants raised in the preliminary interview series (section 4.1.1.1) regarding the duplication of work, perceptions towards understanding customer requirements, the restrictions that had been placed on the division amidst the relatively recent restructuring process, the introduction of COVID19 and the UK furlough process; an argument can be constructed to suggest that changes in communication could be due to a number of recent changes. The first of these factors could be that the restrictions placed on the division led to a decrease in communication overall as individuals are presented with more responsibility amongst a reduced head count. Another possible factor could be the

introduction of remote working, where individuals within the organisation are being deprived of the benefits of in person communication and are being required to adapt to online tools. This reflects directly on literature (Ultrainen, 2017).

When considering 'organisational culture' and its impacts on design, the CSD was initially perceived to be very risk accepting, rather than risk averse, as they were in pursuit of radical innovation within their given market. This difference to literature when considering organisational culture was found to significantly impact change management work within the CSD throughout this research. One possible explanation for this difference is due to the value that the division, and company as a whole, places on innovation and its relationship with risk. As the divisional comparison interview series conducted in section 4.6 shows, more established divisions within the organisation that were less focussed on achieving innovative outcomes as the CSD, and were also more conscious of risk, presented a slightly different organisational culture.

The attribute 'established process' was found to have direct similarities to literature in both aspects of where difficulty might occur and its concept as a barrier to implementation. This is likely because, although other attributes have been identified that may be more significant in change management, the main process used at the time the preliminary interview series was conducted could be considered to be a 'traditional engineering process' as described in section 2.1. Therefore, since there was nothing inherently unusual about the structure or activities contained within the process, this likely led to similar findings when participants were asked for their perspectives.

A number of arguments can be constructed from the data gathered in the preliminary interview series as to why the differences between the attribute of 'organisational structure and hierarchy' (section 4.1.1.4) and the literature theme of 'existing power dynamics' (section 2.7.8) were present; one of which being that the more senior members of the organisation were heavily involved in the overall control and direction of the design of new products within the CSD compared to perceptions externally to the division, as discussed in section 4.1.1.4. Due to this involvement, even participants whose remit included project management or project control perceived a lack of control under the organisational circumstances present. Another valid argument constructed could revolve around the concept of responsibility, as participants frequently commented on the lack of individuals with key project responsibilities within the CSD. This would therefore determine that in some cases the attribute 'existing power dynamics' should also consider the lack of existing power

dynamics, and thus the concept of 'organisational structure and hierarchy' was believed to better represent the data collected.

The arguments presented discussing the involvement of senior management when considering the attribute 'organisational structure and hierarchy' are also valid to the data gathered with regards to the attribute 'resistance to change'. For example, the data collected proposed that change management activities that began with more senior members of the organisation would be more likely to be successful, which would be logical, considering the greater involvement of more senior personnel within the CSD and its projects.

The attribute 'individual mindsets and skillsets' could be proposed to differ from the 'individual mindsets' attribute from literature due to the complexity and training required to design, develop and work with the products developed within the CSD, as mentioned in 4.5.3.3. For instance, this research proposes that if an individual enters an engineering organisation structured similarly to the CSD but has little knowledge of the development or complexity of the products then this in itself would prevent them from engaging effectively with a DT or SE implementation. This directly reflects points raised in literature (Schmidt et al, 2011 and Valentim, Silva and Conte, 2017).

As discussed in section 4.1.1.7, the development of metrics was perceived to hinder innovation and other key market drivers that were determined to be critical by more senior personnel and preferential treatment was perceived to be reserved for more emotive responses to measurement. Therefore, the key differences between the attribute 'project and business metrics' from primary data and 'metrics' from literature is the emphasis that is placed on not just the project and its design-based activities but also the metrics created and considered at a business level. Although this thesis has already discussed the difficulty in measuring the concept of design or design output (Mabogunje, Sonalkar and Leifer (2016), Royalty and Roth (2016), Seidel and Fixson (2013) and Blizzard et al (2012)), the data collected through the preliminary interview series suggests that the implementation of process must be considerate of the wider impact that this has on a business i.e. design focussed organisations should be able to measure their design outputs but should also be able to show how this impacts metrics measured at a business level.

When considering the attribute 'educational resources' and its respective comparison with literature, emphasis is placed much more on the finite resources available to engage and adopt educational material within the CSD rather than the overall education of tools. However, none of the data gathered presented the perspective that the education and

uptake of tools would not be an important attribute to implementation, just that concerns around resource were more prevalent to them. Similar to other discussions presented within this section, this could have been due to the impacts of the reduction in number of personnel through the relatively recent divisional restructuring, the introduction of COVID19 and the resulting UK furlough scheme. Therefore it could be presumed that were concerns around limited resource being unavailable, that this attribute may consider the overall education of tools instead.

The investigation into the differences between proposed similarities and differences in perspective between the data gathered in the preliminary interview series and literature with regards to the divisional ability to implement innovation revealed an interesting dichotomy between different levels of seniority within the division that was not considered in literature. Upon further investigation, this could be due to the communication issues outlined in section 4.1.1.1, where participants from lower levels of seniority that are not involved in discussions with customers, and thus have a very limited access to market requirements, are completing elements of design with minimal input from this area and thus may not perceive that they are meeting market expectations. On the other hand, more senior divisional employees may have a greater access to information regarding the projects proposed markets and thus may perceive that the development of innovation, and in particular technology drivers, is suitable within current projects.

Interestingly although all the interviews conducted in the preliminary interview series were conducted via MS Teams and the organisation had been using this system for a very short period of time at this stage (around 2 months), 'remote design' was raised in the preliminary interview series but was not proposed to be a significant attribute to the implementation of DT and SE. One reason for this could be that due to the major reduction in headcount at the time due to the divisional restructure, COVID19 pandemic and introduction of the UK furlough scheme as the expectations to complete large quantities of design-based work that would normally be present may have been reduced in scope. Another argument could be that participants have simply been working with the new remote structure for too short a period of time and so had not yet identified concerns with regards to remote working. Finally, as although personnel within the organisation are globally distributed all of the design specific teams work in close geographical proximity to each other and in most cases on one site, there is the possibility that participants have not needed to engage with remote working as much as an individual who has worked remotely for a long period of time as it has so far not been required.

One of the most critical, overall differences between the literature review and data gathered from the preliminary interview series was through the perspective that is presented towards each data set; employees within the CSD were openly risk accepting and presented arguments to suggest that some of the negative aspects found in literature were strengths within the organisation and vice versa. For example, literature proposed that challenges related to implementing innovative design could lead to rejection of the overall process-based implementation. Within the CSD though, this innovation was sought after as a key project driver, meaning the challenges to implement innovation were not as prevalent, and thus although participants had commented on this, these comments were predominantly positive. This builds on the understanding present in literature, and shows that the concepts previously conceived to be barriers to implementation could also be positive, hence the change in terminology to attributes to implementation.

This section has considered the validation activities conducted within this investigation and proposed further contextual information and discussions for each attribute to implementation. This section also reflects back to literature to identify how the implementation of DT and SE links to these attributes and propose points that should be avoided in future.

5.1.3) Questionnaire Series

This section considers the questionnaire series conducted and presents discussion points around the suitability of the questionnaire proposed within this investigation. The methodology was first assessed when compared with literature and then as a function as a part of this investigation.

Since the response rate for the questionnaire within the CSD was 20% (17 participants) an argument could be presented to suggest that this questionnaire does not have a sufficient sample to be representative of the division's perspectives. However, attempts were made to ensure that theoretical data saturation was achieved within the questionnaire series and representation was found from each area of expertise and level of seniority in the division, which suggests that the data gathered was suitable in achieving the questionnaire's proposed aims. The use of statements to provide more clarity as to the meaning of a particular attribute in the questionnaire series is a commonly used research method. However, it could be argued that the statements themselves were not all encompassing or relevant to every aspect of the attribute defined through the previously conducted data

analysis. This would in turn lead to numerical data that would not accurately represent the scale with which something may have been a strength or threat within the CSD and so have led to the generation of non-optimal solutions for implementation. Furthermore, errors here would directly impact the ability of this research to answer the first research question proposed; “What are the optimal locations for DT and SE to be implemented in an LEO to generate positive outcomes?” To try and mitigate this, the statements were tested for their accuracy and suitability with a focus group of four participants who were asked to present their own understanding of what each statement meant within the context of the CSD. Importantly, alterations were conducted from the initial statements generated to the ones used within the questionnaire series due to a number of discrepancies and concerns that were raised within this focus group setting.

Some of the data collected through the questionnaire proposed that attributes could be perceived as both a significant strength and a significant threat within the division. However, this could be for a number of reasons. For example, due to the use of strength (present tense) and threat (future tense) if an attribute were currently a strength of the division but could be a threat in the future then this would result in both a high strength and a high threat ranking. Similarly, if a large proportion of participants consistently reported an attribute as a strength and another proportion reported an attribute to be a threat (considering that these criteria are not mutually exclusive), then if the rest of the data were spread more evenly this would present this particular attribute as high in both cases. This could then lead to emphasis being placed incorrectly on high-ranking attributes in the solutions generated and thus lead to implementation failure. However, this should have been mitigated due to the use of co-creation as participants were expected to challenge any improper choice of solution.

An argument can be presented around the use and validity of the words ‘strength’ and ‘threat’ within the questionnaire conducted. On one hand, both words represent the broader positive and negative concepts that were under investigation in this questionnaire. On the other hand though, there are a number of issues with selecting these words. For instance, the word ‘strength’ suggests something that is happening at present whereas the word ‘threat’ insinuates something that could become of issue in the future. This implied meaning could have been recognised by participants within the CSD and the responses gained could reflect this, presenting a bias in the findings generated. Furthermore, as these terms do not represent direct opposites, whereby agreeing with one term should directly contradict the other, the suggestion that the data gathered for each set could validate the suitability of one another is not possible.

Even though the statements generated and used within the questionnaire were validated with a focus group to ensure that they were suitable representations of each attribute to implementation and that statements made logical sense, there is a possibility that the statements used were not suitable for this investigation. For instance, all the statements provided were phrased as positive rather than negative which could have introduced a bias toward identifying statements more positively than they may do otherwise. Alternatively, due to the complexity in each of the attributes identified, preliminary interview series participants may feel that their responses were not taken into consideration when creating these attributes as the statements presented may not reflect their own personal views. Therefore, they may not rank the statements presented accurately when compared to their true personal beliefs or perspectives. On the other hand, the inclusion of each of the attributes to implementation as statements, followed by a contextual piece on what this may mean, would have made the results more accurate but may have added considerable text and reduce the overall completion and response rate found.

When considering overall research quality, the questionnaire series conducted within the CSD could be viewed as a form of member checking (Polit and Beck, 2012); where ideas and concepts that have undergone data analysis are brought back to participants to understand if a particular idea is credible. In this case, it could be proposed that by presenting the attributes to implementation back to participants from within the CSD and allowing them to present any commentary that they may have to support or disagree with any particular concept could be considered to be completing a form of member checking. By also asking interested participants to take part in a questionnaire follow up interview series, this offered two separate opportunities for participants to feedback their understanding and interpretation of the data collected when compared with their own experience.

Although remote design was not considered in the investigation that followed this research method, Ultriainen (2017) proposed that this was because design activities were not being conducted remotely. At the time, this was due to the relatively anomalous external factors of a recent redundancy process, the introduction of the UK furlough period and COVID19 as new developments were placed on hold in favour of maintaining the current line of products. Therefore although this theme was not significant in this investigation, it may be significant in industry as a whole and so should be considered in future work.

This questionnaire series has proposed an important novel contribution when compared to the existing literature (section 2.7) however, as literature has not considered the ranking of

each attribute to implementation based on its significance or prominence within a particular case. The questionnaire conducted has highlighted that some attributes are perceived to be more important than others, with communication internally and externally and opportunities for learning from failure ranked as significant.

5.1.4) Post Questionnaire Interviews

The preliminary interview series was aiming to gather all data on the attributes to implementation and the possible optimal locations of implementation; the post questionnaire interview aims to further contextualise and understand how these points were perceived within the CSD and allow participants the opportunity to identify or contest any attributes to implementation that they feel may be relevant in the implementation of DT and SE within an LEO.

The post questionnaire interview series was conducted with 29% (5 participants) of the total population that took part in the questionnaire, which overall is a very small percentage of the total population of the case study. This might therefore indicate that the overall accuracy and value of the data gathered is low as there would be a strong chance that data from the division may have been missed through not contacting an adequately suitable sample. However, it is important to remember that this interview series is an extension of the preliminary interview series, where the data gathered from the preliminary interview series was to be supported by the questionnaire and post questionnaire interview series to form an understanding of the attribute to implementation of DT and SE.

Although these interviews were planned for a total of 30 minutes, similarly to the initial interview investigation conducted, 20% of these ran over the allotted time by between 15 and 30 minutes which may indicate that the participants had things of note that they did not have a previous opportunity to say. This therefore validates the thinking the initial interview series of length 30 minutes was not long enough to understand the organisational nuance that might be present in the implementation of DT and SE. However, through the emphasis that was placed on ensuring that all attributes to implementation had been identified and in ensuring that research quality was prioritised throughout, this should not have impacted this investigation's ability to answer its research questions.

5.1.5) Quantifying Process Quality

This section aims to assess the suitability of the investigation into process quality conducted in the pre-implementation investigation. The main aim of conducting this investigation (section 4.1.3) and the research methods conducted to achieve it, outlined in section

3.10.2.6, were to quantitatively evaluate the established process present with the CSO through the consideration of process quality (Crosby, 1979) and the concept of late scope change. The data collected considers a total of eight projects over a period of 10 years.

One concern that could be raised about the accuracy of the quantification of process quality was in the methods used to complete it. Due to the case study investigation having separate locations of storage for its accounting software and available project management documentation, an argument could be made that there may be errors present in the collection of data and allocation of overspend and changes in timeframe to late scope change. However where this was not clear or information not readily available, this was therefore consulted with key project stakeholders who presented documentation and arguments to support particular points of change in time within projects as being due to changes in scope. Although a degree of error could still be present within the data collected, by consulting a number of key project stakeholders this would be mitigated as points in time that were not in agreement initially could be discussed in more depth to identify if they were relevant here.

One key point that could be raised in argument against the data collected in section 4.1.3 is the applicability of late scope change as an indicator of process quality. However considering the definition of process quality presented in the literature as “the degree to which a set of inherent characteristics of an object fulfil requirements” (Hoyle, 2017:p.8) and the preliminary interview data that suggests that the metrics of overall project cost, time to market and product quality are valid organisational metrics, investigations that centre around the quality of the current process due to its ability, or inability, to meet these metrics would be valid. The concept of late scope change, if occurring regularly, may not be explicitly documented within the CSD’s established process but alternatively that also means that the process is not explicitly preventing late scope change within projects. Further, late scope change was selected due to its mention in the preliminary interview investigation as being of considerable note in the regular activities of the CSD but a number of other metrics could have been selected to investigate process quality; such as work and re-work (Kasser, 1994) or product mean time between failure.

The existing process within the organisation could be categorised as a traditional or sequential process as outlined in section 2.1, and thus discussions around the concept of process quality reflect clearly on the literature presented by Baxter (1995) where late changes in design are linked to dramatically increasing project costs and time to market.

Therefore, this investigation's findings pertaining to the process quality found within the CSD are plausible within the literature review. Furthermore, although explanations were considered in section 2.1.1 through Prasad (1995), especially when considering inconsistent design, analysis and documentation methodologies that lead to last minute engineering changes, the results found through this investigation propose that equally significant factors in these late changes are the social and cultural factors that are present within an organisation. This would be significant in future work.

The numerical investigation conducted into quantifying the CSD's process quality was only able to obtain data on the large machines that were developed as smaller projects did not necessarily have relevant, similar documentation completed that could be used as an objective comparison. Therefore, the findings from this investigation cannot be proposed to be generalisable to all bodies of work conducted within the division, but this investigation was deemed suitable as it encompassed products that accounted for a significant amount of divisional revenue generation. The inclusion of this data and subsequent analysis serves in this thesis to support the communication of why particular solutions were created for divisional problems and how this could be considered in future work for organisations with similarly long project timeframes.

To conclude, the investigation into process quality was found to be suitable within this investigation as a measure of evaluating changes in project scope due to late changes in design. Alternative measures for evaluating process quality were highlighted and this investigation was linked to the organisational culture characteristics presented within the CSD. The combination of the explicit measurement of process quality, with organisational culture and the implementation of DT and SE is methodologically novel, and highlights opportunities in later DT and SE implementation to create metrics that show the need for process change and reflect on DT and SE benefits.

5.2) Creation of Solutions

This section and the subheadings within it aim to discuss the solutions that were generated and outline key literature around the decisions made. The creation of solutions overall is discussed before each solution is evaluated.

One of the key concepts identified in early conversations within the CSD indicated that there were a great number of organisational niches that must be understood in order to successfully engage with the division and enact change. Therefore the use of co-creation, whereby more established and knowledgeable individuals were brought into the process of

creating solutions so that their understanding of divisional nuance may be considered, was vital in the creation and development of DT and SE solutions within the CSD (Lewin (1947) and Burnes (2017)). However the rapid change in available personnel within the division during the earlier research stages, due to the early restructuring, COVID19 pandemic and furlough period, meant that it was difficult to establish a regular group that were interested in the change management activities proposed and establish a change management plan. Although input could be gained from these individuals more 'transient' in the research, enacting change was also more difficult as strong supporters of the proposed changes may have become unable to share these views within the division. The same argument can also be applied to individuals that were strongly unsupportive of the change management proposed; that the impact of personnel changes within the organisation would have potentially removed individuals that were strongly biased against the implementation of DT and SE.

The introduction of hybrid working, due to the introduction of COVID19 and the UK furlough scheme, within the early stages of this research meant that all aspects in the creation of solutions was conducted virtually. This may have directly impacted the attempts to instigate and manage change within the CSD in a number of ways. First, participants had the option of using their camera in meetings and co-creation activities which could remove any influence that non-verbal communication may have presented (Bal and Foster, 2000). Also, although the primary researcher did predominantly utilise video calls, as this was not always the case some participants may not have been influenced about their perceptions of the primary researcher as a suitable agent of change (Bird, 2019).

The use of co-creation may initially be interpreted as the absence of any individual contribution from the primary researcher. However due to the emphasis on maintaining a DT and SE based process, in practice the co-creation sessions were more focussed on identifying employee needs and ensuring that the solutions created were suitable for the any previously discussed requirements than allowing participants to develop their own solutions to problems. This was done as it was perceived that this would allow participants to still feel like they are being listened to and were involved in the change proposed (Greenberger and Strasser, 1986) but still enabled the primary researcher to maintain control and ultimately drive the direction of solutions created.

5.2.1) Solution 1 – Project Conception Process

The project conception process created can be compared with previous literature around the implementation and application of DT and SE within an LEO to identify how these two design processes have been incorporated into this solution. For instance, the project conception process operates very similarly to a multiple V model (section 2.2) as this particular process acts as a modified concept demonstrator in both aim and structure (Lake et al, 2000). When compared in this way, the project conception process could be considered to be comparable to the first V in the multiple V model that has been adapted with DT techniques. This also considers research by Carlgren, Elmquist and Rauth (2014) who proposed that DT is not often incorporated and used as a standalone design process. Considering instead the work done by Greene et al (2017), this solution is similar in structure to the Inclusive Concept Model (figure 26) where DT is incorporated within a SE process. These comparisons show that the Project Conception Process generated is not novel when compared to theories and empirical data found in literature and is similar in aim and structure to other proposed implementations of DT or SE.

When this body of research was conceived, individuals within the organisation proposed that outputs from the research needed to be completed quickly and often. This was supported in later interview data which commented that the CSD has a drive to 'do things and do them quickly'. This therefore drove the Project Conception Process to be implemented in its first iteration quickly, and thus incurred a number of initial failures as steps in the change management process were rushed to completion. Although specific data has not been generated to investigate the impact of these failures on future process implementation, literature argues that these failures could have impacted employees' perceptions of credibility towards the researcher and the change management proposed and, unintentionally, create more resistance towards activities conducted towards the end of the research process (Kotter, 1996).

The Project Conception Process faced a number of challenges during the initial attempts at its implementation and changes were made in the change management methodology used to enable successful process change. For instance, the initial change management methodology used in this case was proposed by Lewin (1947) and Burnes (2017), where the open and effective communication of the process and any changes made to it were emphasised and individuals within the CSD were invited to challenge this solution and its applicability within their field of expertise. Although this change management mentality led to the collaborative development of a solution that was argued to resolve a number of

proposed problems, enacting change in this way led to a failed initial implementation as the uptake of this process was not considered to be sustainable over a period of time. A number of reasons are attributed to this failure phenomenon, such as;

- Participants reported that they did not want to participate in new change initiatives unless more senior members of the organisation also bought into them. This was perceived to be linked to the attribute organisational structure/hierarchy.
- The proposed process included review gates, documentation and metrics which were perceived to slow down the overall time to market of products. This was perceived to be linked to the attribute project and business metrics and related perceptions to overall process.
- The educational materials developed in conjunction with this process had poor attendance or engagement and thus may not have led to the mindset and skillset shifts required for change (Carlgren, Elmquist and Rauth, 2016A and Schmidt et al, 2011). This was perceived to be linked to the attribute educational resources.

Therefore, the selected change management methodology shifted towards one proposed by Bass (1985) and Kotter (1996) who proposed that individuals within the organisation should be considered as resistors to change and placed an emphasis on leadership to enable change management. This new methodology encouraged the use of more rigorous stakeholder management as the onus was no longer being placed on the divisional personnel to generate change and hold individuals accountable, but the primary researcher.

5.2.2) Solution 2 – Problem Definition Process

One key comparison to draw is between the process created within solution two and previous attempts from literature that aimed to resolve communication issues using DT and SE. Although there are no clear comparisons to implementations in literature of DT and SE, the process does have a DT and SE focus through the use of key activities that reflect on the core values of either DT or SE. For example, within the Problem Definition Process (presented in section 4.2.2), section A places an emphasis on utilising DT activities to engage with customers and more accurately understand the problem space that the division is aiming to engage with. Section B considered a structured series of review gates, akin to SE, and the consideration of failure-based learning using lessons learned reflects on the emphasis placed in DT on iterating and learning from failures. Section C is the Project Conception Process presented in section 4.2.1 also discussed in section 5.2.1 as similar in structure to a modified multiple V model with DT components. Finally, section D focusses on how this knowledge

base is communicated to a project team through the generation and use of requirements and other formal documentation that was created within this process. The proposed Problem Definition Process implementation could also be compared to the Comparative Concept Model proposed by Greene et al (2017) as aspects of DT and SE have been brought together to achieve wanted goals with no clear major process being used more considerably.

In the creation of the problem definition process, the use of larger, collaborative meetings were replaced with small meetings or one to one interviews due to the low attendance at booked co-creation meetings. Although these smaller groups aimed to resolve the same issue as the larger group meetings and still included all key stakeholders proposed, a range of issues may have occurred due to this change. For instance, the use of individual interviews removed the ability for co-creation teams to discuss and explore particular points of note and potentially lead to conflicting information between individuals. However this would also eliminate the potential for bias within the data collected, as individuals that are more assertive could dominate larger meetings with more participants and push their particular agenda as representative of all participants.

The change management undertaken with regards to the Problem Definition Process was not instantaneous within the CSD, and instead occurred over a year-long period to completely shift from the initial communication process to the proposed solution. Similarly to the Project Conception Process, the initial change management methodology was the one proposed by Lewin (1947) and Burnes (2017). However, this attempt at change management failed completely, there was little to no engagement with any of the resources or educational materials created. Instead this methodology was replaced with the Lean Six Sigma DMAIC (Uluskan, 2016), with more of a focus on the mentality proposed by Bass (1985) and Kotter (1996), and more emphasis was placed on effective stakeholder management. In practice, the identification and onboarding of key stakeholders was vital within the division and may reflect on the division's hero culture discussed in section 2.5.1. This investigation proposes the successful implementation of this process was only possible through the identification of one or more divisional heroes that personally supported and enabled it rather than an overall divisional drive to resolve a problem area through process implementation. Furthermore, where the Project Conception Process aimed to utilise the communication channels and meetings already established within the CSD, the implementation of the Problem Definition Process established process specific meetings and touch points within the division. Specific workshops and education material were created to support the implementation of the Problem Definition Process, but these ultimately failed due to a lack of engagement within

the CSD. This also applies to the implementation of metrics that supported this solution, although this predominantly was due to the failure in software within the division that could collect and manage the data proposed within the process plan. Therefore future attempts to implement DT and SE within LEOs must consider the culture and established process that is present within an organisation as it could potentially influence significant aspects of overall change management.

During the implementation of this process, another team within the CSD implemented the aforementioned Atlassian suite of Confluence and Jira which was quickly adopted by project personnel within the division's newest starting project with the intent to generate, manage and disseminate requirements. As Confluence and Jira were supportive of the requirements of this second proposed solution and were already being considered, the adoption of these software as a part of the solution proposed was conducted so that participants had less change occurring within the division, making them more likely to support the changes proposed (Oreg, Vakola and Armenakis, 2011). However, had the Atlassian suite not been installed within the CSD then it would have been likely that this solution would have needed to adopt another platform to be completed successfully. Since the software within the division were not suitable for supporting this process implementation, the selection of a different platform may have caused implementation failure if the uptake of the new software was not possible.

It is important to note that the CSD had characteristics that reflect on literature proposed by Carlgren, Elmquist and Rauth (2016B), who found that in some instances engineering organisations actively did not want employees engaging with customers through fear that they would release sensitive information. In this case, this was proposed to be resolved through the training of individuals that were already engaged with customers, regardless of whether they held a design-based role, and the clear documentation and communication of these customer needs to other individuals within the organisation.

5.2.3) Solution 3 – Low Fidelity Prototyping

When comparing low fidelity prototyping to DT and SE literature, clear comparisons can be drawn between these references and the uses of low fidelity prototyping in this research. For instance, low fidelity prototyping in DT can be considered through its proposed Double Diamond process (Interactive Design Foundation, 2022) where an emphasis is placed on low fidelity prototyping as a means to investigate the solution space and identify areas where innovation may be possible in resolving user need. On the other hand, low fidelity

prototyping is less common in SE, as this process presumes that any solution that resolves a specification is valid and thus low fidelity prototyping, which focusses on design, is unnecessary (Mejia-Gutierrez and Carvajal-Arango, 2017). However, when considering new technologies, SE could propose the use of a multiple V model where the suitability and development of a technology is assessed for its viability in resolving a set of requirements through a concept demonstrator. In this research low fidelity prototyping is proposed to be a core part of the Project Conception Process and valid as a standalone implementation that can be enacted at any stage within the design of a new product to answer or resolve specific questions. This attempt at implementation encompasses the mentalities presented within both DT and SE.

Since solutions 1 and 2 were proposed to effectively form a SE 'concept demonstrator' (Lake et al, 2000), low fidelity prototyping was incorporated within these processes with the aim of de-risking projects before there is a major divisional commitment and increase the opportunities within the division to innovate and explore new ideas with customers. However, this could have been adopted at any stage in the design process utilised by the division and educational materials were created to support this thinking.

5.2.4) Solution 4 – Business Level Metrics for Design

As proposed when discussing change management techniques in the Methodology chapter of this thesis, the use of metrics to implement organisational change projects is critical to enabling relevant individuals to adopt new proposed actions (Royalty and Roth, 2016). Therefore the selection of relevant metrics was conducted with a senior member of the organisation who was also attempting to implement a metrics solution within the CSO to ensure that, based on the learnings found in other solutions at this stage, this solution was given the greatest possibility of success as this would affect other proposed implementations.

The metrics selected to be presented as a part of this solution were all taken from peer reviewed literature sources that aimed to explore how organisations engaged in design activities, and particularly DT and SE activities, could fundamentally measure design. However, most of the implementation successes found within this research have been bespoke processes that incorporate the fundamentals of DT and SE rather than their specific process structures (such as the DT double diamond or the SE V model). Therefore, an argument could be presented that placing more of an emphasis on measuring the CSD's design activities and creating bespoke measurements to suit could have found more success

than the proposed. However, while this may have worked in principle, this would have led to a number of key failings that would have impacted other aspects of this research. First, the proposed adoption of DT and SE metrics as conducted to aid in the implementation of DT and SE processes as individuals within the organisation would be rewarded for following the proposed processes (Kotter, 1996), whereas a deviation from this would reward the status quo and actively work against change. Second, the generation of bespoke metrics warranted a level of understanding of individual activity and need within the division and this was perceived to take too long to generate as other change management activities were being progressed concurrently. Finally, attempts had already been made very shortly before research conception within the organisation to implement a number of bespoke metrics that had ultimately failed to be implemented amongst members of the division. This, therefore, would suggest that re-iterating an attempt at this implementation with similar or the same bespoke metrics might also fail and thus the selection of metrics from literature, which were still novel to the organisation, was more suitable.

This generated solution differed from the other solutions created as a part of this body of research as this was the only implementation that was led, predominantly, by someone other than the primary researcher. This individual was established within the senior echelons of the organisational structure and had people management responsibilities; this led to unintended effects. For instance, the organisational culture point to ‘complete something and complete it quickly’ had a greater effect in the implementation of this solution than others conducted as the individual leading the change had a role, remit and set of responsibilities that were not change focused. This meant that time allocated to this change management was not supportive of their other key activities. This same cultural phenomenon led to a push to complete deliverables of value quickly, which would have been felt much more significantly by an internal member of the organisation than the primary researcher, and this may have contributed to the failure to implement any potential design metrics.

Since the metrics considered in this case were not generated within the organisation but through critical literature review, a discussion could be presented around the suitability and relevance of the metrics proposed within the CSD considering what is known at research completion. For instance, the interview data collected within the preliminary interview series and the final interview series both indicate that the implementation of any process that is perceived to increase the overall time to market will likely struggle to be implemented within

the CSD but some of the metrics proposed would have directly contradicted with this due to their implied suggestion to complete upfront work. These include;

- The number of end users contacted
- The number of personas identified (and contacted)
- The number of prototypes worked on in parallel.

Another point to consider was that the implementation of metrics that were specific to operations or activities that were within DT or SE, had no process at the time to relate to as the implementation of the Problem Definition Process and Project Conception Process had been delayed due to the change management factors discussed in section 5.2.1 and 5.2.2. Therefore, there were a number of metrics that were aiming to be implemented with no tangible link to the established process, such as;

- The use and measurement of DT success stories.
- Reflective measurements considering the use of DT and SE within projects.
- The number of projects initiated using DT activities.

Due to the limited involvement of other participants within the identification and presentation of these metrics, a number of divisional nuances were present that were not otherwise accounted for. The most significant of these being that the processes and systems used traditionally within the CSD were not supportive, or in some cases able to measure, some of the metrics proposed. These included;

- Measuring work and re-work as a percentage of the project completed thus far.
- Requirements, requirements validation and requirements verification trends.
- Customer feedback, gleamed through testimonials about products or concepts.

Finally, some of the metrics proposed initially were simply not considered to have any value within the CSD. Although reasons for this were not explicitly given, it could be inferred from other arguments made in this section that one or more attributes to implementation made them unsuitable. Examples of these are;

- Measuring the cost effectiveness of a new component relative to a similar measure on a prior component that resolved the same problem. A common example in aerospace may be weight.
- Measures that consider analysing and interpreting the working culture present within the CSD and how the use of DT may affect this.

- The number of times that a person is contacted to clarify a document, as a measure of the document's suitability.

To conclude, although co-creation activities were undertaken to ensure that the metrics solution was suitable for the CSD, a number of unknown variables were present in the solution that directly impacted its eventual failure. Section 5.4.2 will continue this discussion and explicitly link the issues presented here to the formerly created attributes to implementation.

5.2.5) Summary of Created Solutions

Section 5.2 has considered the contextual information relevant in the solutions generated within this investigation. Importantly, each of the solutions generated were compared with previous and theoretical implementations of DT and SE to demonstrate that none of solutions created had a structure that would be novel to DT or SE implementations from literature. The solutions themselves, however, represent a novel contribution to literature, as the literature review conducted (section 2.8) highlighted that literature has so far only considered the merging of the concepts of DT and SE rather than the creation of specific, industry suitable processes. Finally, contextual information is presented around each of the solutions generated to ensure that there is a level of traceability as to why each of the solutions were created.

5.3) Implementation of Created Solutions

This section aims to discuss contextual information around the methodology utilised to implement each of the solutions created. These discussions will consider points internally and externally to the CSD and aim to develop more of an understanding of the research question;

1C) What procedures support the implementation of DT and SE within an LEO?

When considering change management within this body of research it is also important to define the organisational culture that is present within the organisation as this provides additional context to why a particular finding may have been uncovered. The CSD for this investigation very closely followed the cultural phenomenon predicted in literature in figure 11, whereby the organisational culture values innovation over control (O'Reilly et al, 2014), had a poor process quality within its division (Cameron and Quinn, 2011) and had developed a 'Hero' culture to reflect on this (Crosby, 1979). Furthermore, the case study division could be classified as pluralist due to the variation of opinion and perspective found within the

interview series conducted, especially when considering the variations between and within levels of seniority and the fields of expertise identified (Fox, 1976).

This pluralist, 'hero' culture had significant impacts on the overall attempts to implement any of the proposed solutions within the case study division. As the change is proposed to be transformative (Bate, 1994), the change approach needed to utilise a pluralist standpoint, through the engagement with key stakeholders (Prajogo and McDermott, 2005), for it to be successful. Therefore, periods where there was a high turnover within the organisation would not be suitable for change management to occur as the sub-cultures present within the organisation have been shown through the interview series conducted to change within fields of expertise and differing layers of seniority. This also suggests that change management cannot occur within the case study division without an element of cultural change, as stakeholders within the CSD will eventually leave the organisation and the new key stakeholder may not share the same values, beliefs and sub-culture as the previous stakeholder.

This investigation found challenges internally to the CSD during this time as the primary researcher's lack of authority (Bass, 1985 and Kotter, 1996), lack of support from senior management (Bass, 1985 and Kotter, 1996), recurring modifications to change vision (Bass, 1985 and Kotter, 1996), reliance on few stakeholders and lack of change management experience (highlighted in 3.13) were all proposed to negatively impact the changes proposed. Engagement with proposed change activities during this timewere suboptimal. This perhaps only characterises part of the challenges identified with change management during this time as participants in the preliminary interview series (4.1.1) specified that change activities during this time were viewed as additional bodies of work and thus were often rejected due to the reduction in headcount and increase in demand on remaining team members.

Within the CSD, the most successful change management activities were ones that were not perceived to drastically change the status quo and were championed by one particular internal 'hero' within the organisation. For instance, the problem definition process and the project conception process were both supported by a senior member of staff whereas the failed solutions were either not supported at all, in the case of the low fidelity prototyping, or were perceived to impact too many of the division's other activities, in the case of the divisional metrics. Furthermore, where an emphasis had been placed on the use of co-creation with participants (again in the problem definition process and the project

conception process) this was reported more positively and more frequently in interview than earlier proposed implementations that did not. This is critical to consider in this case as this provides evidence to the value of utilising co-creation in pluralist, hero cultures and the value placed on understanding the CSD culture as a part of the change management process as a whole. One reason for this is the further understanding and engagement of divisional nuances that were possible after completing co-creation activities as participants identified key factors that should, or should not, be considered in the generation of later implementation. On the other hand, any implementation that was perceived to increase the time taken to complete a particular project were much more contentious (the problem definition process, low fidelity prototyping solution and metrics solution). Similarly, and purportedly due to the CSD's perception of 'requirements' as a concept, solutions that involved the creation, understanding or generation of formal requirements were perceived to be valuable but unlikely to remain within the CSD for a long period of time as they were perceived to prevent the development of innovative technologies. Reflecting this back on the critical literature review conducted (section 2.5), this is likely due to the values and beliefs that are present within the organisation's culture as there is repeated mention in the interview data collected that suggest that time to market and innovation are critical measures in the CSD.

The concept of time is critical to understanding the success or failure of change management activities that occurred within this research and the CSD. In part, arguments have been constructed within this thesis that point to the introduction of external factors at particular points as being supportive or detrimental to overall attempts to enact change or in the ability of the primary researcher to engage with and understand a particular divisional problem. This is important to consider in the research question "What procedures support the implementation of DT and SE within an LEO?" Similarly though, perspectives towards the research conducted changed throughout the research investigation. Three months into the investigation there was very little engagement with the research work being conducted whereas a year after the conception of the investigation there was stronger engagement and a greater understanding of the research's aims and objectives. This was likely caused by the conclusion of the UK furlough period, as groups of individuals returned to work and a more even distribution of workload led to increased capacity to consider change. However, this is also interesting as it highlights that cultures within an organisation can change over a relatively short period of time, given suitable pressures to change, and lead to significantly different cultural stances.

An interesting comparison to consider when understanding the climate within the CSD was the presence of a new SE team that had been conceived shortly before the beginning of the research project; in this case the concept of climate referring to the existing perceptions, cultures and understanding that was present within the CSD. The formed SE team worked predominantly on the creation and development of requirements for the new divisional projects and implemented systems, such as Confluence and Jira, that aimed to improve collaboration between members of project teams. However the role of the SE team was limited in this regard, as literature shows that the SE process and considerations of SE in change management encompass change from complete process (Armstrong, 2000) through systems thinking (Blizzard et al, 2012) to design verification and validation (Kossiakoff et al, 2011). It could be argued that this internally driven change management activity to implement SE demonstrates the values that the CSD believes it requires to generate successful outcomes. However, due to the strong perceptions that were reported regarding requirements and their influence on time to market it could be argued that this perception of value of SE was held by few individuals within the CSD.

As discussed previously in section 5.2, the involvement and interactions presented with a divisional 'hero' in the organisation led to more successful change management activities than implementations that aimed to achieve change without identifying a particular key individual. This involvement with heroes within the division was linked directly with specific implementations that often fell within the remit of their particular role and thus, the implementation proposed would directly affect their role and day to day activities. It could therefore be argued that the successful implementation of these solutions relied heavily on identifying and managing key stakeholders that had the directive to enable change within a particular area of interest to them. In support of this theory, the low fidelity prototyping solution and metrics solutions that both failed to be implemented successfully within the CSD did not have anyone within the division that formally took responsibility for these activities as a part of their role. This could, once again, point to the low value that the CSD placed on low fidelity prototyping activities and the use of metrics within divisional projects.

Literature highlights that if the entirety of a team does not accept a particular process implementation then it will ultimately fail (Schmidt et al (2011) for SE and Crisan and Caldarusa (2017) for DT). This is especially important to consider when put in the context of the CSD's pluralist culture. If the CSD had a unitarist culture, then the solutions generated would only need to accommodate one particular viewpoint, set of values or beliefs (Fox, 1976) and thus a small sample could be used to accurately propose what might be significant

within a given divisional population. However, in this case the solutions generated must be aware of the sub-cultures that are present within the CSD as the viewpoints and values from each of these must be accommodated when creating solutions if their implementation is to be successful. This therefore highlights again, that the understanding and incorporation of an organisation's culture into the change management process is vital to enacting successful change.

To conclude, this section proposed that the change management methodology selected must reflect on the organisation being considered; in particular through an understanding of its organisational culture as discussions show that this has had as significant an impact on the results of this investigation as the selection of change management methodology. In particular, the identification of an organisation as unitarist, pluralist or radicalist (section 2.5.2) and the value that is placed on process (section 2.5.1) is critical when considering the procedures that affect the implementation of DT and SE within an LEO. The CSD of this investigation was identified as pluralist and hero cultured, meaning that change needed to account for each of the cultures and sub-cultures present within the CSD as an onus was placed on each individual to accept or reject SE and DT implementations within their own roles.

5.3.1) Revisiting Attributes to Implementation

In section 4.1.1, a total of ten attributes to implementation were identified that would affect the implementation of DT and SE within an LEO. However, the implementation of solutions found that significant internal and external variables also affected the engagement and acceptance of implementation, such as the internal restructuring process, the impacts of COVID19 and the UK furlough period. Therefore, this thesis proposes that an 11th attribute to implementation should be included; titled Organisational Zeitgeist. This attribute proposes that the overall stability and attitude of an organisation can positively or negatively affect attempts to enact change.

Organisational Zeitgeist was not mentioned as a potential attribute to implementation in the literature review conducted but is commonly referred to within change management literature as an awareness of the other circumstances that exist with an organisation (Wisegarver, 2019) or through concepts such as change fatigue (Liedtka, 2018). This therefore, proposes a novel contribution to combined DT and SE literature and proposes that, when combined with other attributes to implementation, this investigation has created

a comprehensive framework of attributes to implementation of DT and SE that can be used in implementation within another organisation.

5.4) Failure Based Learning within Implementation

This section considers the failure-based learning conducted in section 4.4 and presents arguments that further answer the research questions. Importantly, this section aims to provide discussions as to which attributes to implementation have led to failure in each of the failure-based learning sections considered. Where partial success has been achieved in implementation, the areas of failed implementation are proposed to be indicators where locations of optimal implementation have not been identified. Where failure is found to be due to these attributes to implementation then this should be considered as evidence of the attribute themselves, and the attempt as an example in practice of how the attributes can affect change management activities. It is also important to note that since this research considers the implementation of DT and SE as a function of its core components, any conclusion drawn that considers any of these core components is therefore also applicable to DT and SE as a whole. Failure-based learning is considered through the contextual understanding of the division, external factors and the interactions and prevalence of the previously identified attributes to implementation. This section will discuss this concept of failure in more depth and outline how the results outlined in section 4.4 can be generalised.

The use of co-creation activities in creating the solutions proposed in this investigation pose an interesting question with regards to process failure. By being involved in co-creation activities and proposing that something has value, attention must be drawn to where co-creation participants then choose to reject a solution. One possible explanation is that individual's external factors may come to influence their internal decision making, and so suggests that if the CSD as a whole does not accept something then the individual may not be enabled to accept it either. Considering the CSD's pluralist culture (initially identified in section 4.1.1), this is likely commonplace as subcultures may have other values that differ from the majority (Fox, 1976). Furthermore, this is evidenced in practice through the investigation into the concept of process quality (section 4.1.3), where participants frequently reported negative opinions for late changes made to projects, but this was still commonplace.

5.4.1) Learning within Prototyping Work Package

When interview data suggested that the creation of a prototyping work package would be suitable within the CSD, the division was focussing on one particular project that at the time

was investing large amounts of time and money into the development of hardware with the aim to prove that new technology was viable. However, the failure in the prototyping work package was also likely partially due to the implications of the organisational culture and drive to create hardware quickly to show that projects are progressing. At the time of conception of this work package, emphasis had not been placed on investigating this cultural phenomenon in a great amount of detail as it was perceived to be supportive of the solutions that had been generated. There was a possibility though that this cultural factor was long established with its own process and expectations within the organisation and so the implementation of DT and SE within the CSD may have been prevented by attributes that were not understood at that time. Further failures in the prototyping work package were exacerbated through the failure to implement suitable design and business metrics as this meant that there was no reason for individuals within the CSD to engage with the proposed change (Royalty and Roth, 2016). To conclude, failures in the implementation of low fidelity prototyping were proposed to be directly linked to the previously aforementioned attributes; organisational culture, established process, organisational structure/hierarchy, project and business metrics and resistance to change.

5.4.2) Learning within Metrics Work Package

As previously mentioned in 5.2.4, this particular solution was led by a member of the CSO rather than the primary researcher and this was perceived to characterise the failure that occurred within the CSD. Whereas the primary researcher acts within the organisation as an agent of change and so all efforts and time can be dedicated towards this activity, the metrics work package lead had a number of other activities under their remit that would increase the length of time taken to enact change. Due to their position within the organisation, when more senior members of the organisation pushed to enact the organisational cultural drive to ‘get something done and do it quickly’ (section 4.1.5.6) the individual themselves expressed a lot of pressure to implement a simpler metrics solution than was initially created. This simpler metrics solution predominantly considered metrics that aimed to measure time to market, rather than any aspect of design suggested by DT and SE and was implemented towards the end of the second-year post research conception. This solution was significantly different from the metrics work package proposed and did not support the DT and SE implementations proposed. However, this was too late to have any impact on the other solutions that had been generated and the respective attempts to implement them up to this point.

Literature proposed that the identification of value, and implementation of metrics that reflect on value, is especially difficult where there is a long time to market or when the measures utilised are considered to be 'traditional', such as time to market, costs and overall revenue (Carlgren, Elmquist and Rauth, 2016A). Literature also pointed out that the 'management of large companies is based on specific KPI's that do not necessarily fit within the ambitions of DT', which has been the case in this investigation (Carlgren, Elmquist and Rauth, 2016B: p.46). Finally, this simplified proposed metrics implementation would not have been suitable to support the implementation of DT and SE as the metrics proposed would not accurately measure the intellectual activities of design (Mabogunje, Sonalkar and Leifer, 2016).

There were a number of repercussions to the failure to implement this proposed solution; the most important being that the failure to implement metrics that supported DT and SE meant that subsequent change management projects conducted were not supported by organisational metrics in implementation (Royalty and Roth, 2016). Considering that this is critical in change management literature (presented in section 3.10.1), this failure likely had a significant impact on the implementation of all other processes.

To conclude, failures in the implementation of the metrics solution were proposed to be directly linked to the previously aforementioned attributes; organisational structure/hierarchy, organisational culture, resistance to change and established process.

5.4.3) Learning within Education Materials and Engagement

One of the key deliverables proposed in the preliminary investigations conducted was the delivery of workshop materials. The divisional culture to demonstrate value quickly was proposed to drive the primary researcher to create a number of materials without truly understanding the contextual information that was present within the CSD. As such, the workshops that were created within the initial stages of the research undertaken gained very little traction within the division. Overall, the failure to implement educational materials due to this may have contributed to other failures in the implementations conducted within the CSD. For instance, the failure to implement any educational materials within the CSD meant that the knowledge base required to adopt and accept DT and SE was not present in the division when later implementations were attempted (Mubin, Novoa and Al Mahmud 2017). This could have led to rejection of proposed process due to a failure to identify why change might be important within the division, how change could be implemented or how particular DT and SE activities might be carried out (Blizzard et al, 2012). Similarly, an argument can be

presented to identify the failure to have employees adopt these educational materials as affecting the primary researcher's credibility as an agent of change within the division due to a failure to identify divisional problems and generate a solution of value. When later solutions were created, participants may have perceived the primary researcher's credibility as a driving factor in their choice to adopt or reject proposed bodies of work.

There is a clear dichotomy between the initial interview data characterising the attributes to implementation that suggested that workshops were accepted within the CSD against the findings and failure-based learning from the workshops that were developed to support the implementation of DT and SE. DT and SE education workshops were created that aimed to cover all areas of both design processes that were implemented within the CSD and thus the failure to implement any one workshop would likely have a direct impact on an individual's ability to understand and adopt the relevant aspect of the process that follows this. One explanation for the dichotomy present in this case is that the interviewee that raised the acceptance of workshops was not representative within the division, as they themselves were the only participants to comment on the suitability of workshops within the CSD and no other participants made comment on any other form of educational material. Similarly, there may have been a failure in the workshops created as they may not have engaged with participants suitably in a way to suggest that these techniques would resolve their concerns. However, reasons for this could also be placed with the circumstances that were present when the workshops were first created as this was shortly after the organisation had begun its main furlough period due to the COVID19 pandemic. This could be suggested as the levels of engagement did improve after the ending of the furlough period and as time increased away from it towards the completion of this research. On the other hand, this same phenomenon could also be due to the development of understanding of the CSD and the changes in attempts made by the primary researcher. Finally, this failure could be attributed to the presence of a hero culture within the CSD (initially identified in 4.1.1.5) as this would enable participants to choose whether to engage with these materials in the first place. Although care was taken to research this phenomenon objectively, no successful educational material could be identified within the CSD under standard, non-furlough, conditions and thus comparisons could not be drawn to conclusively prove any one theory.

5.4.4) Learning within Implementing DT and SE Thematically

Although partial success was achieved in the implementations conducted, the ultimate success or failure of the DT and SE solutions in this investigation should reflect on the core elements of both processes, presented in table 2 (section 3.12), as these were the core

foundations with which solutions were created. Table 16 and table 17 have therefore been created to outline where each of these core elements has been achieved or was perceived within the CSD as a part of the final interview series in section 4.5.3.

Table 16 – Critical Analysis of the Core Elements of SE (section 3.12)

Core Elements of SE (Micaelli et al, 2013)	Presentation or Perception within the CSD
Abstraction – requirements are created to generate an understanding of system rather than solution.	Requirements are created for some projects, and these can focus on either system or solution. There is no universal standard in place (section 4.5.3.5).
Decomposability – systems are composed of many smaller elements.	New products are considered as a combination of sub-systems but the interactions that take place between them is often not considered (4.5.3.12).
Pluralism – the system can be designed in many different ways and structure should be created that allows this knowledge transfer.	The use of concept generation and concept selection is limited but the Problem Definition Process does allow for ease of communication (section 4.5.3.2).
Alignment – SE is for the product and for the overall design process.	Alignment of an entire project team to SE occurs on some projects but can be easily removed due to external factors (4.5.3.4).
Incremental Improvement – learning from mistakes is key.	There is a product-based lessons learned and a divisional-based lessons learned present within the CSD (section 4.5.3.7).

Table 17 – Critical Analysis of the Core Elements of DT

Core Elements of DT (Carlgren, Elmquist and Rauth, 2016A)	Presentation or Perception within the CSD
User Focus – the development of a solution always has the end user in mind.	The CSD places cultural value on technology drivers and efforts to change this have failed (section 4.5.3.3).
Visualisation – or more accurately the visual representation of concepts in designs.	The prototyping implementation failed and there is no perceived change to the ideas of concept generation and selection (section 4.4.1).
Problem Framing – Identifying problem and solution spaces and acting on them.	Due to the way that projects start, there is still a disconnect between investigations that occur within a problem space and the design within the solution space (section 4.5.3.2).
Diversity – collaboration of diverse teams in the design process.	Teams that work together on projects have a diverse range of backgrounds and fields of expertise (section 4.1.1.6).
Experimentation – the bias towards testing and trying things out in an iterative fashion.	At project conception there was a strong cultural bias to make models and make them quickly so that iteration can occur (section 4.1.1.2).

These tables shows that success from change management have achieved several core elements of DT and SE; notably success has been achieved with the element's incremental improvement and diversity and partial success has been achieved with the element's abstraction, decomposability, pluralism, alignment and experimentation. This reflects on the partial success of the Project Conception Process and Problem Definition Process and the failure-based learning presented in section 4.4. The overall implementation of DT and SE can be considered to be partially successful within the CSD due to its ability to achieve these core elements.

5.5) Measuring Implementation Outcomes

The investigative methods aiming to measure implementation outcomes were enacted two years after research conception and roughly one year after the implementation of the problem definition process and project conception process (figure 43). Therefore, since participants were asked to engage with these processes fortnightly as a minimum, it was proposed that a suitable period of time had passed post process implementation within the CSD where any proposed change from the solutions implemented could have materialised and thus, become measurable. To understand this effect, all research methods conducted in the outcomes investigation aimed to reflect on the co-created objectives outlined in section 4.2 and holistically reflect on the research questions.

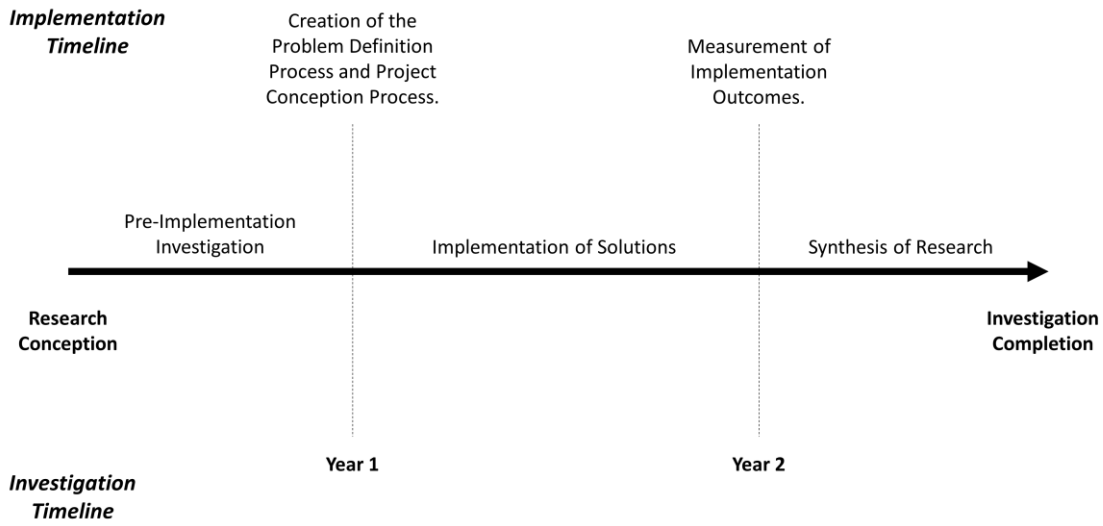

Figure 43 - Implementation Timeline Against Investigation Timeline

Considerations could also be drawn towards the concept of an implementation outcome as at the time of generating this data the primary researcher was still engaged with the

managing and directing of implementation material within the CSO. Therefore, an argument can be proposed here that the immediate implementation outcomes are what is measured in section 4.5 rather than the long-term outcomes presented by implementation as the long-term adoption was still being developed within the CSO. This is due to the content of the preliminary interview series and the attributes that were identified therein in section 4.1.1, where participants reflected on the cultural and hierarchical drives imposed on them within the division and the impact that this has on the long-term implementation of anything that deviates from the established process.

5.5.1) Measuring Communication between Customer Facing and Design Focus

This section reflects on section 4.5.1, where the partial implementation of solution 2 was compared with the traditional communication process present in the CSD. This section will therefore outline relevant points to allow the reader to assess the validity and accuracy of this data.

The investigation conducted that aimed to measure changes in the communication rate between customer facing and design focussed roles was limited in the number of data points that could be collected within each bi-weekly period as the number of points counted in 2020 did not exceed 10 and the number of points in 2021 only once counted greater than 20. Therefore, an increase or decrease of one point would be more significant, when considering the results found, than if the number of points in each category were considerably larger. This meant that dramatic changes in figure 41 could be perceived to be due to significant changes in the division but were likely simply due to changes in the number of data points that were collected in either of the two datasets.

The data presented considers a rolling average of all the data collected over a period of months rather than immediate results from a particular bi-weekly period. This is due to the significant fluctuations that were presented at each bi-weekly period, whereby the number of points generated using the problem definition process or in the previous process could be anomalously high or low. Instead this presentation aims to more clearly demonstrate improvement over a period of time, where the effects of extraneous variables could be mitigated and an overall understanding identified for the reader.

An argument could be presented that there are methodological limitations and complications in comparing the established process data from 2020 against the post implementation data from 2021 due to the introduction of the COVID19 pandemic and the UK furlough scheme. On the other hand, the data set gathered for each case covers a total

of 34 weeks of the calendar year which could be argued to mitigate this effect due to the volume of data gathered and the changing evolution of extraneous variables over time. Furthermore, the furlough scheme was present in the UK between March 2020 and September 2021 which means that the vast majority of the data gathered in the post implementation data set was also collected during the UK furlough scheme, albeit with comparatively less stringent regulations in place.

5.5.2) Project Case Studies

The small project case study outlined in this thesis served to provide one example of where DT and SE was proposed to be able to resolve an internal divisional issue. This section will outline the discussions around the case study conducted and important lessons that would be important to consider in further research.

This case study was completed late into the research undertaken within the CSD which in turn led to the late communication of project outcomes. Since one of the main purposes of this smaller case study was to identify a number of outcomes that could be presented to the CSD to improve perceptions to the change management work that was ongoing, this late dissemination of outcomes can be argued to be far too late in the change management process to have any effect. However, according to Kotter (1996), the use of small, achievable goals in change management activities is vital to the later long-term uptake of any proposed change. Therefore the use of this case study was not to probe employees to view DT and SE more positively before the first implementation, but to support perceptions towards the long-term adoption of these processes.

Another limitation of the smaller case study conducted was that it was mostly led by the primary researcher rather than any member of the CSD. Although this did ensure that an element of control was present within the work conducted, this may have not been representative of how a similar project may have been conducted within the CSD if undertaken by divisional personnel. For example, although divisional personnel were involved in the project, the influences that have been shown to be present in other projects, such as influences of organisational culture and hierarchy, would not affect the primary researcher in the same way.

It is important to note that this case study is a novel contribution to knowledge, as it is a recorded implementation of a merged DT and SE process within an LEO, alongside the successes found in implementing each of the created solutions.

5.5.3) Final Interview Series

This section will discuss the findings from the final interview series within the context of this investigation and the CSD. As mentioned in 3.10.6, the sample size for this interview series was 17% (21 participants) of the total population of the CSD with some repetition between the preliminary interview series and the final interview series. Although an argument could be presented to suggest that this sample may have been too small, representation was collected from all identified fields of expertise and at each level of seniority within the CSD to ensure that the data collected was a suitable reflection of the diverse divisional perspective. Further, this interview series was conducted until theoretical data saturation was achieved which suggests that the sample size was suitable for the investigation proposed. In the event that theoretical data saturation had not occurred at this point, then efforts would have been redirected to identifying more participants to achieve this.

Again, the sampling techniques used in the final interview series were initially proposed to be stratified due to the spread of expertise and seniority within the division but were forced towards selective and pragmatic sampling due to the limitations that were present within the CSD. This would propose that bias may be present in the data collected, especially as the sample that were interviewed in the preliminary interview series would be likely to also be interviewed in this final interview series. To mitigate this, 50% of the interviews conducted were with participants that had not taken part in the preliminary interview series or the questionnaire follow up interview series, although no comparison could be presented against the questionnaire completed due to respondent anonymity.

5.6) Divisional Comparison Interview Series

The divisional comparison interview series was conducted using a relatively small sample of 12 participants, consisting of six participants each between comparison divisions one and two. This may be perceived to be a relatively small sample considering the more considerable interview series conducted within the main CSD. On the other hand, this interview series was not aiming to collect data in as much depth as the CSD, as this data aimed to generate an understanding of the generalisability of this work amongst divisions in other fields of engineering design.

This divisional comparison interview series highlighted important findings in the implementation of DT and SE within an LEO; the interview series conducted in the main CSD and the one conducted in the comparison divisions had significantly different product lines

and ongoing projects but the same organisational culture and hierarchy and reported the same negative attributes to implementation. This therefore proposes that considerations about organisational hierarchy and the organisational culture present are valid across the range of engineering activities investigated and therefore findings from this research are directly generalisable to culturally and structurally similar organisations. However, this alone cannot assess the generalisability of this research to culturally or hierarchically different organisations.

Since this spread of products is very varied (the CSD is high complexity, low volume and relatively new, comparison division one is low complexity, high volume and established and comparison interview two is high complexity, low volume and established) an argument can be presented that LEOs aiming to implement DT and SE within their processes should consider all of the attributes to implementation identified in this investigation. Although cultural and hierarchical influences may enable attributes to be more positively or negatively affect implementation, the comparison interview series identified that these attributes were still relevant in each case.

5.6.1) Implications for Future Work

Although a definitive outcome cannot be determined through this research as to the exact outcomes that would be found when implementing DT and SE within another LEO, the findings from this research do propose that organisations can be categorised, based off of their culture to understand the generalisability of this work to future situations. These categories, and examples of proposed organisations, can be presented in table 18. Importantly, since DT has been found in literature to be implemented in organisations other than engineering, this table shall consider the same.

Table 18 – Comparing Industries and their Proposed Cultures

Cultural Type	Hero	Process
Unitarist	Innovation driven organisations following one key leader's vision (such as new technology start-ups).	High regulated industries where safety is paramount (such as aerospace or medical).
Pluralist	Innovation driven industries where value is placed on teams or individuals (such as politics or organisations with separate, isolated teams).	Regulated industries that involve collaboration with other organisations or teams (such as government).
Radicalist	Traditionally high turnover industries that are undergoing change (such as recently unionised organisations).	High turnover industries that place a focus on mitigating cost (such as fast food).

By considering the influences and importance in culture in enacting process change within this research and outlining where each culture may be found, the concept of generalisability can be assessed more accurately when considering the change management outcomes found. For instance, an organisation that was unitarist and process cultured may find that change is accepted significantly easier than that found within the CSD as process is already valued and the change management only needs to account for one series of values and beliefs. The identification of culture in this way also means that the generalisability of this work can likely be extended to all organisations that are pluralist and hero cultured and thus, as the attributes to implementation were found to be generalisable to all organisations, concludes the identification of this research's generalisability.

The divisional comparison interview series also highlights the generalisability of this research to be towards organisations that have similar engineering and manufacturing requirements as the CSO of this investigation, as when questioned the first comparison case gave conflicting responses to each of the questions proposed to the original data set. This is also shown in the results from the second comparison division more closely matched the original data; although this was not always the case. Therefore, the entirety of the outcomes of this investigation are more closely generalisable to organisations with similar requirements.

5.7) Enhancing Research Quality

Considerations regarding research quality have been taken into account at each stage of the research process to ensure that the criteria outlined in section 3.11 are achieved. This section will consider the overarching areas in which emphasis was placed on research quality and

assess the applicability of this in the wider context of the research. More specific discussions on each research method are present in their respective section in chapter 5.

Triangulation has occurred at various stages in this research with the aim to improve research quality through the mitigation of bias and error. The first instance was with the validation of the preliminary interview data with the literature conducted in the aim to understand and identify the key attributes that would affect the implementation of DT and SE within an LEO. The second was the use of the questionnaire series conducted within the pre-implementation investigations, that aimed to give participants an opportunity to view all of the data collected thus far and provide further perspective on what they believed were the greatest opportunities and threats within the division. This ranking exercise also served to provide a quantitative element to the data collected, and through this, identify a level of significance for each of the attributes created previously. Finally, the post questionnaire interview series was compared with all of the data considered previously, aiming to give participants an overview of perceptions towards the division and allowing them to discuss and develop ideas.

The data collected in each interview series has been collected, analysed and presented in such a way to maintain academic rigour. This was attempted in two key ways in this thesis, through the concepts of confirmability and research authenticity, discussed previously in section 3.11. Considering confirmability, this thesis has aimed to present a range of quotes from interview that evidence the analysis being undertaken and place an emphasis on deriving conclusions from the work presented. To achieve research authenticity, these presented quotes were, where applicable, discussed from opposing or differing viewpoints so that the breadth of knowledge created can be explored. Both criteria are especially important to achieve within the context of this research as this mitigates any biases or perspectives from the primary researcher and ensures that readers are presented with an accurate and faithful reproduction of participants attitudes towards key points.

The validation conducted with literature in section 4.1.2 also served to assess and improve the dependability of the research conducted (discussed in 3.11.2). Since the data within the literature regarding attributes to implementation was identified as predominantly perspective, reflective or failure-based learning data, a direct comparison of the primary research against this understanding was conducted to assess the dependability of this research as the findings therein could be assessed for their replicability with other participants under similar conditions (Koch, 2006).

5.7.1) Evaluating the Case Study Organisation as Representative to Industry

The case study organisation was defined in 1.0.1 and 3.12 as a globally distributed FTSE250 organisation with over 4000 employees and revenue of over £650 million in the 2022 fiscal year. This investigation identified a total of 11 attributes to the implementation of DT and SE that reflected directly on the literature review conducted (section 4.1.1). It further identified that at least one division in the organisation has a pluralist (Fox, 1976), uncertainty culture (Crosby, 1979); where individuals within the division have cultures that differ from one another, and individuals do not have certainty around their role. Further investigation identified that the organisation used a process akin to a traditional engineering process (section 5.1.2).Although original contributions to knowledge have been generated through this body of research, the CSO is perceived to be representative of other organisations that classify as an LEO. The reflection of the first ten attributes directly on to literature demonstrates that the same categories can be construed as challenges to (or support) implementation with minimal change (section 2.7), with the identification of Organisational Zeitgeist reflecting on literature from change management (section 2.6). The novelty of the organisations culture can be assessed through future work when investigating the organisational culture of other LEOs, but it again reflects on literature as it is indicative of organisations that strive to generate innovative solutions (Crosby, 1979). Furthermore, the existing process utilised by the organisation could be considered to be akin to a traditional engineering process, which is not novel to engineering organisations (section 2.1). Additional investigation could be conducted to compare the CSO's product line and technologies with other organisations but given that the each of the CSO's divisions operates within a competitive market it can be assumed that these products and services, while competitively strong, are also not novel.

This section must conclude that the CSO (and so the CSD) considered within this investigation is not significantly different from other LEOs and their operations based on the investigative work conducted as a part of this research. Therefore, although the applicability of some work is limited (as highlighted throughout chapter 5 and summarised in section 6.4), the wider generalisation of the findings of this research is valid so long as these additional limitations are considered.

5.8) Summary of Discussions

The discussions chapter is split into a number of sections that aim to answer different parts of the research questions. The first section considers the pre-implementation investigation

and presents discussions around the validity and accuracy of the attributes to implementation identified in section 4.1. The attributes to implementation from the pre-investigation implementation are assessed through validation with literature and identified that the ten attributes to implementation found were generalisable to other LEOs, thus contributing to the existing knowledge. One of the key discussions present during this period was due to the introduction of COVID19, the UK furlough period and a period of organisational redundancy, where difficulty was found in establishing change management stakeholders due to the relatively rapid turnover and change of working individuals.

Next, the solutions created were compared to implementations proposed in literature that showed that the solutions were not radical in design; meaning that the findings from this investigation would be more generalisable to other DT and SE implementations than an entirely novel approach. In fact, these solutions represent a significant contribution to knowledge as the literature review conducted only considered the merging of DT and SE as concepts, and not as processes that could be applied to an LEO. Furthermore, this section presented the argument that as solutions created used co-creation, they were likely to identify participants' perceptions to the optimal locations of implementation and the outcomes that they perceived would prove the value of DT and SE in an LEO. This is a critical point, as if the organisation had differing existing processes, they may have perceived different outcomes to be of benefit to them. For example, if a highly stringent requirements processes existing within the organisation, then they would likely respond differently to systems engineering than they did with their existing traditional engineering processes. This is because this argument frames the answer to question 1D as an incremental change from what is existing rather than a definition from nothing, meaning that the outcomes of this investigation have limited generalisability to organisations with similar existing processes.

Section 5.3 considered change management and revisited the characteristics that were identified within the division of cultural pluralism and its emphasis on heroes. This was found to be significant in all change management work undertaken and is something that should be considered in future DT and SE implementations. A reflection is then presented on change in this investigation and identified a number of additional challenges, including; the anonymity of the primary researcher as an agent of change, the identifications of champions, the use of co-creation, the disparity between proposed change and organisational culture, the timeliness of implementation, the identification of divisional nuance, the prevalence of more or less significant attributes to implementation and the presence of poor communication channels.

The next section considered failure-based learning and outlined discussions that considered where implementation had been partially successful within the CSD. The challenges reflected directly on the attributes to implementation identified in section 4.1 and gave further credence to the cultural characteristics proposed. This section concluded by considering the thematic implementation of DT and SE within the CSD and identified that partial implementation has been successful during this investigation.

Section 5.5 considered the post-implementation outcomes of this investigation and aimed to critically evaluate the selection of particular metrics and methodologies within the context of this investigation. Drastic changes in the communication measurements were discussed as a reflection of the low number of data points available but were valid. The project case study was found to be conducted too late into to have a significant impact on the overall ability to enact change but was important to support perceptions to long term adoption of DT and SE. The methodology of the final interview series was assessed and, similarly to the preliminary interview series, proposed that theoretical data saturation was suitable in generating representation from the case study population. Finally, discussions were presented with regards to the communication methods that were prevalent within the organisation and the argument was presented that although the primary researcher was not a member of the CSD, attempts were made to integrate them within the CSD and so the data generated can be proposed to be valid.

Discussions were then presented around the divisional comparison interview series as a means of identifying the generalisability of the findings of this research with other LEOs. To summarise, the 10 attributes to implementation presented in section 4.1.1 were found to have slight differences when validated with literature (4.1.2) but thematically are proposed to be generalisable to other LEOs. However, the divisional comparison interview series identified that although the attributes were applicable thematically, they affected the comparison divisions differently, and thus present mixed generalisability. This was found to be attributed, in part, to the cultural characteristics and expectations that were present within an LEO. This is a significant concept that builds upon the existing literature.

Although the comparison divisions presented similarly mixed perceptions to the solutions generated and prevalence to the attributes to implementation as the CSD, the same cultural and hierarchical characteristics were present and this likely affected the data gathered.

This chapter concludes with a discussion around overarching research quality which reflects on the concepts of research quality identified in section 3.11. Triangulation was utilised at a

number of stages within this investigation to mitigate bias and error and assess the accuracy, repeatability and generalisability of data. To achieve confirmability and authenticity (presented in section 3.11) this thesis presented data analysis alongside quotes from interview transcripts and considering differing or opposing viewpoints where applicable. Finally, the dependability of this investigation was considered through a direct comparison with literature to assess the replicability of findings with other participants under similar conditions.

6.0) Conclusions

This chapter of the thesis will summarise the work that has been conducted in answering the research questions proposed initially of;

1) **How can Design Thinking (DT) and Systems Engineering (SE) be combined and implemented in a Large Engineering Organisation (LEO)?**

Which can be split into;

1A) What are the optimal locations for DT and SE to be implemented in an LEO?

1B) What are the attributes affecting the implementation of DT and SE in an LEO?

1C) What procedures support the implementation of DT and SE within an LEO?

1D) Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?

First, a summary of the methodology used to conduct this investigation is outlined and, where important in concluding the research questions, the reader will be reminded of methodological choices. Then this chapter will go on to draw conclusive statements for each research question using the data has been gathered throughout this investigation and identify how this may impact the existing literature. The generalisability and applicability of the research conducted is then summarised. Finally, recommendations for future work are presented based on the results found in this investigation to develop the knowledge that is present in the field of implementation of DT and SE within LEOs.

6.1) Methodology Overview

To answer the proposed research questions, first a realist ontology and critical realist epistemology were established (section 3.3) and followed with the selection of an inductive reasoning approach (section 3.4). The research purpose was deemed to be exploratory due to the limited literature in this field (section 3.5) and a mixed methods research type was considered due to its perceived ability to measure and contextualise the concept of an LEO effectively (section 3.6). A single case study was conducted within one division of one LEO that introduce a number of benefits and limitations to the findings of this research (section 3.7). Within this case study, considerations then were made toward the selection of action research as an inductive research methodology that considered the primary researcher to be an agent of change within the organisation (section 3.7.1). This investigation relied on

interviews, questionnaires and quantitative organisational data, failure-based learning and the use of thematic analysis, to answer its research questions (section 3.8).

The methodology was split into three distinct sections; pre-implementation (section 3.10.2), solution creation and implementation (section 3.10.3) and post implementation (section 3.10.6). First, a pre-implementation investigation was conducted that aimed to characterise the CSD and develop an understanding of how employee perceptions perceived the implementation of DT and SE. Following this, locations for implementation were identified and solutions were generated that aimed to be implemented using a number of change management proposals. These were partially successful and so failure-based learning aimed to understand why failure had occurred and how perceptions may have changed towards any attributes identified through the use of interviews with both key change stakeholders and non-participating stakeholders. This post implementation investigation also aimed to identify where success was found and measure this in comparison to pre implementation values.

6.2) Answering Research Questions

The overarching research question for this investigation is **'How can Design Thinking (DT) and Systems Engineering (SE) be combined and implemented in a Large Engineering Organisation (LEO)?'** Through the consideration of literature, and the variables imposed by the selection of a case study methodology, this thesis proposes that the overarching research question can be split into the research questions 1A, 1B, 1C and 1D and that answering these questions support the answering of the overarching research question. Each research question will be addressed in this section and answered from the data constructed in other sections of this thesis.

First, the critical literature review identified a number of locations of implementation and identification of outcomes of value of DT and SE through previous DT and SE case studies (section 2.2.1 and section 2.3.1). As a part of the literature review conducted, the implementation of process was proposed to require an understanding and manipulation of organisational culture. In turn this identified the organisational culture characteristics of hero versus process culture, and unitarist versus pluralist versus radicalist culture. The literature review also identified a number of organisational change methodologies; such as Lewin (1947), Burnes (2017), Bass (1985), Kotter (1996), Armstrong (2000) and the Lean Six Sigma Change Management Process (Uluskan, 2016). The literature review conducted

concluded by considering the attributes to implementation of DT and SE and identified a total of 10 attributes to implementation (section 2.7).

Within the pre-implementation investigation (section 4.1); the preliminary interview series, subsequent data analysis and attempts at validation identified a consistent series of 10 attributes to implementation when compared with literature. Minor discrepancies between the attributes identified in interview and the attributes identified in literature further contextualise and demonstrate how the attributes to implementation can affect organisations differently (section 4.1.3). The pre-implementation investigation also detailed the process quality of the established design process, using metrics that were identified in interview as important culturally to the organisation, and found that the existing process was not suitable for the products being developed in the CSD. When coupled with the link identified in literature between senior management, organisational culture, process quality and culture at a design level (section 2.5), and the identification of an emphasis on heroes rather than process, the pre-implementation investigation identified that the CSD follows the logical argument presented in figure 11 (page 38).

A total of four solutions were created using co-creation activities that identified the locations of pre-design process (section 4.2.1) and communication process (section 4.2.2) as optimal locations for implementation. The solutions considering prototyping (section 4.2.3) and metrics (section 4.2.4) were found to be partially optimally located as perceptions and circumstances within the CSD changed as time progressed. Change management processes found mixed success within the CSD, to summarise;

- The openness and accountability of Lewin (1947) and Burnes (2017) developed solutions that considered the pluralist culture within the organisation but failed to generate significant traction in implementation.
- The change management process proposed by Bass (1985) and Kotter (1996) enabled the partial implementation of the pre-design process and communication solutions but failed to implement the prototyping and metrics solutions created.
- The Lean Six Sigma Change Management process (Uluskan, 2016) failed to implement the prototyping and metrics solutions created.

The mixed results found with change management processes proposed that the choice of change management process must be more closely related to the organisational culture present.

The use of failure-based learning as a research method in this investigation identified that the challenges found in process implementation could be directly linked to the attributes to implementation coded from the pre-implementation investigation (section 4.4). Failure-based learning considered the prototyping solution, metrics solution and challenges in implementing educational material. Finally, failure-based learning identified an 11th attribute to implementation, named Organisational Zeitgeist (section 5.3.1).

After the implementation of process had been completed, the post implementation investigation aimed to measure changes in communication between pre and post implementation (section 4.5.1), outline a project case study (section 4.5.2) and investigate changes in perception through a final interview series (section 4.5.3). First, the number of data points communicated between customer facing and design personnel was found to increase by up to 175% when compared with the previously established communication channel. Next a project case study was completed that utilised DT and SE in the CSD and improved the overall efficiency of an established process by 20%, demonstrating that there was value in implementing DT and SE in the CSD. The final interview series identified a number of areas that had improved within the CSD. However, the final interview series also found that not all of the objectives defined in the creation of the solutions were able to be implemented and thus only partial success had been achieved in implementation. Finally, measurements were taken that aimed to quantify the communication rates through different communication channels within the CSD. This found that email and virtual messaging had response rates of less than 60% when replies were needed to progress change initiatives and that virtual meetings had an attendance rate of less than 85%. Therefore, this would conclude that change management initiatives, where participants are not required to attend as a part of their role, should avoid messaging services in favour of meetings in order to mitigate poor engagement with change.

This investigation concluded with the divisional comparison interview series (section 4.6), that aimed to identify if the results found within the CSD were generalisable to other organisations. This comparison identified mixed perceptions to the solutions that were generated but proposed that the attributes to implementation were applicable to cases outside of the CSD.

6.2.1) Answering Split Research Questions

To answer the research question 1A ‘What are the optimal locations for DT and SE to be implemented in an LEO to generate positive outcomes?’ data sets were used in the co-

creation of the Project Conception Process (section 4.2.1) and Problem Definition Process (section 4.2.2); two merged DT and SE processes that centrally aimed to resolve the pre-project stage and internal and external communication respectively. Two further solutions were created using this data in the low fidelity prototyping implementation (section 4.2.3) and the proposed metrics implementation (section 4.2.4). In this investigation, the concepts of a pre-project process implementation and communication implementation were found to be consistently optimally located (section 4.3), whereas a low fidelity prototyping and metrics implementation were proposed to be situationally optimally located (section 4.4). Finally, the divisional comparison interview series found that due to differences between divisions, the issues present in the CSD were different from the comparison interview divisions and thus that although some local optimal locations for the implementation of DT and SE may have been found, that the overall applicability and generalisability of these locations (and the solutions created) may be limited to very similar organisational conditions as the CSD. However, this investigation cannot conclude whether this is novel to this CSD or if optimal locations to implementation are novel to each LEO, in practice.

When considering the research question 'What are the attributes affecting the implementation of DT and SE in an LEO?' the preliminary interview series identified a total of 10 attributes to implementation. A further attribute was identified through the analysis of implementation data. These attributes were;

Table 19 - Comparison of Attributes to Implementation

Attributes from Literature	Attributes from Interview	Definition
Education of Design Engineers	Educational Resources	The division's ability to learn new things and the processes that are in place to support this.
Individual Mindset and Skillset	Individual Mindsets and Skillsets	The influence of individuality and diversity between and within teams in the division.
Resistance to Change	Resistance to Change	Resistance to the implementation of new processes, tools and techniques.
Established Design Process	Established Process	The current design processes for all aspects of the division, to include product development.
Implementing Innovation	Implementing Innovation	The division's ability to develop innovative solutions and implement them.
Metrics for Success	Project and Business Metrics	The division's ability to measure the outputs that have been produced accurately.
Organisational Culture	Organisational Culture	The influence of organisational culture on the processes and outcomes of projects.
Existing Power Dynamics	Organisational Structure/Hierarchy	The influence of the organisational structure and hierarchy on divisional outcomes.
Communication Styles	Communication	How the division communicates information both internally and externally.
Remote Design	Remote Design	The division's ability to operate as a globally distributed organisation.
	Organisational Zeitgeist	Any significant positive or negative events that affect an organisation and individual's reaction to them.

These attributes were compared to attributes identified in literature (section 2.7) and validation was conducted that identified no major discrepancies between each of the attributes identified within the CSD and literature, presented in 4.1.2. These were then included in the questionnaire conducted with the aim of identifying the greatest strengths

and threats within the CSD, and through these perceptions directly introduced arguments as to the most important and least important attributes to this CSD (section 4.1.4). A questionnaire follow-up interview series was conducted with the intent to contextualise these attributes to implementation and explore the applicability of these attributes within the CSD (section 4.1.5). These attributes were then considered again after the creation and implementation of the solutions considered within this research, as successes and failures that had taken place within each proposed implementation were discussed with respect to these attributes and the interaction between them. This therefore provided a critical, tested series of attributes to implementation that corroborated literature and would be important to consider when attempting to implement DT and SE within an LEO.

The research question 1C 'What procedures support the implementation of DT and SE within an LEO?' in this body of research was considered through the attempts and instances where change management efforts were used to engage with the CSD. A number of change management strategies were outlined from literature and presented in section 3.10.1. Using this and the initial understanding gained from the pre-implementation investigation, a number of solutions were created using either co-creation techniques or through drawing items directly from DT and SE literature (section 4.2). The primary researcher then attempted to implement these, using themself as an agent of change in the division, whilst utilising change management methodologies proposed by Lewin (1947) and Burnes (2017), Bass (1985) and Kotter (1996) and the Lean Six Sigma DMAIC framework (Uluskan, 2016). Partial success was achieved with the Project Conception Process and Problem Definition Process, with failure-based learning for all implementations presented in section 4.4. In this investigation, the change management methodology presented by Lewin (1947) and Burnes (2017) aided in the creation of solutions but failed to generate meaningful change within the CSD. The change management methodology presented by Bass (1985) and Kotter (1996) implemented the Project Conception Process (section 4.2.1) and Problem Definition Process (section 4.2.2) within the CSD but challenges were identified in relation to process and activity adoption. Finally, the Lean Six Sigma change management methodology (Uluskan, 2016) did not implement the low fidelity prototyping solution and this, alongside the proposed metrics solution, was not implemented before the end of this investigation. Critically, the identification of the CSD as being significantly 'hero focussed' and mitigating its use of defined process meant that the key procedures supporting change were; effective stakeholder management, identification and drive from an organisational champion and the clear communication of any implementation that may be perceived to increase the division's

key metrics. This investigation also identified the important relationship between unitarist, pluralist and radicalist cultures, and change management, and proposes that this relationship was significant in the implementation of DT and SE within an LEO. In particular, the pluralist culture present in the CSD directly affected the implementations conducted, as the presence of subcultures with differing beliefs meant that solutions needed to be tailored to align with these beliefs for implementation success to be achieved. Importantly, the pluralist culture was also found to affect perceptions towards the attributes to implementation initially identified in section 4.1.1, and thus affected all of the change management activities in this investigation.

Finally, when answering research question 1D 'Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?', although a fixed set of outcomes could not be identified that would apply to all cases, a number of conclusions can still be drawn from this investigation. First, the co-creation of solutions within the CSD identified a number of key objectives that implementation was required to achieve success, and thus these are localised outcomes that could have provided evidence of implementation value (section 4.2). Next, when these processes and their objectives were compared in the divisional comparison interview series, the participants identified that these did not necessarily apply to their divisional circumstances due to differences between the CSD and comparison divisions (section 4.6). This identified that the objectives, and thus desired outcomes, proposed within the CSD are not directly generalisable to all other LEOs. However this can partly be attributed to the cultural characteristics identified within the CSD, in particular the 'hero' culture and the presence of cultural pluralism, which would suggest that solutions must be bespoke to a given set of sub-cultures (section 2.5). This is reflected in the proposed implementations as they experienced an element of failure and, as such, the outcomes proposed at the creation of the solutions were not necessarily acceptable in proving the value of DT and SE to all individuals within the CSD.

6.3) Original Contribution to Knowledge

This section specifically details this investigation's original contribution to knowledge and, where applicable, makes direct comparisons to the literature review conducted in chapter 2. These contributions to knowledge are split into the categories methodological, theoretical and empirical.

6.3.1) Methodological

This section will aim to detail the methodological contributions to knowledge, where novel methods were enacted to answer the proposed research questions.

The literature review conducted identified that perspective or reflective data was often employed to investigate the attributes to the implementation of DT or SE. This investigation considered this and also utilised failure-based learning to provide an additional, applied data set for validation and the further contextualisation of the attributes to implementation.

Due to the COVID19 pandemic and subsequent periods of furlough and remote working, the solutions created in section 4.2 were implemented remotely within the CSD, and into a hybrid working environment, which is methodologically novel.

Finally, this investigation had the opportunity to investigate culturally similar case studies that had different design processes and divisional characteristics, rather than case study divisions or organisations that differed in all regards. This meant that the divisional comparison interview series (section 4.6) also provided an assessment of the importance of organisational culture and organisational structure/hierarchy as attributes to the implementation of DT and SE in an LEO.

6.3.2) Theoretical

The following section aims to detail the theoretical contributions to knowledge, where findings from this investigation are shown to adapt, develop, create or oppose the theories and models presented in literature.

This investigation considered the relationship between organisational culture and organisational change (section 2.5) and identified that change management must consider the organisational culture that it is being implemented within to be successful. The identification of the CSD in this investigation as a pluralist, hero culture, was significant in the findings of change management work conducted and specific change management activities, such as co-creation and stakeholder management, were identified as supportive of change within these conditions.

A total of ten attributes to implementation were identified in the pre-implementation investigation as significant in the implementation of DT and SE in an LEO (section 4.1.1), and these were validated with literature (section 4.1.2). This is a new theoretical model, as literature considered in this investigation considered the attributes to the implementation of SE or DT as separate entities. However, in the efforts to implement DT and SE within the

CSD, this investigation identified a further attribute of Organisational Zeitgeist (section 5.3.1). This attribute proposed that significant positive or negative events within the CSD could affect the implementation of DT and SE, as shown in the discussions around the impacts of the organisational restructure, COVID19 pandemic and organisational furlough. Therefore, a novel theory has been created that lists a total of eleven attributes to implementation that affect the implementation of DT and SE within an LEO.

In sections 2.2 and 2.3, the literature review established common areas to implementation of SE and DT individually, and section 2.8 outlined theoretical applications of DT and SE with other processes. This investigation created a series of four DT and SE solutions that were applied to the CSO and could be applied to another LEO.

The methodology of this investigation utilised process quality as a tool for assessing the suitability of existing process and as a tool in enabling organisational change. Although the use of process quality to measure process in industry is not novel, its applications within research and the use of the results of this investigation to generate a sense of urgency, such as proposed in Kotter (1996), is proposed to be novel.

6.3.3) Empirical

Data from this investigation identified two optimal locations of implementation and two partial locations of implementation. The two optimal locations of implementation were found to be at the pre-design process and a communication process whereas the partial locations of implementation were found to be a prototyping and metrics solution.

This investigation empirically concluded a total of 11 attributes to the implementation of DT and SE as a merged process. Ten of these attributes were validated with literature into the implementation of DT and SE as separate design processes. The attributes to implementation were further validated through the failure-based learning dataset conducted in section 4.4.In literature these attributes were often referred to as barriers, which proposed that the possession of these organisational attributes themselves were entirely negative. However, this investigation found that the attributes to implementation identified could positively and negatively affect the implementation of DT and SE within an LEO.

Data from this investigation supported the logical framework composed in section 2.5 in discussing the link between senior management, organisational culture, process quality and culture at a design level. In particular; senior management are proposed to value drivers in innovation (section 4.1.1.4), the organisational culture was proposed to drive projects to

complete something quickly rather than with particular standardisation (section 4.1.1.2), the CSD process quality was found to be poor (section 4.1.3), and the organisation placed an emphasis on heroes rather than process (section 4.1).

Through the failure-based learning detailed in section 4.4, this investigation identified that there are optimal times to implement change as well as optimal locations. In this investigation, the optimal times to implement change were linked to either the development of CSD projects as they moved through stages of the major design process or related to external influences, such as COVID19 or a period of redundancies.

6.4) Research Generalisability and Applicability

Efforts were made during the course of this investigation to improve the overall generalisability of this investigation's results to other LEOs. This section will briefly highlight the limits of the generalisability and applicability of this work to other organisations and to the wider literature.

First, the selection of a single case study methodology limits the direct application of this research to another proposed case study unless the circumstances between both case studies are similar. Two attempts were made to assess the generalisability of this data against other work; the attributes to implementation were validated against a critical literature review of investigations that had been conducted into other organisations and the solutions generated were attempted to be validated against comparison interview data from two other divisions within the CSO. In the first case, the attributes to implementation were found to be similar to that from literature and thus could be considered to be generalisable and relevant to future implementations. In the second case, the interview data from the divisional comparison interview series did not validate the solutions previously generated and instead suggested that differing organisational characteristics and external factors (presented in chapter 5) would lead to the identification of different problems and the generation of different solutions.

This investigation also found that the identification and ongoing consideration of an organisation’s cultural characteristics are key to the implementation of DT and SE and thus, the applicability of this research may initially propose that the results found are not generalisable to any other case that has a differing culture. However considering the successful validation that has taken place (section 4.1.2), the similarities that are present when comparing the CSD to the divisional comparison interview series (section 4.6) and the implications identified when considering differing cultures in section 5.6.1, this research

proposes a series of conclusions. First, the attributes to implementation are generalisable to other implementations of DT and SE due to their successful validation in literature. Second, the change management findings of this investigation should be directly generalisable to other organisations with the same pluralist, hero culture and the overall value of culture in change management is generalisable to all organisations. Finally, the optimal locations to implementation identified within the CSD found mixed perceptions in the divisional comparison interview series and so this may propose that the optimal locations to implementation should be tailored to each organisation's needs. However, this investigation does identify that there are theoretical optimal locations to implementation and optimal times to implementation within an organisation.

Based on the information presented above, and throughout the Discussion Chapter (chapter 5), this investigation would propose that its findings are directly applicable to culturally similar organisations, with similar high complexity engineering challenges, low rates of production and utilising traditional engineering processes. This reflects directly on the findings of section 4.6 (as differing engineering and manufacturing requirements led to conflicting responses to the questions asked), the cultural literature and findings in sections 2.5 and 4.1.6 respectively (as culture at a macro level has been found to be deterministic to the attitudes to change) and when answering research question 1D throughout (as the perceptions to how DT and SE may generate value will likely be different if an innovation or requirements driven process already exists within the organisation).

6.5) Future Work and Recommendations

There are a range of future work and recommendations points that were identified during this research that did not fit within its scope. These reflect directly on the ability of this research to answer its research questions.

The replication of this body of work in another organisation may lead to significant differences in the optimal locations for implementation and outcomes that prove the value of DT and SE as shown in the divisional comparison interview series. Therefore, this investigation recommends that this replication is conducted, and comparisons drawn between another organisation and the CSD from this investigation. If the results are found to be similar, then the findings from this investigation could be considered to be generalisable to a more widespread series of organisational characteristics. However, if the results are found to be different, then this lends further credence to the importance of

understanding an organisation's culture, so that attributes to implementation can be understood, in order to execute planned change.

This investigation found a number of optimal locations for implementation from interviews and co-creation activities that proved to be partially successful when applied to the CSD. Future work should consider investigating the optimal locations for the implementation of DT and SE within other LEOs to assess the generalisability of the locations considered in this case and generate a more conclusive list of the possible locations present. Furthermore, future work should compare this empirical understanding with theoretical data created regarding the implementation of both DT and SE within LEOs with the aim to identify whether the initial assumptions made in section 2.8 are accurate and representative of application.

Further work should also be conducted to evaluate the attributes to implementation identified in this investigation and assess their applicability to other cases. This is particularly true of the attribute 'remote design' (identified in section 4.1.1) as this was not considered during the later stages of this research but may more significantly affect implementation within organisations that conduct design activities from geographically distributed locations. This reflects on a further point, where the attributes to implementation as a collective may affect organisations differently and so a repetition of a questionnaire similar to this investigation (section 4.1.4) would explore the significance of these attributes to other cases.

There was very little literature present that outlined change management processes specifically with regards to the implementation of DT and SE within an LEO of similar characteristics as the CSD. As such, multiple change management processes with different theoretical standpoints were considered in this investigation and utilised in the implementation of the four proposed solutions. However, due to the challenges found in implementation, further research should be conducted that considers the relationship between organisational characteristics, change management and the implementation of design process. As such, recommendations for future work also include a further exploration of the significant cultural aspects identified in this investigation (section 2.5) as these results cannot determine if these factors are likely to be significant in other organisations. This should include an exploration of factors that contributed to the model proposed in figure 11 (page 38) and how these influence the implementation of DT and SE in a LEO. Importantly, this should also include an investigation into the effects of unitarist, pluralist and radicalist cultures within organisations. This could be done through a replication of the work

conducted in this investigation within another case study, as this would provide an evaluation of the generalisability of the work conducted.

Finally, future work should consider the development of a complete series of outcomes that are relevant to the implementation of DT and SE within an LEO. Although objectives were identified in this investigation, individuals' perceptions towards values changed during the course of the investigation. This meant that the objectives identified at a given period in time would not necessarily have value at a later date and thus, may not represent a complete series of outcomes that participants propose to support the value of DT and SE.

6.6) Closing Statements

Not all change is created equally. This investigation has identified, amongst other things, that the implementation of design process must consider the organisational culture that is present in an organisation when selecting its change management methodology, the structure of the process-based solution and whether a particular design process is suitable for a particular case.

7.0) References

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8.0) Appendices

Appendix 1 – Interview Consent Form

Interview Consent Form

Combining Design Thinking and Systems Engineering

This consent form will have been given to you with the Participant Information Sheet. Please ensure that you have read and understood the information contained in the Participant Information Sheet and asked any questions before you sign this form. If you have any questions please contact a member of the research team, whose details are set out on the Participant Information Sheet.

If you are happy to take part in the interview regarding your views on design methods and project development, please sign and date the form. You will be given a copy to keep for your records.

- I have read and understood the information in the Participant Information Sheet which I have been given to read before being asked to sign this form;
- I have been given the opportunity to ask questions about the study;
- I have had my questions answered satisfactorily by the research team;
- I agree and acknowledge that I may have audio recordings during the interview and this may be used at a later date to pull quotes, themes and other data points of interest to the study;
- I agree that anonymised quotes may be used in the final Report of this study;
- I understand that if any part of this study may be reported back to [redacted] then care will be taken to ensure that all data is used anonymous.
- I understand that my participation is voluntary and that I am free to withdraw at any time until the data has been anonymised, without giving a reason;
- I agree to take part in the research

Name (Printed).....

Signature..... Date.....

V1.1, Brandon Robertson, 07/08/2020

Appendix 2 – Questionnaire Consent Form

Questionnaire Consent Form

Combining Design Thinking and Systems Engineering

This consent form will have been given to you with the Participant Information Sheet. Please ensure that you have read and understood the information contained in the Participant Information Sheet and asked any questions before you sign this form. If you have any questions please contact a member of the research team, whose details are set out on the Participant Information Sheet.

If you are happy to take part in the interview regarding your views on design methods and project development, please sign and date the form. You will be given a copy to keep for your records.

- I have read and understood the information in the Participant Information Sheet which I have been given to read before being asked to sign this form;
- I have been given the opportunity to ask questions about the study;
- I have had my questions answered satisfactorily by the research team;
- I agree that any data provided as a part of the questionnaire can be used as a part of the investigation to create a novel design process that leads to better customer outcomes and reduced time to market.
- I agree that anonymised quotes may be used in the final Report of this study;
- I understand that if any part of this study may be reported back to [redacted] then care will be taken to ensure that all data is used anonymous.
- I understand that my participation is voluntary and that I am free to withdraw at any time until the data has been anonymised, without giving a reason;
- I agree to take part in the research.

Name (Printed).....

Signature..... Date.....

V1.0, Brandon Robertson, 22/04/20

Appendix 3 - Research Participant Privacy Notice

Privacy Notice for Research Participants

Purpose of the Privacy Notice

This privacy notice explains how the University of the West of England, Bristol (UWE) collects, manages and uses your personal data before, during and after you participate in the research titled "Combining Design Thinking and Systems Engineering". 'Personal data' means any information relating to an identified or identifiable natural person (the data subject). An 'identifiable natural person' is one who can be identified, directly or indirectly, including by reference to an identifier such as a name, an identification number, location data, an online identifier, or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.

This privacy notice adheres to the General Data Protection Regulation (GDPR) principle of transparency. This means it gives information about:

- How and why your data will be used for the research;
- What your rights are under GDPR; and
- How to contact UWE Bristol and the project lead in relation to questions, concerns or exercising your rights regarding the use of your personal data.

This Privacy Notice should be read in conjunction with the Participant Information Sheet and Consent Form provided to you before you agree to take part in the research.

Why are we processing your personal data?

UWE Bristol undertakes research under its public function to provide research for the benefit of society. As a data controller we are committed to protecting the privacy and security of your personal data in accordance with the (EU) 2016/679 the General Data Protection Regulation (GDPR), the Data Protection Act 2018 (or any successor legislation) and any other legislation directly relating to privacy laws that apply (together "the Data Protection Legislation"). General information on Data Protection law is available from the Information Commissioner's Office (https://ico.org.uk/).

How do we use your personal data?

We use your personal data for research with appropriate safeguards in place on the lawful bases of fulfilling tasks in the public interest, and for archiving purposes in the public interest, for scientific or historical research purposes.

We will always tell you about the information we wish to collect from you and how we will use it.

We will not use your personal data for automated decision making about you or for profiling purposes.

Our research is governed by robust policies and procedures and, where human participants are involved, is subject to ethical approval from either UWE Bristol's Faculty or University Research Ethics Committees. This research has been approved by the Faculty Research Ethics Committee for the Faculty of Environment and Technology in the University of the West of England. The ethics application reference number is FET.20.02.035 and the email contact details of the research ethics committee for queries, comments or complaints is Researchethics@uwe.ac.uk. The research team adhere to the **Ethical guidelines of the British Educational Research Association (and/or the principles of the Declaration of Helsinki, 2013) and the principles of the General Data Protection Regulation (GDPR).**

For more information about UWE Bristol's research ethics approval process please see our Research Ethics webpages at:

www1.uwe.ac.uk/research/researchethics

What data do we collect?

The data we collect will vary from project to project. Researchers will only collect data that is essential for their project. The specific categories of personal data processed are described in the Participant Information Sheet provided to you with this Privacy Notice.

Who do we share your data with?

We will only share your personal data in accordance with the attached Participant Information Sheet and your Consent Form.

How do we keep your data secure?

We take a robust approach to protecting your information with secure electronic and physical storage areas for research data with controlled access. If you are participating in a particularly sensitive project UWE Bristol puts into place additional layers of security. UWE Bristol has Cyber Essentials information security certification.

Alongside these technical measures there are comprehensive and effective policies and processes in place to ensure that users and administrators of information are aware of their obligations and responsibilities for the data they have access to. By default, people are only granted access to the information they require to perform their duties. Mandatory data protection and information security training is provided to staff and expert advice available if needed.

How long do we keep your data for?

Your personal data will only be retained for as long as is necessary to fulfil the cited purpose of the research. The length of time we keep your personal data will depend on several factors including the significance of the data, funder requirements, and the nature of the study. Specific details are provided in the attached Participant Information Sheet. Anonymised data that falls outside the scope of data protection legislation as it contains no identifying or identifiable information may be stored in UWE Bristol's research data archive or another carefully selected appropriate data archive.

Your Rights and how to exercise them

Under the Data Protection legislation you have the following **qualified** rights:

(1) The right to access your personal data held by or on behalf of the University;
(2) The right to rectification if the information is inaccurate or incomplete;
(3) The right to restrict processing and/or erasure of your personal data;
(4) The right to data portability;
(5) The right to object to processing;
(6) The right to object to automated decision making and profiling;
(7) The right to complain to the Information Commissioner's Office (ICO).

Please note, however, that some of these rights do not apply when the data is being used for research purposes if appropriate safeguards have been put in place.

We will always respond to concerns or queries you may have. If you wish to exercise your rights or have any other general data protection queries, please contact UWE Bristol's Data Protection Officer (dataprotection@uwe.ac.uk).

If you have any complaints or queries relating to the research in which you are taking part please contact either the research project lead, whose details are in the attached Participant Information Sheet, UWE Bristol's Research Ethics Committees (research.ethics@uwe.ac.uk) or UWE Bristol's research governance manager (Ros.Rouse@uwe.ac.uk)

v.2: This Privacy Notice was issued in April 2020 and will be subject to regular review/update.

Appendix 4 – Interview Research Participant Information Sheet

Interview Research Participant Information Sheet

What is a Participant Information Sheet?

The Participant Information Sheet is the document that is given to potential participants with written information about the study. Its purpose is to help potential participants to decide whether they want to take part and to provide relevant details, including contact details

Combining Design Thinking and Systems Engineering

You are invited to take part in research taking place at the University of the West of England, Bristol. It is funded by [redacted]. Before you decide whether to take part, it is important for you to understand why the study is being done and what it will involve. Please read the following information carefully and if you have any queries or would like more information please contact Brandon Robertson, Faculty of Environment and Technology, University of the West of England, Bristol at Brandon2.Robertson@live.uwe.ac.uk.

Who is organising and funding the research?

The Director of Studies for this research is Dr Richard Mawle and the supervisory team is composed of Dr Louis Rice and Ms Marion Gillet. The team's bios and details of their work are available at; https://people.uwe.ac.uk/Person/RichardMawle, https://people.uwe.ac.uk/Person/LouisRice and https://people.uwe.ac.uk/Person/MarionGillet respectively. [redacted] is funding this research and the University of the West of England is the proposed sponsor. As such, the information collected by this research will be used to create and develop a novel design process, described further below, that will be owned by [redacted] but the data itself will be collected, analysed and owned by the University of the West of England.

What is the aim of the research?

The research is looking at two complimentary design processes, design thinking and systems engineering, and how these can be used to allow designers to quickly create customer orientated solutions that accurately reflect the needs of the customer. Further this research is looking at how this can be implemented into a large engineering organisation and how project stakeholders can be taught these methods so that they can be deployed effectively. Our research questions are;

- How can Design Thinking (DT) and Systems Engineering (SE) be implemented in a Large Engineering Organisation (LEO)?

Which can be split into;

- What are the optimal locations for DT and SE to be implemented in an LEO to generate positive outcomes?
- What are the attributes affecting the implementation of DT and SE in an LEO?
- What procedures support the implementation of DT and SE within an LEO?
- Can outcomes provide evidence of the value of the implementation of DT and SE within an LEO?

To help us answer these questions we will be conducting interviews. The aim of this will be to collect information that will be made anonymous.

The results of our study will be analysed and used in a report made available in the University of England's open access repository. The anonymised results may also be used in conference papers and peer-reviewed academic papers.

Why have I been invited to take part?

As a stakeholder, we are interested in gaining information about your views and opinions so the interview will ask you about these things. We will not be asking any questions about your personal life or any details about your working life except those that are relevant to the aims of the interview. The purpose of the questions will be to gain a deeper understanding of the sort of things that you believe may be important in the development of a product or service and the process that may be followed to understand this. Personal data that we may collect will include; length of time in current role, field of expertise, level of seniority, previous experiences in industry or level of education.

Do I have to take part?

You do not have to take part in this research. It is up to you to decide whether or not you want to be involved. If you do decide to take part, you will be given a copy of this information sheet to keep and will be asked to sign a consent form. You are able to withdraw from the research without giving a reason until the point at which your data is anonymised and can therefore no longer be traced back to you. **This point will take place three months from the date you signed your consent form**. If you want to withdraw from the study within this period, please write to Brandon Robertson, Faculty of Environment and Technology, University of the West of England, Bristol or contact Brandon2.Robertson@live.uwe.ac.uk. Deciding not to take part or to withdrawal from the study does not have any penalty to your current or future working life and will have no bearing on your career progress.

What will happen to me if I take part and what do I have to do?

If you agree to participate you will be asked to take part in an interview that aims to further explore your views and opinions on the product or services that we are developing at the current time. In particular at this time we are looking to understand more about the current [redacted] design process and how this is used by stakeholders during a current project. This will be conducted by Mr Brandon Robertson. The surrounding team are all experienced in the subject matter and are sensitive to issues it may raise. The interview will take

approximately 30 minutes. The interviewers can travel to the [redacted], the University of the West of England site at Frenchay or interviews can be conducted over means such as Skype or Microsoft Teams so long as this is agreed in advance with the interviewers.

The subject and focus of the discussion will be regarding the current [redacted] design process and how this is interacted with by stakeholders in current [redacted] projects. Your answers will be fully anonymised and any project information that you choose to not to share, will further not be reported by the researcher.

Your interview will be recorded on a voice recorder but the recording will not contain your name. Instead a unique identifier will be used to re-identify you if you choose to withdraw from the study within the withdrawal period of three months. At the point of transcription, your voice recording will be deleted. Your data will be fully anonymised at three months from being collected and will then be analysed with interview data from other anonymised participants.

What are the benefits of taking part?

This work is funded by [redacted] to meet the demands of developments in the field of design and the shift in design to user centred methods. Importantly this research will ensure that large organisations can adopt user centred "Design Thinking" methods which has been shown to improve the time to market and customer satisfaction of a product. If you take part in this research you will be helping us to gain a better understanding of the barriers that exist in adopting new design methodologies that will ultimately help large organisations to create products that are more suitable for consumers. Further you will aid in the design and development of a novel design process, and accompanying educational tools, that will aim to be used within [redacted].

What are the possible risks of taking part?

We do not foresee or anticipate any significant risk to you in taking part in this study. If, however, you feel uncomfortable at any time you can ask for the interview to stop. If you need any support during or after the interview then the researchers will be able to put you in touch with suitable support agencies. The research team are experienced in conducting interviews and are sensitive to the subject area. The interviews have been designed with these considerations in mind.

What will happen to your information?

The information we receive from you will be treated in the strictest confidence. All the information that you give will be kept confidential and anonymised at three months from collection. The only circumstance where we may not be able to keep your information confidential is in the event that you raise anything that concerns the research team about the wellbeing of yourself or others around you. Hard copy research material will be kept in a locked and secure cabinet onsite at [redacted] that can only be accessed by the

interviewers. Voice recordings will be destroyed securely immediately after transcription and anonymised three months from the date you signed the consent form. Your anonymised data will be analysed together with other interview and file data, and we will ensure that there is no possibility of identification or re-identification from this point.

Where will the results of the research study be published?

A Report will be written containing our overall research findings. This Report will be available on the University of the West of England's open-access Research Repository, and will likely be published in October of 2022. This data will also be used in other supporting publications until the conclusion of this investigation, at which point all data will be destroyed. The project funder is [redacted]. Any data used in these publications will be anonymised before publication.

A hard copy of the Report will be made available to all research participants if you would like to see it. Key findings will also be shared both within and outside the University of the West of England with the supervisory team managing the research project and key members of staff within [redacted]. Anonymous and non-identifying direct quotes may be used for publication and presentation purposes.

Who has ethically approved this research?

The project has been reviewed and approved by the Faculty Research Ethics Committee for the Faculty of Environment and Technology of the University of the West of England. Any comments, questions or complaints about the ethical conduct of this study can be addressed to the Research Ethics Committee at the University of the West of England at:

Researchethics@uwe.ac.uk

What if something goes wrong?

In the event that you have a concern, query or complaint; these can be sent in the first instance to the lead interviewer Brandon Robertson (Brandon2.Robertson@uwe.ac.uk) or to the Director of Studies for the project Dr Richard Mawle (Richard2.Mawle@uwe.ac.uk).

What if I have more questions or do not understand something?

If you would like any further information about the research please contact in the first instance:

Brandon Robertson

Faculty of Environment and Technology, University of the West of England, Bristol, BS16 1QY

Brandon2.Robertson@live.uwe.ac.uk

Thank you for agreeing to take part in this study.

You will be given a copy of this Participant Information Sheet and your signed Consent Form to keep.

V1.2, Brandon Robertson, 22/10/2021

Appendix 5 – Project Motivations Document (Project Conception Process)

[redacted]

PROJECT MOTIVATIONS

OPPORTUNITY DETAILS			
Opportunity name:		Issue:	
Author:		Date:	
Description (include diagrams if possible):			

PRELIMINARY MARKET ASSESSMENT	
Market or customer need:	
Target market description:	
Current / emergent competition:	
What is our value proposition?:	
Patentable features:	
Target launch date:	
Latest acceptable launch date:	
Additional information: (e.g. research to date, specific customer interest, strategic information)	

PRELIMINARY NEXT STEPS	6 MONTH PLAN
Action:	Comments:

LESSONS LEARNED	
Previous Project:	Value

CONTACTABLE PARTIES	WITHIN [redacted]
Name and Role:	Email:

[redacted]

DIRECTIONS FOR THIS DOCUMENT

This document is intended to be completed alongside the [redacted] at the end of the Project Conception Process and aims to inform appropriate members of the design and management teams about the motivations and direction proposed for the project. This document should therefore also be used as a reference piece during the project and detail who the appropriate management figures are in the project development.

Opportunity Details

This has been taken directly from the [redacted] and should simply be replicated here. The idea behind this is that the design and management teams will need to know the details of the initial motivation for starting the project so that they can have an input on designing for innovation later in the project development. Importantly the design teams need to know how we intend on the product operating, how it may be manufactured and how we plan on testing the final design.

Preliminary Market Assessment

This section is key to this document as it should serve to disseminate to the reader what the thought process is with regards to our proposed value proposition and how we have done enough research to understand the current market. This should serve to drive conversations around the project towards a common goal and lead to innovative solutions that will further separate the completed product with the market.

Preliminary Next Steps

This section highlights the proposed next steps for the project and how designers should expect the next six months to operate. This level of clarity will help designers and management to understand what to expect from the initial project development and how they should expect to plan their time in the foreseeable future.

Lessons Learned

The considerations behind this section are to put an emphasis on understanding the work that has been carried out prior to the proposed project and how this will affect development moving forward. Similar previous projects should be analysed to identify the problems that they faced and how this may or may not be important for the proposed project.

Contactable Parties

This section details the notable members of management in the project and who to contact in the event that a member of staff has a query about a project. In the interest of encouraging collaborative design, emphasis should be placed on reminding the design teams that if they have a suggestion regarding the product development then they should make the project leads aware of this. This should be investigated in more detail and, if applicable, should be designed and developed further to have an impact on the project.

Appendix 6 – Pre-Implementation Interview Plan

Preconceptions Interview Plan

Before we begin;

- You should have received a copy of the participant privacy notice, participant information sheet and an interview consent form. A signed copy of the consent form needs to be returned to the myself.
- This interview will be recorded using Panopto recording software to record your audio which will be transcribed according to the information in the documents listed above.
- Everything said during the interview will remain anonymous and no data will be shared outside of this interview unless in a format that protects the anonymity of the interviewee. Under no circumstances will audio files be disseminated, only extracts taken from the transcription process.
- If at any point during the interview you do not wish to continue, please inform myself. The interview will stop immediately and none of the data given up to that point will be used without your consent.
- If at any point within the next twelve weeks you wish to remove your data from the dataset collected then please inform myself. You do not have to give a reason, your data will be removed and any insights generated will be removed.
- A copy of all of this information is available in the aforementioned documents for review in your own time.

Are you happy with all of the above?

Control Questions

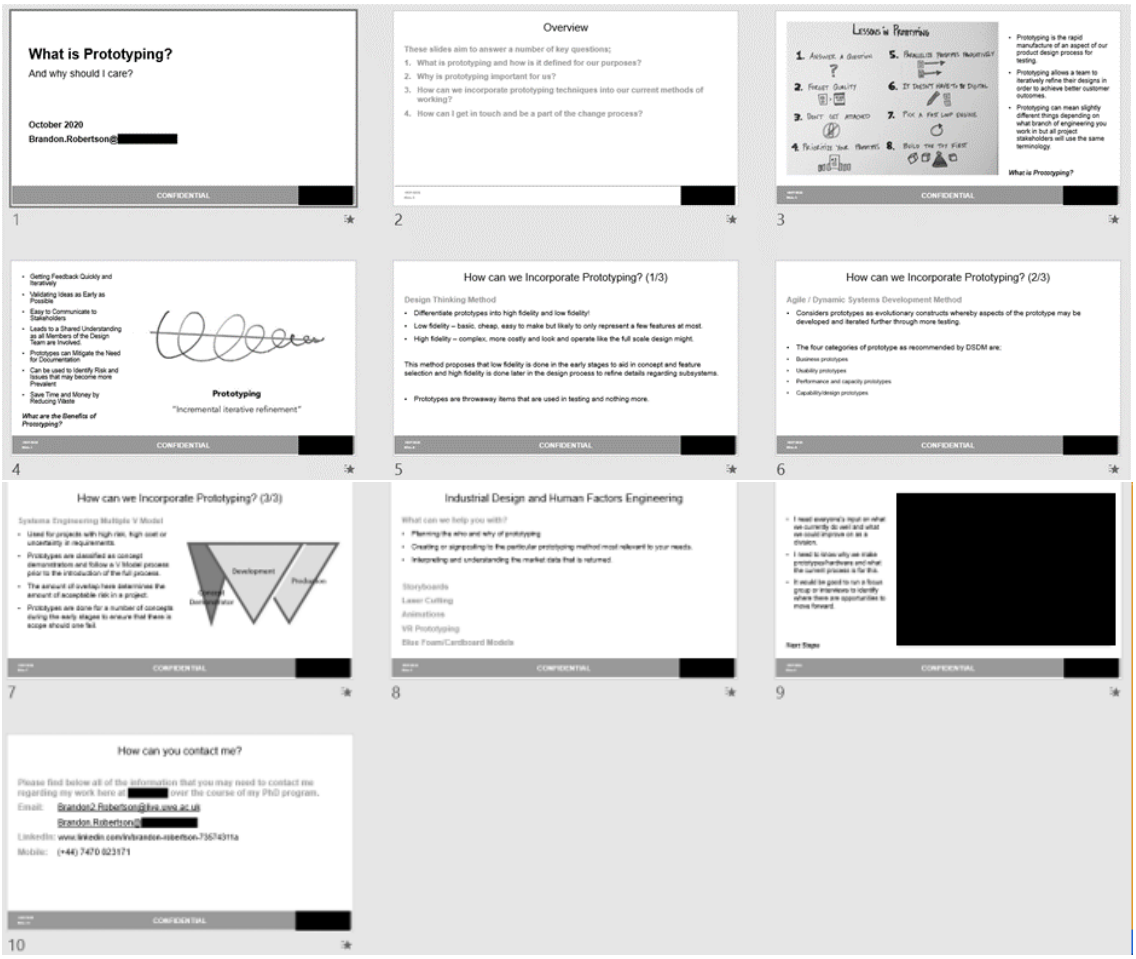
1. What is your current role within Renishaw?
    a. Would you classify your current role as early career (less than three years), product design, manufacturing, software, management, senior management or other?
2. How many years have you worked in your current role?
3. How many years have you worked in industry?
4. Have you previously attended university?

To reiterate, this part of the investigation is aimed at identifying the preconceptions of any opportunities or barriers that may arise when implementing design thinking and systems engineering within a large engineering organization. Therefore with this in mind;

1. Are you familiar with design thinking?
2. Are you familiar with systems engineering?
3. Where do you think the key areas of implementation for both processes will be within Renishaw?
4. Are there any aspects of design thinking and systems engineering that you think will be easily applicable to Renishaw?
    a. Why?
5. Are there any aspects of design thinking and systems engineering that you think will be particularly hard to apply to Renishaw?
    a. Why?
6. What would the ideal scenario be for you in your role from the implementation of these design processes?

Appendix 7 – Early Workshop Slides for Project Conception Process

Appendix 8 – Early Presentation Slides for Prototyping Solution



Appendix 9 – Journalling A: Extract from Traceability of Specifically Requested Bodies of Work

Requests for Work

07/02/2020

Create a talk for [redacted] regarding requirement elicitation and generation

11/02/2020

Create a 3 to 4 hour workshop regarding design thinking methods for requirement generation. Create a similar workshop regarding research methodologies (interviews, focus groups, surveys etc) for requirement generation. Focus on the prior first.

16/03/2020

Create a paper that reflects on the presentation that had to be cancelled because of Coronavirus for the end of the month. Shortly after the meeting [redacted] let me know that the [redacted] did not see any value in this project outside of the requirements generation stages and that we needed to get onboard quickly. [redacted] stated that this was to be completed around the end of April.

03/04/2020

Shorten the paper above down to a few pages to discuss the tools only in the context of the [redacted]). Create a series of slide for the Kickoff meeting that "sales pitch" design thinking as a part of the systems engineering framework to be presented to other senior management staff (Roughly 2 Weeks). To work with [redacted] on creating a modified version of [redacted] by implementing agreed upon design thinking tools (By the end of the month).

08/04/2020

To go over the Kickoff Powerpoint and make all recommended changes to the formatting and style. Still to get into contact with [redacted] and work with [redacted] on generating a merged version of the [redacted] and the design thinking tools.

Appendix 10 - Journalling B: Extract from Journalling Activities

06/03/2020

Email to [redacted] asking about future workshop plans for both systems engineering and design thinking workshops. I was told at this time by [redacted] that the systems engineering workshops had been delayed because of coronavirus and that I should send over the workshop aims, target audience and outline, which I did over email on the 10th, and asked about whether there was anything else that I could do moving forward to get teaching moving too. I received no further emails in this chain from there. At the time I was a little unsure if I had been too vague in my line of questioning and needed to narrow down the focus of the email into a specific want or need that I could address. However because of the limited nature of what I was aware of I am not sure how I could have attempted this differently.

6 Emails, 1 Response

16/03/2020

Meeting with [redacted] with the aim of discussing how it might be best for us to get on board with the [redacted] developments that they are being made for the long term. The takeaway I got from the meeting was that the team in [redacted] needed a paper created that explained each of the methods that could be implemented at this early stage and how this might work, similar to the workshop. However, on further conversation this was not needed. This was not great as this had taken a long period of time and the resulting paper was not used in any format as it was deemed to be too long and was not useful to employees that might need to use it. Could a potential barrier for implementing these methods actually be that the industrial company themselves don't know what it is that they want but they want results?

1 Meeting, 1 Output

27/03/2020

Emailed [redacted] regarding my personal skype details as contact seemed to be a problem. Replied soon after saying that the company had switched to Teams and that I would be sent a link whenever it was needed. This seemed positive as it insinuated in my mind that we were perceived as important and necessary to the project. However I could not get access to the [redacted] teams system as I did not have access to their laptop or a working account so this has made things difficult.

2 Emails, 1 Response

30/03/2020

Emailed [redacted] with regards to a question about the [redacted] which documents the planned [redacted] design process at the moment. [redacted] emailed back to explain that it was a Prince 2 document that is completed before a go/no go decision is made to begin a project. This was interesting as up to this point I thought that this was a "business as usual project" at [redacted] and didn't deviate from their usual methods. Upon closer look after this, this project is being used as a test case for some of their new tools and methods.

1 Email, 1 Response

03/04/2020

Email to [redacted] regarding the [redacted] so that I could make comparisons. Reply with all needed documents the same day. This is great as I now have paperwork that tells me the current [redacted] process for doing things, but since this has not been published anywhere it may need validation with another method. Something to think about later on I think as this correlates nicely with the paperwork regarding the [redacted] a little while ago.

1 Email, 1 Response

9.0) Published Works

9.1) PhD Study Report – The Design Journal (Volume 23, Issue 6, p.811-819)

Combining Design Thinking and Systems Engineering to Improve Customer Outcomes

Authors

Brandon James Milne Robertson

PhD Student at the University of the West of England

Bristol

United Kingdom

Biography

Brandon is a PhD student at the University of the West of England studying the implementation of user centred design methods in large engineering organisations; in particular with design thinking and systems engineering methods. Previous to this he completed his MEng in Aerospace Engineering at UWE, Bristol.

Overview

The field of engineering is a major contributor to the economic stability and growth of the UK and other economies. Therefore, the efficient operation of engineering companies and firms is vital. However, design projects undertaken by large engineering organisations are often beset with a number of problems and constraints that stem from the decision-making process and design process that have been selected. This PhD aims to investigate whether the design processes of design thinking and systems engineering can be combined. This would lead to better customer outcomes and reduced time to market, and thus remove the problems often found in large engineering organisations to improve the overall operational efficiency. The overarching research methodology used in this investigation will be action research and is likely to be predominantly qualitative in nature as it has been found that it is very difficult to establish quantitative metrics for design.

Keywords

Design Thinking; Systems Engineering; User Centred Design; Large Engineering Organisation; Qualitative Research; Design Process

Background

In 2022, the engineering sector is predicted to contribute £608.1 billion GDP to the UK economy and is expected to employ around 5.8 million people. Contributions from the engineering sector in 2014 equated to 27.1% of the total UK GDP (Centre for Economics and Business Research, 2015). Therefore, the efficient operation of engineering companies and firms is vital to sustain the economy. However, design projects undertaken by large engineering organisations (LEOs) are beset with a number of problems and constraints that include technological, economic and political factors. The cause of many of these problems is related to the design process undertaken in LEOs and the decision-making process that has resulted from the design process selection; this research investigates alternative design processes as a means through which to improve the delivery of projects in LEOs and the potential for development for inventive solutions to very complex problems.

The Traditional Engineering (TE) design process shows that as a design develops and gets closer to production; the costs incurred for changing any aspect of the design increases dramatically. As a project progresses, the design becomes more fixed and project artefacts such as technical drawings, prototypes and manufacturing techniques are created, meaning that changes to the design of the part itself has implications for other work that has already been conducted thus far. Systems Engineering (SE) is a design process that was developed to reduce the probability of changes occurring later in the design process as SE aims to ensure that the implementation that has been selected is suitable for the stakeholder needs. SE directly contradicts TE techniques as it focusses on the design of an entire system and its subsystems, by considering the wider context, to resolve the stakeholder needs, whereas TE focusses predominantly on individual components and individual component design. In SE, a system is considered in its simplest form to be a set of

parts that work together to resolve a design requirement (Cloutier, Baldwin and Alice, 2015:19).

Monat and Gannon (2018) identified case studies for which the systems engineering process was not effective. Analysis identified four rationale; 'failure' to identify environmental factors, 'failure' to understand that the problem could not be solved simply using technological innovation but requires other considerations (economic, political or sociological as examples), 'failure' to address interactions between the systems components that are either planned or unplanned and 'failure' to recognise that the product is part of a user experience system so that the product fails to be useable. This research proposes that principles of Design Thinking (DT) can be utilised to address these 'failures'.

Razzouk and Shute (2012:1) defines Design Thinking (DT) as '*an analytic and creative process that engages a person in opportunities to experiment, create and prototype models, gather feedback and redesign*'. Design thinking is seen as an interdisciplinary tool that takes a pragmatic approach to design and considers human needs as the centre of the design process (Brenner, Uebernickel and Abrell, 2016). As such it introduces a design toolbox that focusses on the in-depth investigation of the customers wants and needs prior to the design, development and prototyping stages. One example of this is found in requirements generation; SE processes will base their requirements from the perceived wants of the consumers generated by the key project stakeholders and will deliver a product or service based solely off of these requirements. In contrast DT techniques will actively aim to identify who the consumer is, what the consumer truly needs, and how the end result may be created with an entirely user centred focus in mind. At every stage the identified consumers are consulted about how they believe that the product or service may benefit them and how they perceive it to be flawed.

DT techniques focus on the overall user experience, ensuring that the needs of the end user are identified early. Importantly, DT techniques help shift the design of a product from a marketable item to a resolution for a customer problem. As DT puts more emphasis on considering the potential consumers and the scenarios that the solution may be implemented (Seidel and Fixson, 2013), it generates a holistic understanding of a problem that will include all external factors when creating a solution.

DT has been selected in this context over other design processes as the strengths of design thinking compliment the weaknesses of systems engineering. This is especially true in situations whereby the problem considered is very complex, or wicked, and potentially has a number of different factors causing the issue and thus potentially has a number of complex solutions. However other human centred design approaches were considered for this project; one of which was Agile for its flexibility and the ability to create products rapidly. This was not chosen for this investigation due to the emphasis it places on the frequent development of software which is something that will simply not be possible on the types of projects that are being undertaken with the sponsor.

Therefore this project aims to identify the opportunities and barriers in blending design thinking into a systems engineering design process within an LEO. In particular, this project aims to develop a design process that yields better customer satisfaction and reduced time to market for complex and innovative products without stifling the creativity of a design team. As the success of a project is directly linked to the effectiveness of the design carried out and its suitability for a consumer, this research is incredibly important in the current economic climate to give LEOs the tools required to provide an effective service to their consumers and to aid in the development of novel ideas for very complex problems.

This project will consider the work of Carlgren, Elmquist and Rauth (2016), who conducted a series of interviews with 31 senior members of staff in large organisations that had used design thinking for at least five years to identify what the barriers were to adopting this design process. They found that the challenges of implementing design thinking were actually linked to the characteristics of the theory itself; a misfit with existing processes and structures, the resulting ideas and concepts being difficult to implement, the value of design thinking is difficult to prove, the design thinking principles or mindset clash with the organisational culture, the existing power dynamics are threatened, the skills needed to use design thinking are hard to acquire and the communication style required is different from the norm. Interestingly this suggests that issues around achieving implementation are not solely with design thinking as a concept but will actually focus more around the cohesion of the company structure and culture.

Several investigations conducted into the applications of design thinking processes (Mabogunje, Sonalkar and Leifer, 2016; Plattner, Meinel and Leifer, 2012; Seidel and Fixson, 2013 and Blizzard et al, 2012) have found that it is very difficult to 'measure' the effects of design as the concept of design has no real measurable variables or KPI's. In this context design refers to the generation of a product or service that fulfils the needs of a given consumer and so this trend suggests that it is difficult to compare one product to another if both were aiming to fulfil the same role.

Research Questions

The research question identified is as follows;

1. What are the opportunities and barriers in integrating design thinking within the systems engineering process of a large, established company?

Research Methodology

This investigation aims to use a single case study methodology to answer its research questions. This is because the resources allocated to the project have clear, distinct boundaries and the sponsorship with an external engineering organisation includes the ability to conduct research within their operations. Therefore, the researcher will be involved directly with the LEO and its current, ongoing projects.

As this is the case there are two prevailing theories that shall be considered as a part of this methodology; action research and theory for change. Action research, when discussed with the aim of generating change, can be referred to in its simplest form

as the introduction and manipulation of interventions that can be monitored over a period of time in order to generate a required result (Payne and Payne, 2004:9). Theory of change however will be considered more heavily as the framework for this investigation, as this theory proposes that change can be planned based off of the perceived causality of an issue and tackled by creating implementations that will resolve these root causes. Figure 1 shows the preliminary outcomes framework which considers all of the themes outlined thus far from literature and aims to identify actions that can be chained together to resolve the research question for this investigation.

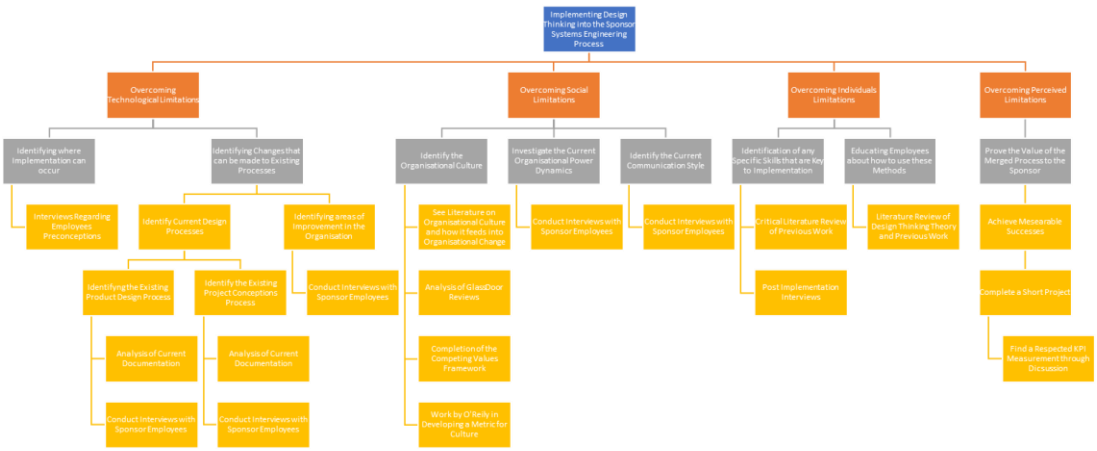


Figure 1 - Preliminary Outcomes Framework

In this investigation participants will be professionals working in the engineering or engineering management profession as they are the users of the teams that will be affected as a part of this implementation and thus they will provide the greatest insight into the opportunities and barriers that may be found. Participants will be selected predominantly from the sponsor company. This is likely to limit the available sample size for interviews due to participant suitability and willingness to take part. However, minimum sample sizes shall be calculated for any interview investigation undertaken and considerations made for the type of sampling and available resources at any given time (Payne and Payne, 2004:205). This is to potentially include participants of differing levels of seniority and shall vary based on the investigative and data analysis methods that have been determined.

This project has been identified to be predominantly qualitative in nature due to the work of Mabogunje, Sonalkar and Leifer, 2016; Plattner, Meinel and Leifer, 2012; Seidel and Fixson, 2013 and Blizzard et al, 2012 as they have found that it is very difficult to establish quantitative metrics for design. Therefore, the research methods used predominantly in this project will be unstructured interviews, semi-structured interviews, post workshop feedback surveys and in-depth reviews of existing literature. These were selected based off of the perceived resources available and the intricacies of the necessary data to answer each section of the main research question at each stage. A simplified research methodology plan has been created below to demonstrate the general direction that the project is expected to take.

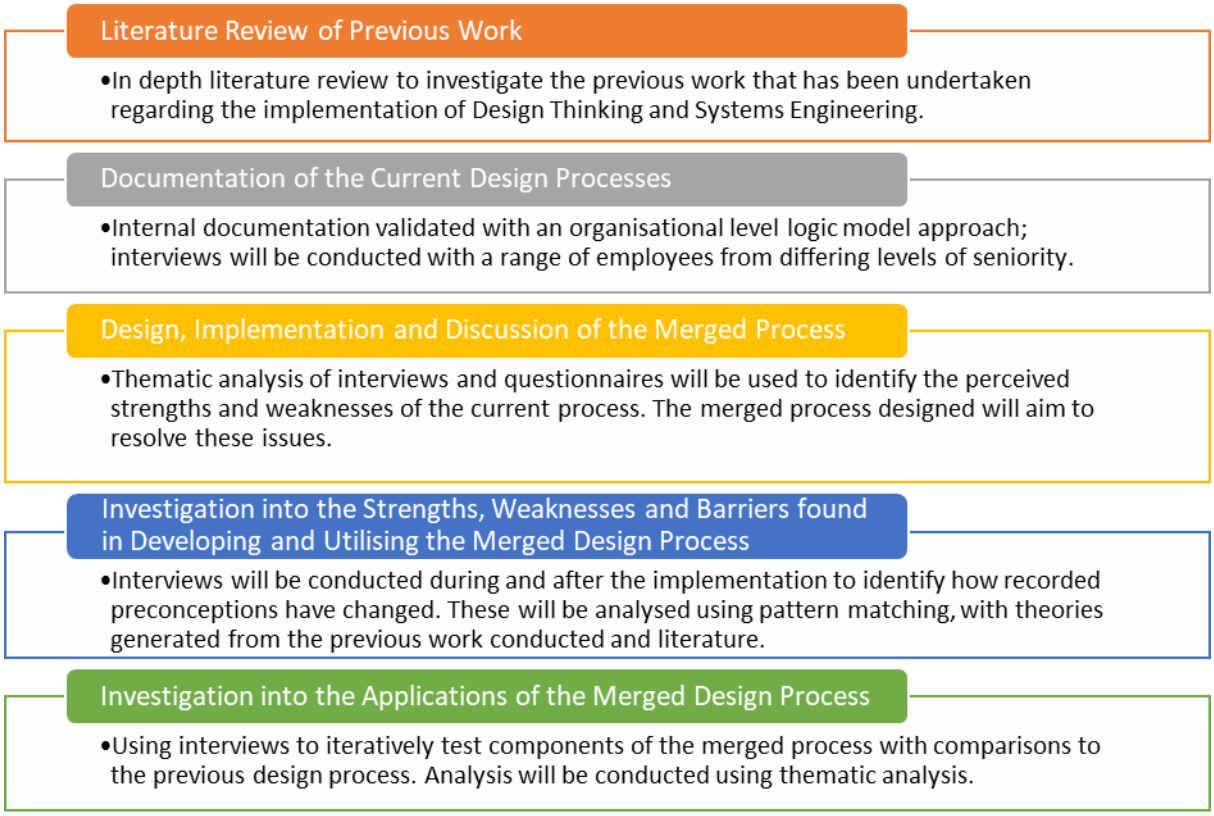


Figure 2 - Research Methodology Plan

Due to the current influences of the COVID-19 pandemic this research will also investigate the aspects of the merged design process that can be completed within a remote working environment. Under normal circumstances this could be shown to represent a globally distributed design team that are all aiming to work together on the same project or alternatively, it could reflect a company culture where remote working is accepted as a part of the organisational structure that a design team might have. Regardless, an emphasis will be placed on investigating how design thinking and systems engineering can operate in these contexts and the kinds of tools and techniques that are required to effectively achieve design outcomes.

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Appendices

Appendix 1 - Table of Figures

9.2) Short Essay – The Open Review Journal (8th Edition)

Not All Change is Created Equal – Understanding Organisational Culture and its Effects on Change

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ABSTRACT

An organisation's ability to change is vital to remaining competitive and maintaining agility in rapidly changing climates. There are a plethora of change management methodologies present in literature that argue for particular courses of action when considering organisational change. However, previous research into organisational culture has identified that there can be cultural differences between organisations of similar size and that these play a significant role in the change management process. This proposes that some attempts to implement change will be more difficult than others and is especially true when considering change management methodologies that place an emphasis on collaboration against those that do not. This short essay discusses the types of organisational culture that are reported in literature, so that organisations can be characterised, and makes comparisons to existing change management methodologies so that readers can better evaluate appropriate methods of change in future.

BIOGRAPHY

Brandon Robertson is a final year PhD student and associate lecturer at the University of the West of England, aiming to investigate the implementation of novel design processes within Large Engineering Organisations. His research interests are process implementation, organisational change, fluid dynamics, aero engine design, spaceflight and entrepreneurship and he is happy to be contacted about other research projects.

INTRODUCTION

The ability of an organisation to change is critical in developing and improving organisational quality (Smith, 2011), reacting to external factors or expectations (Howells, 2014) and maintaining a competitive advantage within evermore complex markets (Hana, 2013). Change can be initiated from a number of circumstances, such as;

- Grassroots organisational change, where change managers collect actors at lower levels of seniority to collectively create and manage change (Mars, 2009),
- Programmatic change, where change is planned using a known situation and change activities are manipulated deliberately to achieve a desired result (Wisegarver, 2019).
- Opportunistic change, where individuals or groups take advantage of unplanned events to enact change. (Wisegarver, 2019).

When considering organisational change, literature has identified that the implementation of solutions may require a degree of cultural change (Ragsdell, 2000) and that it is critical to consider the internal and external environment that is present in an organisation (Bate, 1994). Furthermore, change management literature already identifies that attempts to implement change should consider how change is constructed (Prajogo and McDermott, 2015). However, this is not reflected in change management methodologies which are often presented as solutions to all change situations.

This short essay presents the hypothesis that organisational culture significantly impacts organisational change and thus should be considered when enacting all change activities. In this case, organisational culture is defined as a set of norms, beliefs, principles and ways of behaving that gives an organisation a distinctive character (Brown, 1995). First, I present a background to the concepts of (1) organisational culture, (2) hero culture versus process culture, and (3) unitarist versus pluralist versus radicalist cultures; and include a discussion on each characteristic and its influences on change. Next, theoretical comparisons are made with the core values of

collaboratively focussed and non-collaboratively focussed change management methodologies to identify where change management processes may be more or less applicable to different change environments. Finally, the hypothesis presented in this essay, that organisational culture is a critical attribute in successful organisational change, is re-addressed and theoretical conclusions drawn from the comparisons made.

BACKGROUND

This section will address the background required to answer the hypothesis proposed in this paper; namely that organisational culture has a direct effect on organisational change. This section will introduce organisational culture as a whole, before detailing cultural characteristics of note that are present in literature. This background is not exhaustive but serves as an example of how culture can be categorised and considered.

Organisational Culture

Literature identified a total of four properties of organisational culture (Bellot, 2011);

1. Organisational culture exists.
2. Organisational culture is ill-defined and includes contradictions, paradoxes, ambiguity and confusion.
3. Organisational culture is socially constructed by groups with shared experiences.

   Organisational culture is unique to a given organisation and is malleable.

Organisational culture has been identified to be created from the beliefs and behaviours of early organisational leaders and interpreted by organisational members to create guiding assumptions (Wilcoxson and Millett, 2000). These interpretations are proposed to be considered sub-consciously, are not easy to change or manipulate and take a long period of time to be accepted as valid (Wilcoxson and Millett, 2000). Inciting change that directly or indirectly contradicts these cultural values and beliefs is therefore proposed to be difficult to implement successfully.

Organisational culture has been identified to have a direct impact on an organisations management style, understanding of strategy, organisational climate, reward system, leadership and fundamental organisational values (Cameron and Quinn, 2011). Although there are a number of established means of measuring organisational culture, this essay aims to consider culture

more generally through the identification of organisational characteristics. These characteristics are proposed to be a dichotomy between hero and process culture, and the concepts of unitarism, pluralism and radicalism, discussed further below.

Hero Culture versus Process Culture

Crosby (1979) proposed that the early emphasis and value that is placed on the development of suitable organisational processes can lead to unplanned cultural effects. In the event that the processes utilised are not suitable within an organisation, defined as 'poor process quality', then an organisation is proposed to be in an uncertainty environment where management have very little knowledge or control over the overall product or service quality. This poor process quality elicits organisational heroes, due to a lack of suitable process or metrics, who are critical to the success of projects within this uncertain environment as they bring their own expertise or skill sets to manage projects. To summarise the uncertainty environment, it is characterised by poor process quality, a lack of metrics and the utilisation of heroes that conduct workloads the way they see it fit to achieve organisational goals (Crosby, 1979). Examples of an uncertainty environment may include organisations with rapidly changing and varied projects or high innovation start-ups. On the other hand, when considering organisations that have developed processes that are suitable for their activities, defined as strong process quality, there is absolute certainty. In this case, management are knowledgeable and confident that projects have a suitable level of quality as metrics are utilised throughout. There are no heroes within the organisation as individuals can rely on the processes that have been selected with no detrimental side effects (Crosby, 1979). Examples of the certainty environment would include organisations that work in high control environments, such as aerospace or medical.

However, the argument between poor process quality and strong process quality can be explored further when considering this in collaboration with other literature around organisational culture. First, literature identified a distinct link between the views of senior management within an organisation and an organisations culture (O'Reilly, 2014). Next, the values that an organisation has within its culture reflect directly on its choice of design

process (Cameron and Quinn, 2011). Finally, as mentioned in this section, the acceptance of process quality is directly linked to either a ‘hero culture’ or ‘process culture’ (Crosby, 1979).

In conclusion to the review of hero versus process culture, this analysis identifies that there is an inherent link between senior management, organisational culture, process quality and culture at a design level. This will be explored further when considering its implications on change management as this direct link suggests that organisational culture would directly affect organisational change activities.

Unitarist versus Pluralist versus Radical Cultures

The presence of culture within an organisation can also be broadly categorised into unitarist, pluralist and radicalist cultures (Fox, 1996 and Fox, 1974). This section will aim to describe each of these categories of culture so that its effects on organisational change can be identified.

A unitarist organisation has all members of the organisation sharing the same culture, values and beliefs, and working together to achieve the same goals. This type of organisation is associated with harmony, co-operation, effective leadership, high performance and strong team working (Fox, 1974). In contrast, a pluralist organisation has a number of sub-cultures that may operate independently from one another as different working groups, but all making decisions towards a common goal (Fox, 1974). In this instance, individuals within the organisation may have differing values and beliefs to their immediate colleagues, and in some cases aspects of these cultures may be significant and opposed to one another. Finally, a radicalist culture is considered as two directly opposing classes; a high paid, low workload, managerial role that gives orders and a low paid, high work, group of ‘order-obeyers’ (Fox, 1974). In a radicalist culture both classes believe that a gain for one side results in a loss for the other, meaning that their values and beliefs are fully opposed. This leads to continuous friction, distrust and a poorly performing organisation.

More recently, unitarism, pluralism and radicalism have been considered within the Relational Quality Index (Kaufman et al, 2020). This measure

identified a series of variables that were linked to each cultural category. For example, a high RQI score is linked to a unitarist culture, positive management styles and justice in the workplace. Alternatively a low RQI score is linked to a radicalist culture, distrust between more and less senior roles and organisations with a perception of significant organisational disruption. This again evidences the idea that an organisations culture directly affects organisational activities, and so will directly affect attempts to incite change.

Importantly, Prajogo and McDermott (2005) proposed that change implementations themselves should be considered from a unitarist or pluralist perspective. A unitarist perspective on change would propose that change is a fixed activity that is being applied to one specific culture and the change must be adopted as a whole to be successful. A pluralist perspective on change would propose that there are multidimensional cultures operating within an organisation and that the change managers should be aware of how proposed changes will be viewed by all cultures that will be involved.

Summary of Organisational Culture

The background presented in this paper serves to outline the importance of understanding organisational characteristics when completing change management activities. First, four properties of organisational culture were identified (Bellot, 2011) and a brief summary of how change is formed, accepted (Wilcoxson and Millet, 2000) and affects organisational activities (Cameron and Quinn, 2011) is proposed.

Next, the background highlighted the concepts of hero culture and process culture, and proposed that there was a direct link between senior management, organisational culture, process quality and culture at a design level. This is incredibly important as this link clearly identifies the influence that an established organisational culture has on several significant areas of an organisation.

Following this, the background considered the difference between cultural (Fox, 1974);

- Unitarism (where employees share one culture),

- Pluralism (where a number of sub-cultures are present),
- Radicalism (where a high seniority culture and a low seniority culture work in opposition to each other).

These key cultural characteristics were found to directly influence the operations of an organisation (Kaufman et al, 2020) and were necessary to consider when determining change management strategy (Prajogo and McDermott, 2005).

It is important to remember that the concepts of hero culture versus process culture and unitarist versus pluralist versus radicalist are not mutually exclusive; an organisation can have a hero culture and be unitarist, pluralist or radicalist as well.

IMPLICATIONS FOR CHANGE MANAGEMENT

This section will consider the theoretical organisational culture characteristics defined previously and identify how these characteristics may affect organisational change.

Implications of Hero Culture Versus Process Culture

When attempting to enact change, the identification of an organisation as either a hero culture or a process culture directly impacts the change management techniques that should be considered and should impact the solutions being proposed. These differences will be outlined and discussed within this section. To reiterate, a hero culture is presented in literature as being identified symptomatically by poor process quality, very few metrics and an onus on individuals processes and knowledge to complete organisational projects. On the other hand, a process culture is presented as having strong process quality, universally accepted metrics and adherence to documented process.

First, if an organisation culturally does not place value on process quality as a part of its operations then this would indicate that process is not valued. Therefore, an organisation that is identified as being predominantly hero cultured could find that implementing process-based solutions is more challenging than in a process culture as individuals within the organisation must first be convinced of the benefits of process.

Similarly, if a hero culture considers very few metrics as a part of its operations then this would indicate that the use of metrics or measures to control organisational projects may not be culturally accepted. As such, change that utilises metrics considerably or change that considers only the implementation of new metrics may be notably more challenging than that found in a process culture. However, a localised sub-culture of heroes that have culturally similar values could implement metrics at a local scale.

Finally, due to the onus that is placed on heroes within a hero culture to adopt practices that they believe are worthwhile, heroes within this culture may have more of an onus to accept or reject change management projects. This may

lead to the devotion of more time and resources from change management activities which may become significant during the course of change. A process culture would likely not find this same issue.

Implications of Unitarism Versus Pluralism Versus Radicalism

As mentioned in the background to this short essay, research has begun to incorporate the concepts of unitarism, pluralism and radicalism as a part of change management activities. This section will theoretically expand on this understanding through a comparison of each category to applied change.

Literature has identified the concept of defining change activities as either unitarist or pluralist (Prajogo and McDermott, 2005) and these can be directly linked to each cultural category. In the case of a unitarist culture, there is one culture to be considerate of and therefore change management solutions can be unitarist. Similarly, in the case of a pluralist culture there are many cultures to be considerate of and so change should be pluralist to maximise the chance of successful implementation. Finally, as a radicalist culture has two opposing cultures, it may not be possible to utilise the theory of unitarist or pluralist change solutions unless a level of commonality is identified and accepted. In this instance, the proposed change should still attempt to be pluralist as that will allow for greater identification of the scope of this commonality.

When a particular change management approach considers sampling, it would also be important to consider the cultural characteristics of an organisation when delivering change. For example if an organisation has a unitarist culture, a representative sample size would be much smaller than if an organisation had a pluralist culture as the values and beliefs of individuals in a unitarist culture are the same. The pluralist culture, however, may present differences in viewpoint around a particular subject and so a larger sample must be taken to understand how the values held within an organisation differ between different organisational areas. Finally, in a radicalist culture samples should be selected based off of the type of change and change management methodology that is being considered. For instance, a grassroots change project would need to be considered and structured differently to a management driven change project.

Comparison to Existing Change Management Processes

As mentioned in the background of this short essay, the identification of cultural characteristics should directly impact the change management approach that can be taken. This section will detail two change management approaches and provide an argument as to how organisational culture characteristics may make them more or less applicable to particular situations.

The first change management approach considered was proposed by Lewin (1947) who proposed that openness and accountability are vital to generating support for change. All employees within an organisation are informed about all aspects of change and enabled to collaborate or challenge particular courses of action. Furthermore, change leaders or groups are held accountable for any changes made to the change plan. This change management approach has been noted as facilitating activities such as co-creation well, as participants are involved in the change management process, but is difficult to sustain in times of high pressure or workload over essential tasks (Carlgren, Elmquist and Rauth, 2016).

The second change management methodology considered in this essay was proposed by Kotter (1996) who suggested that an organisation's employees should be viewed as resistors to change and stressed the importance of management driven change initiatives. This methodology is most commonly portrayed as Kotter's eight step model (Kotter, 1996) and aims to deliver radical change outcomes. Kotter's change management approach is criticised however, as it proposed that change should be accomplished, and change leaders rewarded, at high cost to the employees that are affected by change and in minimising the role that change leadership must take in the change management process (Hughes, 2015).

To reiterate, this short essay hypothesises that the difference in style and emphasis of change management processes make them more suited to some organisational cultures than others. In particular, it proposes that the more collaborative change management approach of Lewin (1947) and the resistance driven approach of Kotter (1996) could lead to differing results due to culture. A brief summary of the theoretical implications of this are presented

in the sections below to understand the importance of organisational culture in change management.

Summary of Cultural Categories Comparisons

Hero Culture – Lewin's (1947) change management process enables heroes to challenge and improve proposed change at the cost of time and resources, which may lead to successful implementation. On the other hand, Kotter (1996) proposes that change is fixed which may prevent some heroes from adopting proposed change and leading to failure.

Process Culture – Lewin's (1947) change management process may be slower to enact change than Kotter's (1996) process in a process culture due to its emphasis on employee involvement.

Summary of Category of Culture Comparisons

Unitarist Culture – Both change processes would be suitable for enabling change in a unitarist culture.

Pluralist Culture – The change management process proposed by Lewin (1947) considers all viewpoints in an organisation and so could lead to more supported change at the cost of time and resources. However, Kotter's (1996) change management process does not consider these views which may lead to faster implementation, or implementation failure depending on other organisational factors.

Radicalist Culture – Lewin's (1947) process could identify commonality between high seniority and low seniority groups and allow for change that is supported by both cultures. On the other hand, Kotter's (1996) process would propose that change should be forced, which may be successful but will lead to poor employee satisfaction.

CONCLUSIONS

To reiterate, this short essay proposed the hypothesis that organisational culture is a critical factor in the implementation of organisational change. Considerations were made in this essay for the overarching cultural attributes of hero culture and process culture, and further for unitarist, pluralist and radicalist cultures. This paper first theoretically identified that the presence of any of these cultural characteristics would affect the change solutions that might be accepted within a given organisation.

Next, a discussion on the application of change management methodologies was constructed that considered Lewin's (1947) and Kotter's (1996) change management approaches against the cultural characteristics identified. It proposed that change management processes could be identified to be more suitably applied in different applications, and therefore that not all change can be considered as equal.

This short essay must conclude that organisational culture would theoretically affect organisational change solutions and activities, based off of the organisational culture characteristics of hero versus process culture and unitarist versus pluralist versus radicalist culture. Furthermore, this short essay proposes that there are suitable and unsuitable change management methodologies for particular cultural circumstances. Specifically, where cultural characteristics are identified as hero cultured, pluralist or radicalist, collaborative change methodologies may be more suitable than non-collaborative methodologies.

As change has been identified to be vital in delivering key organisational properties, the conclusions of this essay should be paramount when considering other organisations. This essay has identified that there is a significant gap within literature in understanding how organisational characteristics impact attempts to enact change. This essay also frames change management as dependant on particular organisational characteristics. Further research should aim to develop an empirical understanding of the significance of each of these cultural characteristics in change management and evaluate whether change management

methodologies can be optimally selected for certain organisational cultures. This proposal would allow organisations to identify their own cultural characteristics, and what this means in practice, and enact changes accordingly.

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