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Collaboration, Brokerage and Technology Development

Providing New Insights to Minimise the Risk of Network Failure

Collaboration, Brokerage and Technology Development: Providing New Insights to Minimise the Risk of Network Failure

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Abstract

In recent years, inter-organisational collaborations have gained popularity as a vehicle for organisations to develop technology, becoming increasingly prevalent in a range of industry sectors. Such prominence has been exacerbated as technology and engineering companies seek to react to rapid contextual changes in their core markets. Specifically, this increasing contextual complexity is positively influencing many organisation's predilection to collaborate in an attempt to remain competitive through diversification and service expansion.

However, whilst the motivations and reasons justifying the acceleration of collaborative models are well understood, approaches to support the development and maintenance of them are not. Specifically, there exist no practical approaches which seek to minimise the risk of organisations working together for the purpose of technology development. As a result, the majority of industry collaborations that form are prone to failure.

This thesis seeks to address this problem. Drawing on a multi-methodological approach including case study and action case research, this thesis develops a framework of principles to support the design of collaborative technology developments inferred by extant literature and industry best practice. The thesis then seeks to better understand how such principles can be applied more constructively in a practical setting by testing several techniques on industry cases. Finally, the thesis explores how the composition and distribution of actors present in a collaborative technology development may be assessed, from a network level perspective, to infer the likelihood of failure. Three key characteristics are identified and a recommended distribution and typology of actors are presented.

Declaration of Authorship

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, this work is my own work. Work done in collaboration with, or with the assistance of others, is indicated as such. Any views expressed in the dissertation are those of the author.

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Publications, Presentations and Awards

Conference Papers

[1] Hale, A. & White, L., 2016. Towards a Process of Collaborative Technology Brokerage. In *British Academy of Management Annual Conference 2016 Proceedings*. p. 210.

[2] Hale, A. & White, L., 2014. Developing a framework to establish collaborative enterprise networks. *8th Annual IEEE International Systems Conference, SysCon 2014 - Proceedings*, pp.431–438.

[3] Hale, A., Van Someren, M. & White, L., 2013. Addressing the Barriers to UUV Development: Reflections from the Aviation Industry. In *Undersea Defence Technology Conference*. pp. 1–7.

[4] Tully, P., Hale, A., Parsons, P., 2014. Engineering the Organization : Providing New Insights Into Organizational Design Using Systems Principles. In *8th Annual IEEE International Systems Conference, SysCon 2014*.

Industry Publications

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Contents

Chapter 1: Introduction……………………………………………………………………………23

1.1. Problem Statement………………………………………………………………………… 23

1.2. Research Questions ……………………………………………………………………...24

1.3. Thesis Structure……………………………………………………………………….…..25

Section One: Understanding Collaborative Technology Development………………29

Chapter 2: Literature Review……………………………………………………………………31

2.1. Introduction………………………………………………………………………………….31

2.2. Collaboration……………………………………………………………………………....31

2.3. Brokerage…………………………………………………………………………………….63

2.4. Gaps in the Literature ……………………………………………………………………71

Chapter 3: Methodology……………………………………………………………………….…73

3.1. Introduction…………………………………………………………………………………73

3.2. Research Questions………………………………………………………………………..75

3.3. Methodological Considerations……………………………………………………...77

3.4. Overarching Research Strategy…………………………………………………….…81

3.5. Research Methods……………………………………………………………………….…90

3.6. Ethical Considerations…………………………………………………………………....93

Chapter 4: Industry Case Studies…………………………………………………………….97

4.1. Introduction………………………………………………………………………………….97

4.2. Case Study A: ASTRAEA……………………………………………………………….....100

4.3. Case Study B: Carbon Trust Offshore Wind Accelerator…………………………….110

4.4. Cross Case Analysis……………………………………………………………………….117

4.5. Development of a Framework for Collaborative Technology Development…..128

Section Two: Supporting Collaborative Technology Development…………………..141

Chapter 5: Unmanned Underwater Vehicles Action Case……………………………...143

5.1. Introduction……………………………………………………………………………....143

5.2. Objectives…………………………………………………………………………………144

5.3. Approach……………………………………………………………………………….….144

5.4. Plan......145
5.5. Act......147
5.6. Observe......155
5.7. Reflect......156
5.8. Revised CTD Framework......158

Chapter 6: UK Defence Sector Action Case......167

6.1. Introduction......167
6.2. Objectives......168
6.3. Approach......168
6.4. Plan......169
6.5. Act......177
6.6. Observe......181
6.7. Reflect......187
6.8. A Framework for Technology Brokerage......195

Chapter 7: UK Rail Sector Action Case......197

7.1. Introduction......197
7.2. Objectives......198
7.3. Approach......199
7.4. Plan......199
7.5. Act......206
7.6. Observe......215
7.7. Reflect......216

Section Three: Research Findings......221

Chapter 8: Discussion......223

8.1. Introduction......223
8.2. Review of Key Chapter Outputs......223
8.3. Synthesising the Research......233

Chapter 9: Conclusions......249

9.1. Research Question One......249
9.2. Research Question Two......249
9.3. Research Question Three......250

9.4. Contributions to Industry……………………………………………………………………………...250
9.5. Limitations of Research…………...………………………………………………..251
9.6. Directions for Future Research……………………………………………………………....251

References………………………………………………………………………………………………….255

List of Figures

Figure 1: Overview of thesis structure...26

Figure 2: Organisation set perspective...41

Figure 3: Example of cognitive map. (Taken from Eden and Ackermann [2004])............60

Figure 4: Overarching Research Strategy...74

Figure 5: Research Framework (Braa & Vidgen 1999)...82

Figure 6: Case Study Method (Yin 2014)...84

Figure 7: Simplified Action Learning Loop...89

Figure 8: Action Case method location framework (Braa & Vidgen 1999)...........................89

Figure 9: Typology of participant observation researcher roles (Gold 1958)......................91

Figure 10: Overview of ASTRAEA Collaborative Structure...106

Figure 11: Overview of OWA Network Structure...114

Figure 12: Overview of Framework for Collaborative Technology Development...........128

Figure 13: Overview of proposed collaborative structure...152

Figure 14: Overview of Revised CTD Framework...160

Figure 15: Overview of Collaborative Structure...175

Figure 16: Overview of approach taken to UK Defence Action Case....................................183

Figure 17: Proposed extended timeline illustrating process of collaborative technology brokerage...190

Figure 18: Nested system of knowledge systems...191

Figure 19: Framework illustrating principles for Technology Brokerage..........................195

Figure 20: Overview of CTB process...200

Figure 21: Overview of application approach for CTB process...205

Figure 22: Overview of actor plot characterised by collaborative behaviour and technical capability...238

Figure 23(a): Distribution of actors in ASTRAEA...239

Figure 23 (b): Distribution of actors in CT OWA..2 39

Figure 23 (c): Distribution of actors in Defence AC..239

Figure 23 (d): Distribution of actors in Rail AC.. ..239

Figure 24 (a): Distribution of actors in ASTRAEA...242

Figure 24 (b): Distribution of actors in CT OWA..2 42

Figure 24 (c): Distribution of actors in Defence AC..242

Figure 24 (d): Distribution of actors in Rail AC.. ..242

Figure 25: Suggested distribution of actors in a collaborative technology development 244

Figure 26: Suggested typology of actors in a collaborative technology development...245

List of Tables

Table 1: Forms of collaboration……………………………………………………………………..35

Table 2: Theoretical paradigms of collaboration…………………………………….....................39

Table 3: Types of centrality in ego level research...46

Table 4: Governance mechanisms.. 53

Table 5: Five forms of brokerage.. 65

Table 6: Assessment Framework...99

Table 7: Detailed framework displaying principles for Collaborative Technology Development.. 134

Table 8: Revised Detailed Framework for Collaborative Technology Development......161

Table 9: Workshop attendees characterised by role and company…………………………...213

Glossary of Terms

ADM	Autonomy and Decision Making
ASTRAEA	Autonomous Systems Technology Related Airborne Evaluation & Assessment
AUV	Autonomous Unmanned Vehicles
BIM	Building Information Modelling
CAA	Civil Aviation Authority
CSS	Communications, Security and Spectrum
CT	Carbon Trust
CTB	Collaborative Technology Brokerage
CTD	Collaborative Technology Development
DECC	Department for Energy and Climate Change
EDA	European Defence Agency
EIT	Enabling Innovation Team
EU	European Union
FNC	Frazer Nash Consultancy
GOHSI	Ground Operations & Human Systems Interaction
GST	General Systems Theory
HQ	Headquarters
IOC	Inter-organisational Collaboration
IOE	Inter-organisational Entities
IOR	Inter-organisational Relations
IPR	Intellectual Property Rights
MAS	Marine Autonomous Systems Group
MMCM	Maritime Mine Counter Measures

NAO	Network Administrative Organisation
NASA	National Aeronautics and Space Administration
NCC	National Composites Centre
NDAs	Non-disclosure Agreements
NGO	Non-governmental Organisation
NHS	National Health Service
NR	Network Rail
OSP	Organisation Set Perspective
OWA	Offshore Wind Accelerator
PAC	Product Acceptance Certificate
PANDA	Participatory Appraisal of Needs and Development of Action
PC	Principle Consultant
PD	Programme Director
PM	Project Manager
RSSB	Rail Safety and Strategy Board
SA	Sense and Avoid
SARUMS	Safety and Regulation for European Unmanned Maritime Systems
SODA	Strategic Options Development and Analysis
SPS	Social Problem Solving
SPURV	Self Propelled Underwater Research Vehicle
TB	Technology Brokerage
TR	Technology Roadmap
TRLs	Technology Readiness Levels
TSB	Technology Strategy Board
UAV	Unmanned Air Vehicles

UK	United Kingdom
UMS	Unmanned Maritime Systems
USP	Unique Selling Point
UUV	Unmanned Underwater Vehicles

Chapter One
Introduction

1.1 Problem Statement

In recent years, inter-organisational collaborations have gained popularity as a vehicle for organisations to develop technology, becoming increasingly prevalent in a range of industry sectors including pharmaceuticals, biotechnology, aerospace, health, defence and rail (Kogut 1989; Jorde & Teece 1990; Dodgson 1993; Hagedoorn 1993; Weijan Shan et al. 1994; Powell 1996; Powell 1998; Barringer & Harrison 2000; Hagedoorn 2002). Such prominence has occurred for multiple reasons. Notably, collaborating with partners provides benefits in terms of reduced financial risk, bridging knowledge gaps, accessing added resource, accelerating commercialisation and enhancing the capabilities of individual organisations to name but a few (Kogut 1989; Jorde & Teece 1990; Gulati & Gargiulo 1999; Pfeffer & Salancik 1978; Powell 1990; Trist 1983)

A further reason for the emergence of collaborative approaches is a response to the increasingly complex demands of the external environment and the lack of capability of a single organisation to deliver against them. Specifically, in recent years technology and engineering companies have witnessed a significant rise in the complexity of market context (Fleming & Sorenson 2001), creating the need for them to diversify or expand their service offering to remain competitive. As a result, organisation's predilection to collaborate has increased, as they seek to adequately react to such a rapid contextual change (Powell et al. 1996; Hagedoorn 2002).

However, whilst the motivations and necessary contextual conditions required for entering into collaborative relationships are well understood, approaches to support the development and maintenance of them are not. Specifically, when the core market of an organisation shifts or expands considerably due to an increase in complexity, understanding and defining the new requirements as well as the coordination of the various actors can be difficult to navigate. In the context of technology development, minimal research or evidence of approaches capable of supporting organisations in such positions exists.

Further, extant literature suggests that many collaborations are in fact prone to failure (Hagedoorn 2002; Ortiz-Gallardo et al. 2010; Burgers et al. 2008; Vangen 2016). However, there is no attempt by the literature to understand the likelihood of collaborative failure from a network level perspective. Specifically, no tools or techniques exist to assist organisations collaborating for the purpose of technology development to understand if they are on track to deliver their collaboration successfully.

This thesis seeks to address this problem. Drawing on a multi-methodological approach including case study and action case research, this thesis develops a framework of principles to support the design of collaborative technology developments inferred by extant literature and industry best practice. The thesis then seeks to better understand how such principles can be applied more constructively in a practical setting by testing several techniques on industry cases.

Finally, to better understand how to minimise the risk of failure, the research also seeks to better understand how collaborative approaches to technology development may be assessed, based on their composition of actors from a network level perspective, in order to infer the likelihood of failure.

1.2 Research Questions

This thesis makes contributions to knowledge by focussing on three specific research questions;

Research Question One: What are the key principles to consider when designing collaborative approaches to support technology development?

The thesis primarily seeks to understand the key principles of collaborative technology development. Through drawing together a critical analysis of the literature with two industry case studies, the thesis develops a framework of key principles, to inform the design of future industry collaborations.

Research Question Two: How can the principles of collaborative technology development be constructively applied in industry?

To address this gap, the thesis explores the application aspect of the collaborative principles developed in response to question one. Through identifying several industry cases in which to apply the framework, the principles are tested and developed further. Particular attention is sought around the function of delivery ie the process through which the collaborative principles are best applied. With this in mind, the role of brokerage in the support of collaborative technology development is a specific area of interest explored.

Research Question Three: How can the risk of failure of collaborative technology development be minimised from a network level perspective?

Finally, this thesis seeks to synthesise the learning of this research, through a grounded review of the cases conducted. The review seeks to build on the learning from the cases to understand how the likelihood of collaborative failure may be predicted based on the composition, distribution and typology of actors involved.

1.3 Thesis Structure

This thesis is split into three sections. Commencing with a review of current literature, it identifies gaps in the extant body of knowledge, which are used to inform the creation of three research questions. The study then moves on to explore the theme of collaborative technology development through two industry case studies. Informed by the findings of the literature review and guided by the research question, the assessment of the case studies adopts an interpretivist approach, seeking to develop a framework of principles to inform the design and development of a collaborative technology development. Subsequently, the research becomes more interventionist through the application of three action cases, with the researcher an active participant in real industry projects. The intent of the action cases is to test and validate the framework in a practical context. Further, it seeks to understand the practicalities of supporting collaborative technology developments in an industry context. Finally, the thesis moves into section three, where the research findings are synthesised through a grounded review of the cases. Three themes, pertinent to the success of a collaborative technology development are identified and a suggested distribution and typology of actors presented, designed to minimise the risk of failure, from a network perspective. An overview of the structure is presented in figure 1.

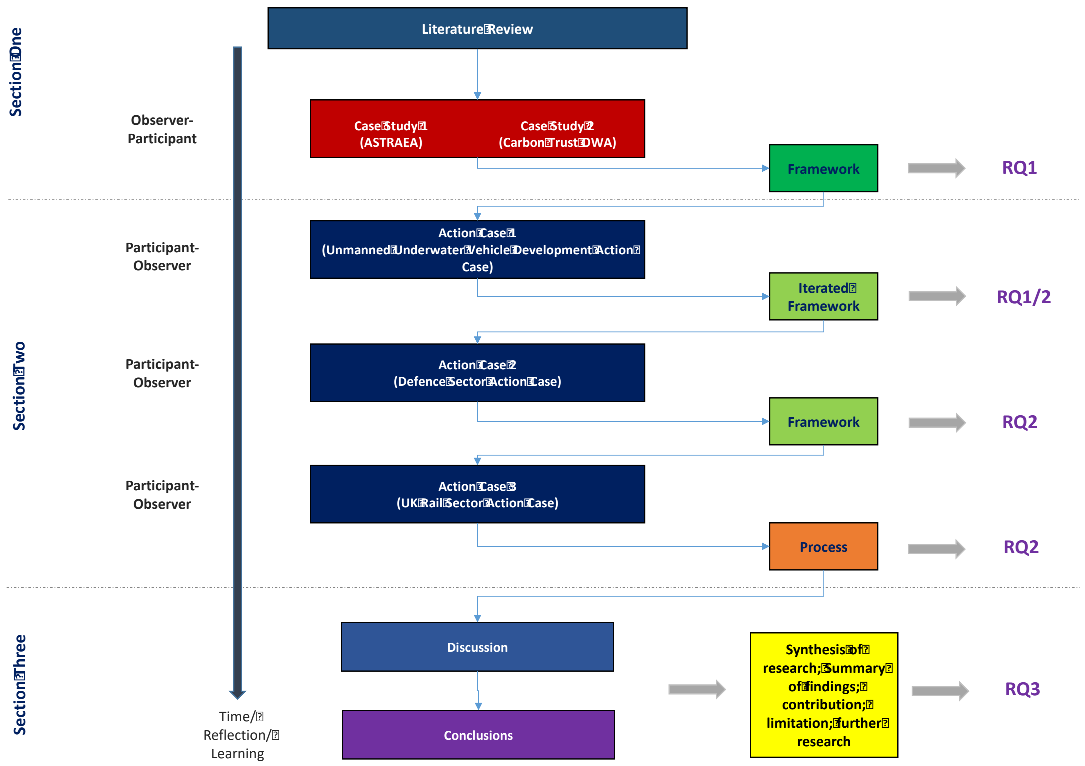


Figure 1: Overview of thesis structure

Section One: Understanding Collaborative Technology Development

This section begins with a literature review, exploring extant literature in the fields of inter-organisational collaboration and brokerage, seeking to understand their role in the context of technology development. The review of the subject areas highlights key gaps in the literature including the current lack of convergence regarding collaborative technology development research.

Chapter three explores the philosophical assumptions of the research and defines the overarching research strategy.

Chapter four builds on the literature review through the analysis of two industry case studies, with the aim of formulating a better theoretical understanding of the principles of collaborative technology development.

Section Two: Supporting Collaborative Technology Development

Chapter five seeks to test and validate the principles of the framework identified in chapter four and explore the functionality of the framework by applying it through an action case approach with a client in the marine sector.

Chapter six continues to explore the functionality of the framework established in chapter four and through the utilisation of an action case approach, seeks to build on the work conducted in chapter five. Whilst the previous chapter sought to appraise the appropriateness of the framework to support the *design and establishment* of a technology development collaboration, this chapter focusses on a slightly different context. Specifically, this chapter seeks to understand the value of the framework to support the assessment of an *already established and functioning* collaboration in the UK defence sector.

Chapter seven seeks to combine the learning from chapters five and six to develop a process to support the development of a novel technology, in the early stages of development. The process is applied through an action case approach to support a project in the UK rail sector.

Section Three: Research Findings

Chapter eight reflects on the research conducted in sections one and two. By drawing together the learning from the case studies and action cases, it seeks to synthesise the research to understand how the opportunity for failure in collaborative technology developments may be minimised. Referring back to the original research questions, the section discusses the implications of the research.

Chapter nine concludes the impact of the research highlighting the contribution to knowledge and industry. This chapter also identifies limitations of the research and areas for further research.

Section One:

Understanding Collaborative Technology Development

This sections consists of the following chapters;

- Chapter Two: Literature Review
- Chapter Three: Methodology
- Chapter Four: Industry Case Studies

Chapter Two
Literature Review

2.1 Introduction

This chapter reviews extant academic literature in key areas pertaining to this doctoral study. The areas reviewed are inter-organisational collaboration and brokerage, seeking to understand the roles both play in the development of technology. The review highlights key trends and themes within each topic of literature and identifies key points of disagreement.

The first area explores the theme of collaboration, within which several sub-themes are reviewed. Initially, to bound the literature review and provide a semblance of structure to the theme, the review seeks to develop a definition of collaboration, which is specific to this doctoral study. The review then moves to explore the relationship between inter-organisational collaboration and technology development, identifying gaps in the extant body of knowledge. Finally, methods to support collaborative technology development in practice are reviewed.

The second area reviews the theme of brokerage. This part of the review contains two sections, the first exploring the development of brokerage as an academic area of study. The second seeks to better understand how brokerage may support collaborative approaches, specifically in the context of technology development.

The purpose of this review is to provide an understanding of current thinking in research areas related to this doctoral study, highlighting opportunities to make further contribution to the literature. The end of this section presents a summary of gaps identified in literature.

2.2 Collaboration

Collaboration is a subject that has received significant attention as an area of academic study (Oliver 1990; Dodgson 1993; Oliver & Ebers 1998; Barringer & Harrison 2000; Borgatti & Foster 2003; Brass et al. 2004; Provan et al. 2007;

Smith-Doerr & Powell 1994). Arguably originating in literature pertaining to evolutionary biology, it is a topic which spans a multitude of disciplines including, but not limited to, organisational and behavioural theory, management science, psychology, neuroscience, biological and natural systems, strategic management, business studies, public administration, healthcare, sociology, communications, computer science, engineering, systems, physics and technology development (Borgatti & Foster 2003; Provan et al. 2007).

Conducting a comprehensive literature review in all these areas would be difficult and potentially futile. Consequently, this literature review when exploring the topic of collaboration has been limited to key areas.

2.2.1 Defining Collaboration

As stated, collaboration as a research topic has received a significant amount of attention. Consequently, a common definition is difficult to find. This problem is further exacerbated as a significant number of words and phrases are used interchangeably, when referring to collaboration (Huxham 1996; Hagedoorn 2002; Provan et al. 2007).

Cooperative (Mcgee & Dowling 1994), joint venture (Gulati 1998), public-private partnership (Babiak & Thibault 2007; Huxham 1996), inter-firm alliance (Hagedoorn 2006), inter-firm network (Grandori & Soda 1995; Uzzi 1997), multi-stakeholder group(Role et al. 2007), enterprise (Blegen 1968; Crossley 2008), strategic partnership and alliance (Hagedoorn 1993; Gilsing et al. 2007; Albers et al. 2013; Parkhe 1993), consortium (Anderson 1995), inter-organisational relations (Nooteboom 2004; Nooteboom 2008; Steensma 1996; Gray 1985; Stuart 2000; Ackermann et al. 2005; Powell et al. 1996; Vangen & Huxham 2003), supply chain (Choi & Hartley 1996; Wilhelm 2011), community development (Huxham 1996), informal framework agreement (Mcgee & Dowling 1994), multi-agency (Huxham 1996; Huxham & Vangen 2000; Taket & White 2000; White 2008) and networks (Provan & Milward 1995; Provan et al. 2007; Obstfeld 2005; Apicella et al. 2012; Ahuja 2000; Gulati 1998; Gulati & Gargiulo 1999; Gulati et al. 2002; Gould

& Fernandez 1989; Dhanaraj & Parkhe 2006; Barabasi 2003; Borgatti & Foster 2003) are just some of the examples of terms used in exchange for collaboration.

As a result of such a broad field of literature, one of the main challenges when studying and researching collaboration is defining it (Phillips et al. 2000). However, when reviewing the literature in these areas, it is clear that whilst differences in definitions occur, they do so at a detailed level.

For instance, Huxham describes collaboration as "…a very positive form of working in association with others for some form of mutual benefit" (Huxham 1996). This is somewhat similar in detail to Brass' definition of a network "a set of nodes and the set of ties representing some relationship, between the nodes". Such high level definitions provide a general classification of the meaning of collaboration, something noted by Cropper et al., "Despite the considerable differences in theoretical approaches, what unifies collaboration research, in one way or another, it focuses on the properties and overall patterns of relations between and among organisations that are pursuing a mutual interest while also remaining independent and autonomous" (Cropper et al. 2008).

Similarly, Provan et al. (2007) note "Despite differences, nearly all definitions refer to certain common themes, including social interaction (of individuals acting on behalf of their organisations), relationships, connectedness, collaboration, collective action, trust, and cooperation". From the above, a general definition for collaboration and its associated synonyms can be taken as "More than one entity, combining for a purpose". However, such a loose definition does not prove useful in all contexts.

For instance, "more than one entity" would permit two or more entities together to be classified as collaboration, ignoring differences in dyadic and triadic relationship contexts. Furthermore, "combining for a purpose" could mean a collective purpose, individual purpose or a purpose that is neither mutually or individually beneficial to either entity. Consequently, other scholars have deemed it appropriate to extend their definitions, to incorporate more specific details. However, this is where differences begin to arise.

For instance, Gray defines collaboration as “the pooling of appreciations and/or tangible resources, e.g. information, money, labour etc., by two or more stakeholders, to solve a set of problems, which neither can solve individually” (Gray 1985). Here, Gray has specified in slightly more detail, the elements to be combined if it is to be considered a collaboration. Furthermore, she states that the aim is for the collaborators to “solve a problem, which neither of them has the capacity to do individually”. Using Trist’s (1983) definition, Gray defines what she constitutes a problem domain as “a functional social system, which occupies a position in social space between a society as a whole and the single organisation” (Gray 1985). Gray continues to specify that the collaboration must occur between “inter-organisational domains”, as opposed to collaboration within a single organisation. As a result, Gray’s detailed description and accompanying explanation provides a more specific definition of collaboration, when compared to perhaps Huxham or Brass.

However, greater clarity to a definition does not necessarily mean it is universally accepted. Phillips et al. (2000) define collaboration as “a cooperative relationship among organisations that relies on neither market nor hierarchal mechanisms of control”. A relatively inclusive and general definition, Phillips et al. then add on three “critical characteristics” that distinguish their definition of collaboration. These are that collaboration is an inter-organisational phenomenon, occurring between organisations; the collaborative relationships are not mediated by market mechanisms; collaborations are distinct from hierarchal relations. The inclusion of these characteristics, mean that forms of partnering such as buyer-supplier relations or supply chains, where one organisation exhibits a superior market position or dictates the conditions of the relation from a more hierarchal position may not be defined as collaboration. However, under Grays definition they may be.

Providing even greater detail, Barringer and Harrison (2000) identify six different forms of collaboration (Barringer & Harrison 2000). Whilst agreeing on a loose, high-level definition of collaboration, they provide a more in depth description of six sub-varieties, as seen in table 1.

Mode of Collaboration Examples	***Definition***
Joint Venture	An entity that is created when two or more firms pool a portion of their resources to create a separate jointly owned organisation.
Network	A hub and wheel configuration with a local firm at the hub organizing the interdependencies of a complex array of firms.
Consortia	Specialized joint ventures encompassing many different arrangements. Consortia are often grouping of firms oriented towards problem solving and technology development, such as R&D consortia.
Alliance	An arrangement between two or more firms that establishes an exchange relationship but has no joint ownership involved.
Trade Association	Organisations (typically nonprofit) that are formed by firms in the same industry to collect and disseminate trade information, offer legal and technical advice, furnish industry-related training, and provide a platform for collective lobbying.
Interlocking Directorate	An interlocking directorate occurs when a director or executive of one firm sits on the board of a second firm or when two firms have directors who also serve on the board of a second firm. Interlocking directorates serve as a mechanism for interfirm information sharing and cooperation.

Table 1 – Forms of collaboration (Barringer & Harrison 2000)

As can be observed from table 1 the six forms of collaboration identified are joint venture, network, consortia, alliance, trade association and interlocking directorate. Whilst all are classified as collaboration, distinct differences are clear. For instance, joint ventures are described as entities created when two or more firms pool a portion of their own firms to create a separate jointly owned organisation. However, the definition of an alliance states it is an arrangement between two or more firms that establishes an exchange relationship but has no joint ownership. Consequently, whilst both definitions agree collaboration compromises of two or more firms, they principally differ over the structural form of the new entity that is created. One requires a sharing of ownership, whilst the other requires no ownership at all.

The discrete nuances in the definitions may seem immaterial, but they provide an important dimension to the research on collaboration. That is, they provide an indicator as to the particular focus of the research being undertaken by the academics that define them. Using Brass' high-level definition of networks to illustrate this point, the research attached to the definition is similarly high-level, providing an overarching perspective of organisational networks, focussing on interpersonal, inter-unit and inter-organisational levels of analysis.

The focus of the research theme influencing the particular definition also lends an explanation to the differences between Gray's (1985) and Phillips et al. (2000) more detailed definitions of collaboration. The aim of Phillips et al. research is to capture a broad sense and purpose of the meaning of collaboration, whilst discounting the role that power of participants may play in influencing it or the eventual outcome of the collaboration. Instead, they aim to focus on "the degree to which the roles and practices that characterize the relationships are uncertain and do not rely on pre-existing mechanisms such as market and hierarchy" (Phillips et al. 2000). Conversely, much of the focus of Gray's research *is* the distribution of power throughout a collaboration and its affects on relationships, governance and ultimately, the outcome (Gray 1985).

The influence of an academic's research focus upon the chosen definition of collaboration is something also noted by Huxham, who states that these differences relate to "an author's conception of collaboration they are concerned with" (Huxham 1996). Building on this, Huxham identifies three broad dimensions, which lend explanation to the differences in meaning of collaboration. These three dimensions are 'organisational form', 'structural form' and 'rationale'.

Further explanation for the differences in research focus and interpretation of meaning is provided by Barringer and Harrison (2000). In their paper, they identify six theoretical paradigms, from which collaboration is traditionally studied (see table 2).

As can be observed from table 2, the six paradigms they identify are transaction cost economics, resource dependence, strategic choice, stakeholder theory of the firm, organisational learning and institutional theory. Each theoretical paradigm is argued by Barringer and Harrison to form the basis upon which studies into collaboration have evolved, from the traditional perspective of transaction cost economics to the more contemporary paradigm of organisational learning (Barringer & Harrison 2000).

Each paradigm provides a different perspective as to where an organisation's control and thus boundary ends, meaning their view of what constitutes collaboration also differs. As a result, the different theoretical perspectives have led to the development of a variety of reasons and justifications as to discerning the motives for collaborating. Barringer and Harrison's portrayal of the key theoretical paradigms also presents an elegant representation of the key research themes and topics that have been studied in the field of collaboration to date.

From reading the history and trends in collaboration research, it becomes clear that an individual's definition of what constitutes collaboration essentially frames the research. Consequently, it is important to provide a definition of what the author constitutes as collaboration, in relation to this doctoral study, in order to accurately instruct and bound the remainder of this literature review.

This research is initially concerned with two key concepts. Inter-organisational collaboration (IOC) and technology development. As will be explained in the next section, the research is also concerned with viewing these IOCs from an overarching or collective, network-level perspective. Therefore, when referring to IOCs, it is in the context of separate organisational entities coming together to

Theoretical Paradigm	*Description*	*Rationale for Collaboration*
Transaction Cost Economics	Focuses on how organisation should organize its boundary-spanning activities so as to minimise the sum of its production and transaction costs.	Minimization of the sum of production and transaction costs. Collaborations can reduce uncertainty caused by market failure and reduce costs associated with establishing a hierarchy.
Resource Dependence	A theory rooted in an open system framework that argues that all organisations must engage in exchanges with their environment to obtain resources.	Organisations form collaborations to exert power or control over organisations that possess scarce resources. Alternatively, an organisation may enter collaboration in an effort to fill a perceived resource need.
Strategic Choice	Study of factors that provide opportunities for firms to increase in competitiveness or market power. Profit and growth are typically the major firm objectives that drive strategic behaviour	An organisation will enter into a collaboration if the financial benefits of doing so exceed the costs. Collaborative strategies may increase the ability of a firm to deliver superior products and services efficiently or work to decrease competition in an industry.
Stakeholder Theory of the Firm	Organisations are at the centre of an interdependent web of stakeholders and have a responsibility to consider the legitimate claims of their stakeholder when making decisions and carrying out business transactions.	Organisations form alliances, also called networks or constellations, to align their own interests with the interests of stakeholders and to reduce environment uncertainty.
Organisational Learning	Concerned with the processes that lead to organisational learning. A key factor is absorptive capacity, which is defined as a firm's ability to recognize the value of new knowledge, assimilate it, and apply it in a business setting.	Absorb as much knowledge as possible from collaborative partners, thus increasing organisational competencies and ultimately adding value to the organisation.
Institutional Theory	Suggests that institutional environments impose pressures or organisations to appear legitimate and conform to prevailing social norms.	Organisations form collaborations to obtain legitimacy or as a result of succumbing to isomorphic pressures by mimicking firms that have established collaborations.

Table 2 – Theoretical paradigms of collaboration (Barringer & Harrison 2000)

form a collaborative group, with shared objectives and motivations, contributing skills and resources to develop a collective piece of technology. The goal of the collaboration is the collective output. However, success cannot be assessed until the developed technology has been integrated and adopted within its system successfully.

In this view, classifying the research in one of the established paradigms cited in table 2 may prove difficult. Building on Dodgson's (1993) definition, who describes collaborative technology development as "an activity where two or more partners contribute differential resources and technological know-how [knowledge and skill required to do something correctly] to facilitate the collective development of technology" then, the definition of IOC in the context of technology development used for this research is;

"A process in which multiple organisations, bounded by a problem space for a distinguished period of time, contribute specific skills, knowledge and resources to facilitate the collective development and integration of technology".

2.2.2 Inter-organisational Collaboration and Technology Development

Inter-organisational collaboration (IOC), also often referred to as "Inter-organisational Relations" (IOR) or "Inter-organisational Entities" (IOE) have arguably been the subject of study since the inception of organisations. The early foundations of IOC studies can be traced back to organisational research in the early 20th Century, particularly in areas such as economics, sociology and political science (Weber 1947; Cropper et al. 2008). At this time, the main focus of organisational study focussed on the internal happenings of firms, concentrating on bureaucratic related themes such as efficiency (Kast & Rosenzweig 1972). However, the development of Von Bertalanffy's general systems theory (GST) in the middle of the 20th Century together with Boulding's seminal piece on the Skeleton of Science (Boulding 1956), enabled problems and organisations to be viewed from a different perspective; a systems perspective (Emery & Trist 1965; Evan 1965; Blegen 1968; Kast & Rosenzweig 1972; Trist 1983; Gray 1985).

In his seminal paper, Evan (1965) outlined that current thinking of organisational study was confined by the perspective, influenced by the bureaucratic nature of previous research by Weber and Taylor (Kast & Rosenzweig 1972; Gray 1985). Building on Von Bertalanffy's GST, he highlighted that it was important to view firms as part of larger, interacting systems, arguing that until that point there was a "widespread neglect of problems of inter-organisational relations" (Evan 1965). Evans subsequently developed a theory of inter-organisational relations, presenting the object organisation as "focal" amongst a set of environmental pressures from external firms. Evans called this perspective the "Organisation Set Perspective" (OSP) (Evan 1965) (see Figure 2).

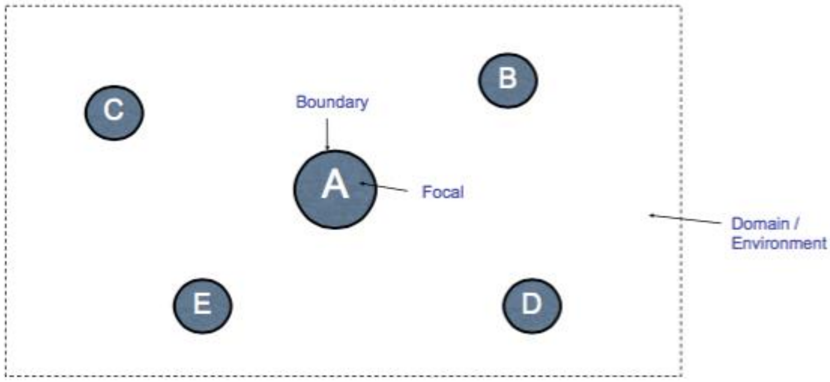


Figure 2 – Organisation set perspective

Evan's paper was considered somewhat of a turning point in IOC research (Cropper et al. 2008). Within a relatively short space of time, many more scholars began paying attention to IOC, building on Evan's work. However, whilst Evan's work can be viewed as one of the early attempts at inter-organisational research, many scholars have since criticised the organisation set perspective and it's ability to deal with "turbulent, environmental problems" (Emery & Trist 1965; Trist 1983).

The primary concept in OSP is that the organisation is the focal of the study, embedded within the environment. Typical of the "mechanistic" organisation type of the time (Burns 1963), it assumes that control of the managers of that focal firm is constrained within the boundary of the organisation (see Figure 2). When an organisation is subsequently confronted with a complex problem beyond the capacity of that single firm, also known as "messes" (Ackoff 1974), "inherently wicked" (Rittel & Webber 1973) and "invisible" (Aldrich 1976), proponents of this perspective struggle to "conceptualize the problem", consequently failing to adapt and react (Emery & Trist 1965; Trist 1983; Gray 1985).

In reaction, Emery and Trist proposed that the inter-organisational field in which the organisation was embedded was not closed off to the organisation, but instead was a characteristic of its environment (Emery & Trist 1965; Osborn & Hagedoorn 1997). Similar to Burn's definition of an "organismic" organisation (Burns 1963), it allowed a more holistic view of the interactions between organisations to be studied and considered. This work supported the emergence of resource dependency views (Pfeffer & Salancik 1978) and lead to further studies in the development of inter-organisational domains (Trist 1983) and a general systems approach to organisations (Berrien 1976).

The different perspectives of scholars such as Evans and Trist continue in IOC research and can be observed based on the different approaches taken to their research. Evan's work could be argued to resemble the first take on ego centric level of analysis of an organisation, whilst Trist's work on "domain-level' research could be seen as the first attempt to take a network level perspective. Regardless of the stance though, what is widely accepted is that before Evan's work and indeed systems theory, inter-organisational relations was not a substantial area of enquiry. Since then however, it has continued to grow in both size and diversity.

As the field has continued to grow, the development of these various perspectives has supported greater interest in the study of IOCs, with the research between and among organisations being documented in a wide variety of studies (Barringer & Harrison 2000; Cropper et al. 2011). So vast is the research on IOCs it has attracted the attention of academics from a wide variety of backgrounds, with multiple theoretical perspectives, ontological positions and differing research objectives. Consequently, the field has become particularly fragmented making accumulating the knowledge of IOCs into a succinct body of literature, that is adequately detailed and practically significant, difficult, (Barringer & Harrison 2000; Brass et al. 2004; Osborn & Hagedoorn 1997; Provan et al. 2007; Smith-Doerr & Powell 1994) although attempts have been made (Oliver & Ebers 1998; Cropper et al. 2011; Oliver 1990; Cropper et al. 2008; Borgatti & Foster 2003; Culpan 2009). However, it is this very complexity involved in approaching such an expansive subject that has played a part in the exponential growth of the field over the past 50 years (Zaheer et al. 2010).

A further reason for the continued increase in interest is partly due to the increase in IOCs in industry (Hagedoorn 1993; Dodgson 1993; Powell et al. 1996; Barringer & Harrison 2000). Increasingly, it has been noted that firms need external support to deal with the increasing complexity of problem domains (Trist 1983; Ackoff

1974), the constant refinement of customer requirements (Hagedoorn 1993; Hagedoorn 2002) and the increased complexity of scientific and technological development (Jorde & Teece 1990; Kogut 1989; Hagedoorn 1993; Tyler & Steensma 1995; Powell 1998). A throwback to Ashby's law of requisite variety, the premise is that the complex problems of today require equal complexity in the solution (Ashby, 1960). As a result, IOCs have become a more familiar response, specifically in the context of technology development (Hagedoorn 2002) and so the opportunity to study them is more apparent.

The benefits and hence the stimulus for firms to enter into IOCs have been widely studied (Hagedoorn 1993; Nooteboom 1999). Consequently, many reasons have been identified as to why companies enter IOCs. Motivations for entering into collaborative efforts can be driven by external or internal forces. As mentioned, typically, IOC formation has been viewed to be driven by exogenous factors, such as the distribution of technological resource or the social structure of resource dependence (Pfeffer & Salancik 1978). In this view, organisations create ties to manage uncertain environments and to satisfy their resource needs. As a result, they enter ties with other organisations that possess resources and capabilities required to deal with the exogenous constraints (Gulati & Gargiulo 1999).

Further examples of motivations have also been identified and include minimisation of technical and financial risk, enhancement of strategic position or organisation, access to specific knowledge or resource currently lacking, opportunity to learn, accelerating the commercialisation of products and access to new markets (Kogut 1989; Teece 1986; Jorde & Teece 1990; Hagedoorn 1993; Hagedoorn 2002; Powell 1990; Dodgson 1993; Nooteboom 1999).

Whilst multiple reasons exist, the common principle consistent to all decisions to enter a collaboration is the recognition that there is a perceived benefit in working with others (Barringer & Harrison 2000). The study of this perceived benefit and how an organisation may achieve the benefits stated above, has attracted much attention and accounts for a large proportion of IOC research, with some scholars doubting the effectiveness of IOC approaches (Barringer & Harrison 2000). To assess these benefits, the traditional approach to IOC research has focussed on three distinct levels of assessment. These are dyadic, ego and network levels of analysis.

2.2.2.1 Dyadic Level

Research at the dyadic level focuses on the characteristics of the relationships between two linked actors (organisations). The key focus of the research has been to understand and evaluate the nature of the relationship between the actors. Key themes include tie strength (Granovetter 1973) and degree of trust (Vangen & Huxham 2003; Zaheer et al. 1998) and how these characteristics effect the relationship's continuation, renewal, dissolution or other outcomes (Zaheer et al. 2010).

Tie-Strength

The concept of tie strength stems from Granovetter's work on weak ties (Granovetter 1973). In essence, a strong tie resembles a close relationship between two actors, where as a weak tie resembles a relationship of less mutual importance or occurrence.

The benefits of strong ties have been widely researched with a high level of embedded strong ties having been shown to help increase performance of organisations. They are also better for the transfer of tacit knowledge and supporting sustained performance when the environment demands high levels of exploitation. However, the over reliance on strong ties can also damage economic performance of firms, making them susceptible to sudden environmental changes due to the limited diversity of knowledge they ay possess (Uzzi 1997).

Conversely, the presence of weak ties can protect organisation from such sudden environmental "shocks" by preventing over-embeddedness. Also, weak ties have been shown to be better in support of the transfer of explicit knowledge.

Research at Dyadic Level

Recently, dyadic level research has been criticised for its limitation of viewing networks and collaborations as a collection of two-part relationships (Provan et al. 2007). More commonly, such arrangements are multi-organisational structures or systems, possessing triadic or multiple connections. It has been argued that in order to observe the true impact of relationships between actors, a network level view must be taken (Provan et al. 2007)

2.2.2.2 Ego level

Research at the ego level focuses on an individual actor, usually involved in a network of two or more actors. Traditionally, the research at this level looks to assess the effect of the network, in which the ego is embedded, upon the focal organisation (ego) in terms of behaviour and performance, (Zaheer et al. 2010). Rather than resulting from the characteristics of dyadic relationships, the effects result from the organisation's connection's to other organisations (alters), the characteristics of these alters, the subsequent affiliates of alters and the position of the ego organisation within the network.

Centrality

Organisation centrality is a measure of an ego's prominence within a network (Wasserman & Faust 1994). An actor is considered to be prominent if it's ties make it visible to other actors in the IOC network (Zaheer et al. 2010). There are several ways in which an ego can be considered to have a high level of centrality. Table 3 outlines the primary methods used to calculate centrality of an ego.

Centrality Measure	*Description*
Degree Centrality	The degree centrality is the most basic measure of an organisation's centrality in a network. It is calculated by counting the number of direct links maintained by an organisation with alter-organisations (Zaheer et al. 2010). An organisation deemed to have a high centrality maintains a high level of connections to other organisations and is recognised as a major channel of information (Wasserman & Faust 1994)
In-degree and Out-degree Centrality	In degree and Out-degree centrality may be calculated when an IOC or network has been formed with 'directional' relationships (Zaheer et al. 2010). In-degree centrality assesses the number of 'assets' such as information, resources, clients etc flowing into the organisation; the number of "in-ties". Conversely, the out-degree centrality is the assessment of number of resources flowing out of the organisation; the number of "out-ties". An organisation with a large number of "in-ties" is deemed to have a high level of prestige, where as an organisation with a large number of "out-ties" has a high level of centrality (Provan et al. 2007; Zaheer et al. 2010).
Betweeness Centrality	Betweeness centrality is an assessment of the extent to which an organisation acts as a gatekeeper within an IOC network. It is calculated by observing the individual position of the actor organisation as to whether it lies between the positions of alters, which are otherwise unconnected, without the direct ties to the actors organisation (Provan et al. 2007).
Bonacich Eigenvector Centrality	The Bonacich eigenvector centrality is a more global representation of an organisation's centrality in a network. As well as measuring the centrality of the ego organisation through the sum of it's connections to alters, it also considers the centrality of each of the connected alters to assess their impact on the ego's overall centrality. Depending on the importance of the alter being considered, a weighting mechanism can be employed to ensure an accurate measure is attained (Bonacich 1972; Oliver 1990; Zaheer et al. 2010).
Closeness Centrality	Closeness centrality is the assessment of the shortest path, which connects the ego organisation with all other alter-organisations in the IOC network (Provan et al. 2007). Unlike the case with degree centrality, indirect connections are also considered and are viewed as valuable mechanisms for the exchange of resources.

Table 3 – Types of centrality in ego level research

Structural Holes and Closure

The concept of structural holes was introduced by Ronald Burt and refers to a separation between two non-redundant organisations in a network. (Burt 1992). A structural hole is present when two organisations, B and C, are directly connected to the same third organisation, A, but no direct tie exists between B and C. Instead the two organisations, B and C, are connected by a bridge – organisation A, thus forming a hole between B and C directly (Burt 1992).

Such a structural arrangement provides the connecting actor, organisation A, with benefits of two kinds, information and control. These benefits are additive rather than overlapping as they perhaps would be for actors whose alters are connected to each other (Burt 1992).

Information benefits are identified by Burt to occur in three forms; access, timing and referrals (Burt 1992). Access benefits relate to the ego organisation "receiving a valuable piece of information and knowing who can use it" (Burt 1992). Timing refers to receiving information before other actors in the network. Referral benefits arise when the ego actor's name is mentioned in a positive way and at a time and place as to provide opportunities for the organisation (Burt 1992; Zaheer et al. 2010).

Burt also identified that structural holes can bring about control benefits for the ego; the organisation acting as the "bridge" or "the third" (Burt 1992). Building upon Georg Simmel's work on negotiation, Burt refers to this control benefit as "the tertius gaudens"; "the third who benefits" (Simmel 1923; Burt 1992). Burt highlights that the ego may benefit from tertius gaudens in two ways - by being the third between two or more players after the same relationship, or, being the third between players in two or more relations with conflicting demands.

The structural holes theory is similar in premise to the weak ties theory proposed by Granovetter (1973), something which Burt himself notes. However, he differentiates between the two thusly; "the weak tie argument is about the strength of relationships that span the chasm between two social clusters. The structural hole argument is about the chasm spanned." (Burt 1992; Burt 2004). Burt highlights that benefits brought about do not solely stem from the person that spans the hole, but the context, position and characteristics of the hole spanned. He summarises "whether a relationship is strong or weak, it generates information benefits when it is a bridge over a structural hole." (Burt 1992).

A significant part of Burt's theory of structural holes builds on the social capital literature, introduced by James Coleman (1988). Together with financial capital and human capital, Burt identifies social capital as the third characteristic that "every player brings to a competition" (Burt 1992). Coleman defines social capital by its function as "a variety of entities with two elements in common: They all consist of some aspect of social structures, and they facilitate certain action of actors - whether persons or corporate actors - within the structure." (Coleman 1988; Portes 1998).

In relation to structural holes, social capital is generated by the third organisation, which brokers between two unconnected organisations. Here, social capital is generated by participation in and control of information diffusion across the network (Burt 2001). However, Coleman proposed a theory in which social capital is generated through "closure" of a network. Here, closure is the opposite of a structural hole as all the actors in the network are connected to each other. Coleman argues that social capital is created in situations such as this through the strong interconnected ties between the actors (Coleman 1990; Burt 2001). An IOC network with a high level of closure has been demonstrated to increase cooperation and trust, increase knowledge sharing between actors and ultimately increase the performance of individual organisations (Rowley 1997; Ahuja 2000; Uzzi 1997; Zaheer et al. 2010; Coleman 1990).

The concepts of structural holes and closure are both then said to generate social capital, despite them being empirically opposite in their theory. However, since their introduction and subsequent debates over which theory is correct, attempts have been made to reconcile both theories as two complementary forms of social capital generation (Burt 2000; Burt 2001). In this complementary view, it is acknowledged that organisations need to access information externally from the network, however, they also need to share this information within the network in order to be effective (Burt 2001; Zaheer et al. 2010). Burt extends this explanation by referring to the context in which the network is embedded. For instance, if it is a competitive context, then structural holes will create social capital. However, if the context is more collaborative then closure will support the generation of social capital (Burt 2001).

As well as Burt's attempts to reconcile the two theories, there have been several other lines of research attempting the same. Soda et al. (2004) proposed a contingency approach, where they introduced a temporal variable to discriminate between when structural holes and closure provided value. Here, they argued that past closure is valuable in a network, whilst current structural holes are also valuable (Soda et al. 2004). Furthermore, Koka and Prescott (2002) have proposed that social capital is a multidimensional construct arguing that both information richness and information diversity are dimensions of social capital, stemming from closure and structural holes respectively (Koka & Prescott 2002).

Clusters and Cliques

A clique, or cluster, represents a group of three or more organisations closely connected to each other. From an ego level perspective, the number of cluster's an organisation is attached to can impact the outcomes of said organisation, in ways that differ to the impact of dyadic relationships (Provan et al. 2007).

Research at the Ego Level

Research at the Ego level accounts for the majority of IOC research, with the dominant focus on quantitative, cross sectional studies (Oliver & Ebers 1998). Furthermore, a significant portion of ego level research has focussed on organisations in the health sector. For instance, Shan et al. (1994) have demonstrated that a firm's centrality on the biotech industry increases it's innovation output, whilst the degree centrality of a start-up organisation in the biotechnology sector has been found to have a positive correlation with the performance of that firm, in terms of revenue, R&D spending growth, employment growth and patenting rate (Baum et al. 2000).

Similarly, Powell (1998) has demonstrated that the more connections a firm in the biotechnology or pharmaceutical industry has, and the greater the flow of knowledge from "external relations", then the greater chance that firm has of sustaining a competitive advantage (Powell 1998; Powell et al. 1996). Having a larger alliance network has also been demonstrated to increase the opportunity for venture capital investment in early stage start-up firms in the biotechnology industry (Baum & Silverman 2004).

Whilst there are some examples, there is a distinct lack of qualitative research at the ego level of analysis. Furthermore, there is little research that attempts to take a longitudinal perspective of IOC networks at the ego level. A further criticism of research at this level is that it tends to focus on established IOC networks, which are either relatively stable in terms of size or exist for a significant period of time. Minimal extant research explores the initial formation of IOC networks from a qualitative viewpoint.

2.2.2.3 Network level

Network level theories draw on many of the themes developed by dyadic and ego level researchers. However, the focus is not on the individual organisations or relationships, but on explaining properties and characteristics of the network as a whole. Consequently, the key considerations are outcomes at the network level rather than for the individual actors in the network (Provan et al. 2007).

For instance, instead of assessing how the centrality of an organisation might affect the performance or level of influence of an ego organisation, a network level perspective focuses on the overall network structure. Consequently, the objective is to understand the centralisation or density of the network as a whole, where the focus is for optimization of the whole network, not individual actors (Provan et al. 2007).

Despite the majority of focus on outcomes at the network level, there has also been a recent increase in interest exploring how the effect of whole networks and the outcomes of networks impact upon the performance of individual organisations, within that network (Barabasi 2003; Nooteboom 2008; Gilsing et al. 2008; Gilsing et al. 2007). There are several key themes in the network level of analysis;

Density

Density at the network level can be characterised by the level of connectedness among the organisations present in the collaborative group. Research on density has explored topics such as the level of density that is the optimal for network efficiency and the impact of increased levels of density upon network performance (Provan et al. 2007).

Centralisation

Centralisation refers to the extent to which organisations within the collaboration are centrally located. Barabasi (2003) identifies one form of highly centralised network as a hub and spoke model. Here, a large concentration of organisations are heavily interconnected in the core of the network, with fewer loosely connected organisations around the periphery (Barabasi 2003). Networks classified as decentralised are considered to have organisations, which are more dispersed and contain a more even spread of connections between them (Provan et al. 2007).

Clusters, Cliques and Small Worlds

As explained in the ego level section, clusters and cliques can be characterised as groups, consisting of three or more organisations, which are closely interconnected. Porter (1998) describes them as "geographic concentrations of interconnected companies and institutions in a particular field". They may also refer to a concentrated group of organisations, or "sub-networks" within a larger IOC network (Provan et al. 2007).

Similarly, the term "Small Worlds" has also been used in reference to a group of highly interconnected groups (Fleming et al. 2007). However, it has also been used in reference to a "cluster of clusters" (Clarke 1991). The primary theme constant to all definitions is the presence of three or more organisations, heavily interconnected through mutual interests and geographic location (physical or virtual) (Fleming et al. 2007).

Governance

Governance research at the network level explores the mechanisms that are used to control the overall IOC network. Unlike research at the dyadic and ego levels, which focus on protecting the interests of individual organisations and relationships respectively, network-level governance research is concerned with managing the interests of the overarching IOC network (Provan et al. 2007).

Provan et al. (2008) have identified three specific collaborative governance mechanisms employed at the network level; self/participant governance, hub-firm/lead-organisation governance and network administrative organisation (NAO) model (Provan & Kenis 2008). Table 4 outlines these three mechanisms in more detail.

Research at the Network Level

Whilst research at both the dyadic and ego level of network analysis is considerably advanced, network level research has only recently blossomed during the past decade, remaining primarily conceptual (Dhanaraj & Parkhe 2006; Koka et al. 2006). Similar to research at the ego level, whole network research so far has predominantly focused on health sector collaborations (Provan & Milward 1995), with small amounts of comparative work completed in other settings (Owen-Smith & Powell 2004). These studies build on the approaches adopted at the ego level of analysis, with so far preference given to quantitative studies around IOC network structure, governance, development and outcomes (Provan et al. 2007). The lack of focus in other areas provides an opportunity to enhance existing research with the use of industry focused case studies.

Governance Mechanism	*Description*
Participant (self) Governance	Participant governance relates to a form of governance in which the members of the IOC network manage themselves. In this form, there is no independent or external entity, which supports the governance of the collaboration. Instead, the members manage themselves through a decentralised, shared governance mechanism (Provan & Kenis 2008). Success of shared participant modes of governance depend on the commitment and investment of all IOC members. Processes usually consist of formal meetings of representatives or informal relationships of collaborators with a vested interest in the successful outcome of the IOC network.
Lead Organisation Governance	Lead organisation governance is when one organisation assumes control and governs the IOC network on behalf of the other organisations. Such an approach is endemic in instances of vertical, buyer-supplier relationships, especially when there is a single buyer or supplier who demonstrates significant power advantages over other buyer/suppliers in the IOC network (Provan et al. 2007; Provan & Kenis 2008). Traditionally, in lead organisation governance models, the single organisation in the role is responsible for all key decisions and activities. As a result, the lead organisation assumes an almost broker role, causing these networks to display a high level of centralization. The role of the lead organisation may emerge as a result of other organisations voting based on what seems to be most efficient and effective, or it may be mandated, often by an external entity with a vested interest (Provan & Kenis 2008).
Network Administrative Organisation Governance (NAO)	In a NAO model of governance, a separate organisation or entity, external from the IOC network, is employed to govern the network and its activities., in the role of a facilitator or broker (McEvily et al. 2003; Provan et al. 2004). In this model, although network members interact with one another, as with the lead organisation model, the NAO model is centralised. The benefits associated with the NAO approach are being able to better deal with unique and complex net-work-level problems and issues, as well as reducing the complexity that arises through shared governance (Provan et al. 2004).

Table 4: Governance mechanisms

Of the four identified areas, research exploring IOC network structure is the more developed (Provan et al. 2007). A significant number of the studies conducted in this area have focussed on characteristics such as network density, centralization and the existence of sub-networks (Provan et al. 2007). It has been demonstrated that both individual positions of organisations and general network structure influence knowledge transfer throughout an IOC network, whilst density and centralization supports increased integration and coordination (Provan & Milward 1995). Conversely, it has been found that networks with a high level of differentiation usually display a low level of centralization (Bazzoli et al. 1999). This has proved important to support the formation of clusters, but suggests that centrally coordinating a broad scope of work is difficult to manage centrally (Owen-Smith & Powell 2004; Bazzoli et al. 1999).

An area of the IOC structure research, which is not as advanced is understanding how specific collaborative structures impact the ability and effectiveness of the IOC network to achieve their identified goals. For instance, cohesive networks and bridging networks are two distinct models of collaboration. Whilst cohesive arrangements promote trust, ensuring communication throughout the network, bridging networks present a single organisation with control over knowledge between two otherwise unconnected actors (Burt 2004; Granovetter 1983; Nooteboom 2004). There are advantages and disadvantages to both network structures, but minimal research has examined them in the context of industrial technology development.

IOC network development is another area, which has received considerable attention in network-level research, having recently benefited from the completion of multiple longitudinal studies (Provan et al. 2007). Particularly, research in this area has focused on how key actors and organisations within IOC networks play central roles in the emergence and growth of a new IOC network. For instance, it has been demonstrated that dominant organisations in a central role of an IOC network influence the evolution of a dominant logic within the greater area of that network (Bazzoli et al. 1999; Owen-Smith & Powell 2004). Further research in this area has focused on the likelihood of IOCs forming based on an organisation's prior knowledge and affiliation with other organisations (Gulati & Gargiulo 1999), whilst Powell et al. have demonstrated the temporal variable of IOCs emergence and that collaborators at one point in time may become competitors later and vice-versa (Powell et al. 2005).

Despite a reasonable volume of work, gaps in the literature on IOC network development exist. An example of such is the understanding of whether the development of all IOCs can be defined through common, evolutionary stages or whether they form under certain conditions and environmental contexts (Provan et al. 2007). Furthermore, research into the lifespan of IOCs, their ability to evolve and adapt or their ability to remain stable is considerably lacking (Powell 1990; Provan & Milward 1995). Understanding the role of trust at the network level as well as the dyadic is a further gap in the research (Gulati 1998; Zaheer et al. 1998).

Governance research at the network level has received minimal attention in the literature and is considerably less well understood (Zaheer et al. 2010; Provan et al. 2007). Although it has been acknowledged that governance has definite impacts on network outcomes (Provan & Milward 1995), gaps in the literature exist around how inter-organisational collaborations specifically govern themselves (Provan et al. 2007). Specifically, understanding how different government mechanisms emerge, which mechanisms are most effective in particular contextual environments, the relationship between governance and the structure of an IOC network and the agility of various governance mechanisms are all areas lacking in the current body of knowledge.

Further, whilst work at the dyadic level has examined the role of trust and formal contractual agreements in fostering relationships and aiding collaboration from an individual organisation's perspective (Coleman 1990; Vangen & Huxham 2003; Weijan Shan et al. 1994; Nooteboom 2004; Gulati 1998; Zaheer et al. 1998; Uzzi 1997), there has been scant exploration into how the interests of the IOC network as a whole are protected.

As with other areas of collaboration, a key aspect missing from research at the network level is an attempt to synthesise the learning. An area of research which does not yet exist from a network perspective is an understanding of how the key themes pertaining to collaborative formation and development may be united into a singular set of principles. Further, whilst a focus on how individual themes may influence the outcomes of IOCs in industry, there is no attempt to explore how the entire composition of a collaborative network may be analysed to provide an indication of outcome. Specifically, there is scant evidence of any extant research, at the network level, seeking to understand how the likelihood of success or failure of collaborative technology developments may be assessed, based on the composition and relationships of that network.

2.2.3 Methods and Approaches to support Collaborative technology development

The literature review so far has provided an overview of the development of the IOC field, highlighting the overlap with technology development and identifying key themes, which have emerged in the literature. However, it has not reviewed extant methods and approaches, designed to support collaborative technology development. A reason for this is, put simply, they do not explicitly exist.

Performing searches with variations of the terms "collaboration", "technology", "development", "techniques", "approaches", and "methods" using databases such as Google Scholar, Web of Knowledge and general search engines, does return results. In fact, a search for "Collaborative technology development methods" on Google returns over 79 million results. However, whilst reviewing all these results is not feasible, those which were reviewed could not be categorised as methods to support collaborative technology development. Instead, existing approaches tended to fall under two categories; those which support collaboration and those which support technology development.

Within the two categories, further sub themes emerged, such as collaborative problem structuring, collaborative problem solving and collaborative decision making. Whilst some of these sub-themes can be considered essential parts of the technology development process, the point is such techniques were not created for that explicit purpose.

Of the methods that do exist to support collaboration, there are distinct limitations in their applicability and relevance for supporting technology development. For instance, McCann's (1983) process for social problem solving (SPS) may be considered one of the first attempts to describe a process to support the collaborative approach. Consisting of three phases; problem setting, direction setting and structuring, the process outlines how inter-organisational domains develop (McCann 1983; Gray 1985). McCann explains that the problem setting phase involves identifying relevant actors who have a stake in the domain level problem. This is followed by the direction setting phase, which comprises the development of agreements about values, collective goals and actions. Finally, the structuring phase ensures that stakeholders are organised in an appropriate way in terms of institutionalising the shared meanings through a formal agreement.

Whilst McCann's SPS process is useful in terms of identifying several key principles of collaboration, its application has been limited. Specifically, the researcher cannot find any evidence of the application of the process to assist collaborations for the purpose of developing technology. Further, the process is considerably high level, lacking specific detail required to make it a valuable approach in the context of collaborative technology development.

Since it's inception, McCann's process has been further developed and iterated by other academics (Gray 1985; Huxham 1996; Gray 2007), which have in turn influenced the emergence of further collaborative models, both within academia and industry. A recent version of this is the Industry British Standard for Collaboration, or BS 11000.

Developed by the Business Standards company BSI, BS 11000 provides "a framework for collaborative business relationships, to help companies develop and manage their interactions with other organisations for maximum benefit to all." (BSI 2010). Consisting of eight stages, it has been developed within industry as a general approach to support organisations within any sector enter into collaborative arrangements. However, there are many limitations to the framework.

For instance, although considered a British Standard, BS11000 is not an academic document. Consequently, it does not provide justification for the inclusion of each of the eight stages, nor does it ground the framework within existing literature in any sort of rigorous way. Whilst as a commercial document there is no requirement for this, for it to be accepted academically one would expect a greater level of explanation as to the grounding of the framework within the current body of knowledge. Further, BS11000 is designed to support individual organisations enter into collaborations, to benefit said organisation. Consequently, it becomes apparent that the framework is designed from an 'ego level' perspective. Consideration is not given as to the best way to develop the collaborative arrangement from a network level.

Finally, the most notable limitation of BS11000 is evident when reviewing the detail of the framework, where the guidance for application seems to provide minimal instruction, often resorting to high-level rhetoric. This possibly stems from the fact that the document is advertised as "being suitable for organisations in *any* sector" (BSI 2010) and so remaining general in description is a necessity for it to be relatable in all contexts. However, this highlights a significant flaw of the approach. As noted already, collaborations are complex (McCann 1983; Gray 1985; Trist 1983) and are often responding to complex problems. To provide a framework deemed suitable to *all* contexts then is at best foolish and at worst a complete mis-understanding of the problem area in which the proposed framework is designed to support. General solutions to complex problems do not exist (Aldrich 1976; Ackoff 1974; Rittel & Webber 1973) and so one must question how a general framework designed to instruct collaborative formation in any given context may then exist, at least in any useful capacity. More pertinently, in the context of supporting collaborative technology development, such a framework provides minimal evidence of being useful.

An industry tool that has proved useful to support collaboration is Building Information Modelling, or BIM. Described as a process which involves the generation and management of digital representations of physical places and assets, BIM has proved especially useful in the construction industry. In terms of supporting collaboration, BIM enables designers, planners, architects and engineers of varying backgrounds to form a collective understanding of proposed constructions, in a virtual space. It then allows for early identification of potential issues, prior to construction, minimising the risk of time and cost overruns.

In terms of supporting collaborative construction projects, BIM has proved incredibly adept. However, it does have limitations. Specifically, BIM is a digital platform which supports communication and understanding of problem areas and proposed solutions. It is not a framework, or a process, to support the lifecycle of collaboration. For this reason, whilst BIM may be able to support aspects of collaborative technology development, it does not represent a ready-made template to support all aspects of the process.

Away from industry, similar tools and techniques, designed to support specific aspects of collaborating also exist. An example of such a technique is cognitive mapping.

The technique of cognitive mapping stems from personal construct theory (Kelly 1955) and has the intention of capturing participant's 'personal construct systems' (Eden et al. 1979) to support the development of a collective understanding of a problem. The process involves the capturing of actor's beliefs, values, perceptions and expertise relating to a specific issue, through interview or document analysis. These views are then collated into a collective model and presented as a cognitive map. An example of such is visible in figure 3.

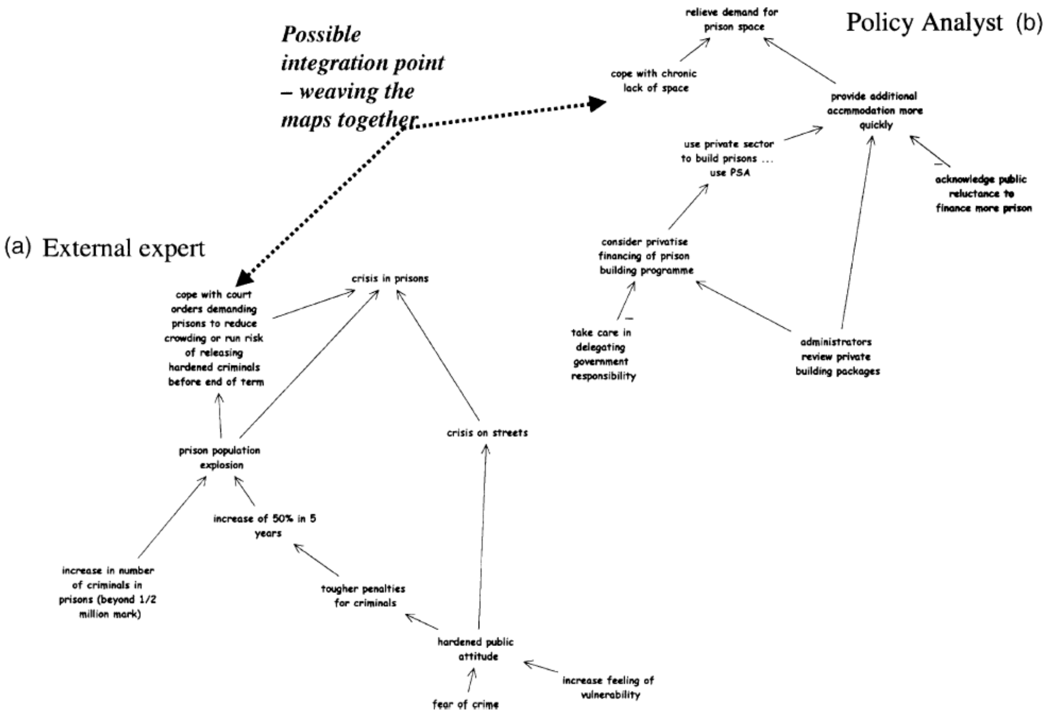


Figure 3 – Example of cognitive map. (Taken from Eden and Ackermann [2004])

Cognitive maps have been largely used to support group decision making, as is the case with the example in Figure 3. In this particular case, cognitive mapping was used to better understand the issue of UK prison capacity, by collating the perspectives of several experts who work in that area. Further employment of the technique has been used to inform strategy in both the public and private sectors (Eden & Ackermann 2004).

Despite its use, cognitive mapping, similar to BIM has its limitations. Whilst it undoubtedly has the capacity to support collaborative decision making, this again only represents one aspect of the collaborative process. Similar criticism can be levelled at other techniques identified in the literature, such as PANDA (participatory appraisal of needs and development of action) (Taket & White 2000), the Delphi method (Delbecq et al. 1975), soft systems methodology (Checkland 1981) and SODA (Strategic Options Development and Analysis) (Eden 1989). Collectively known as problem structuring methods (PSMs) (Rosenhead 1996), whilst all these approaches seek to combine multiple perspectives from a variety of actors for the purpose of supporting decision making in multi-agency groups, they do not demonstrate the capacity to support the entire process of collaboration when developing technology.

Aside from tools and techniques designed to support collaboration, the literature review also identified approaches to support technology development. An example of such an approach is a technique developed by NASA called Technology Readiness Levels (TRLs). Created in the mid 1970s, TRLs consist of nine levels supporting a more effective assessment of the maturity of new technologies as they are developed. The scale begins at TRL1, in which "basic principles are observed" and progresses to TRL 9 in which the "actual system is flight proven through successful mission operations" (Mankins, 1995).

The overarching premise of TRLs is to provide a progressive path to support the development and integration of a new technology. The progression detailed is linear, with each level acting as a stage gate. The approach has gained almost universal acceptance in the engineering industry as an approach to minimise the risk of technology development (Moorhouse 2001). However, the technique does not accommodate a collaborative approach to technology development. Instead, the focus is purely on the technology in question, understanding how it has progressed and what needs to be done to progress to higher levels of maturity. Further, it is a retrospective process, only possible to enact once a technology has reached a certain stage and unable to make predictions about *how* best to progress.

A technique which does support detailing *how* a technology should progress is the technology roadmap (TR). Developed in the US automotive industry, technology roadmaps are similar to TRLs in the sense they describe a linear path of progression for a technology to follow. However, whereas TRLs are retrospective in their analysis, TRs assess the future development trajectory of said technology. Specifically, a TR can be defined as "a time-based chart, comprising a number of layers that typically include both commercial and technological perspectives" (Phaal, 2004).

TRLs have been widely adopted by many technology-driven companies such as Philips, BP, Motorola, Rockwell Automation, NASA etc (Wells et al., 2004; Galvin, 2004), providing support for strategic, technological and policy decisions (Yasunga, 2008). However, despite their popularity, they have significant drawbacks. Specifically, TRs focus on the evolution of technology with minimal consideration of the actors and organisations who possess the capability to develop it. Further, they also offer little in the way of understanding final integration, in terms of technology adoption and operation. For these reasons, whilst TRs can definitely support aspects of collaborative technology development, they again do not provide a defined process or framework, which can be readily applied to the entire development.

2.3 Brokerage

The literature on brokerage, whilst not quite as expansive as IOC, is still significant in size and has appeared in a diverse range of research areas (Gould & Fernandez 1989; Burt 1992; Aldrich 1976; Fernandez & Gould 1994; Spiro et al. 2013; Currie & White 2012b; White et al. 2014; Hargadon & Sutton 1997; Hargadon 1998). Defined by Marsden as "a process by which intermediary actors facilitate transactions between other actors lacking access to or trust in one another" (Marsden 1982), it has become the focus of a large amount of research.

Fernandez and Gould (1994) simplify this definition slightly, defining brokerage as "a relation in which one actor mediates the flow of resources or information between two other actors who are not directly linked" (Fernandez & Gould 1994).

More recently, this definition has been simplified further by Spiro et al. (2013), removing the specification of what need to be transferred, they state, "brokerage occurs when one actor serves as a bridge between two other actors who themselves lack a direct connection to one another." (Spiro et al. 2013).

The common principle between all three definitions is the presence of at least 3 actors, embedded within a network. The broker then occupies a unique position within the network, whereby they have the ability to unite two otherwise unconnected actors. The fundamental assumption of brokerage here is that people and their connections can be modelled as networks.

Whilst the high-level definition is sufficient to communicate the general premise of brokerage, Gould and Fernandez (1989) identified that a broker played a different role and executed different tasks, based on their context and position within a network (Gould & Fernandez 1989). Based on this, they subsequently identified five structurally distinct types of broker, or, five types of brokerage relation. The five types are liaison, representative, gatekeeper, itinerant (or consultant) and coordinator (Gould & Fernandez 1989; Currie & White 2012b). Table 5 details the differences between the various types of brokerage as well as a visual representation.

Gould and Fernandez's categorisation of the five forms of brokerage has led to a considerable amount of further research, where it has enabled scholars to categorise the various types of brokerage they witness in differing contexts. A particular theme of interest that has emerged is exploring the role of actors and organisations acting as brokers, to support the transfer of knowledge across intra- and inter-organisational boundaries. For instance, Currie and White explore the role of brokers in supporting the diffusion of context specific knowledge within the UK Health Sector (Currie & White 2012b). Here, they show how professional affiliation and associated power differentials impact upon knowledge brokering at the individual and group levels within an organisation (Currie & White 2012b).

The theme of knowledge brokering has also been popular in the inter-organisational context too, particularly around the area of innovation. Literature surrounding innovation is vast and the attention afforded to it by scholars exploring the role of brokers to support it is equally large (Klerkx & Leeuwis 2009; Bessant & Rush 1995; Howells 2006; Chesbrough 2003; Parjanen et al. 2011; Munoz & Lu 2011; Jorde & Teece 1990; Hargadon & Sutton 1997; Hargadon 2002).

Dodgson et al. define innovation as both an outcome and a process. It involves the successful application of new ideas, which stem from the combination of various resources (Dodgson et al. 2014). Smits (2002) takes this definition forward by identifying the resources to be combined as hardware, software, and orgware. He defines them as; hardware relates to the material equipment required, and software concerns the knowledge in terms of manuals, software, digital content, tacit knowledge involved in the innovation. Orgware refers to the organisational and institutional conditions that influence the development of an invention into an innovation and the actual functioning of an innovation (Smits 2002).

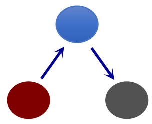
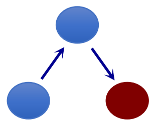
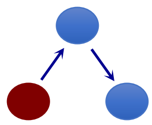
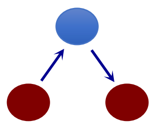
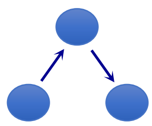
Brokerage Type	***Visual Representation***	***Description***
Liaison		A liaison brokerage relation is one in which all three actors belong to different groups. Without any prior affiliation, the broker provides a link between the two other actors (Gould & Fernandez 1989).
Representative		A representative brokerage relation refers to a situation in which one member of a subgroup takes upon itself or is given an order to communicate information to, or negotiate exchanges with members of an external group (Gould & Fernandez 1989).
Gatekeeper		The gatekeeper role relates to when an actor screens or gathers resources from the outside of their subgroup and distributes them to members of their own subgroup (Gould & Fernandez 1989). Here, the broker is more likely to be self appointed and may filter knowledge aligned with self-interest (Currie & White 2012b).
Itinerant (Consultant)		Itinerant or consultant brokerage refers to when two actors belong to the same sub group, while the intermediary, or broker, belongs to a different group. In this context, the broker mediates between the two actors in the same group.
Coordinator		Coordinator brokerage refers to a situation when all three actors are members of the same group. Gould and Fernandez term this the "null" type, in the sense that it describes any brokerage relation in which no partition is imposed on the actors; but it also describes mediation between actors within a specified subgroup (Gould & Fernandez 1989).

Table 5: Five forms of brokerage

Consequently, the exchange of knowledge between actors is an imperative part of the innovation process, hence the interest in brokerage (Klerkx & Leeuwis 2009).

Whilst a great deal of the research into brokerage has built on the five types of brokerage identified by Gould and Fernandez, there also exist criticisms. For instance, Spiro et al. question the lack of a temporal consideration in the five characterisations. Instead they propose three brokerage processes; transfer, matchmaking and coordination, which demonstrate a more dynamic quality (Spiro et al. 2013). By classifying brokerage in this way, Spiro et al. argue that the value of brokerage can be measured more easily, whilst it also opens up new directions for research, focussing explicitly around the temporal importance of actor interrogation.

Further disagreements around brokerage focus on the broker themselves and relate to power. Specifically, some scholars have sought to explore the power a broker gains and how they can use this to their advantage and value (Hargadon & Sutton 1997; Burt 1992; Padgett & Ansell 1993). Referenced to as the "Tertious-Gaudens" or "powerful third" in Burt's structural hole theory (Burt 1992), Hargadon also illustrates this point in his five-stage process for knowledge brokering (expanded upon in section 2.3.1). Through classifying brokers as designers, Hargadon affords brokers a significant level of power within the network. permitting them to exploit and manipulate information flow for their own personal gain and benefit (Hargadon & Sutton 1997). However, other scholars believe brokers should not occupy a position of power for personal gain.. For instance, Dodgson et al. state "brokers have neither the goal of codifying knowledge for repetition, nor the promise of status and power that accrue to those who use it to gain advantage within a single domain" (Dodgson et al. 2014).

Despite an agreed definition of brokerage and whilst the various characterisations provide an overview of what constitutes brokerage in differing contexts, the literature is currently lacking an accepted convergence of principles, which seek to define what capabilities a broker should possess. There is also considerable debate within the literature as to what the benefits of brokerage are, how a broker best delivers value and in what context the various forms of brokerage should be applied.

Further, the extant literature currently does not address the very premise of what a broker seeks to transfer; knowledge. Specifically, there is no attempt to define what level of knowledge, experience or competency a broker must possess in order to identify brokerage opportunities and successfully enact the process. Scholars either assume the knowledge is present based on professional standing (Burgess & Currie 2013; Currie & White 2012b) or they do not address the issue (Gould & Fernandez 1989; Burt 1992; Spiro et al. 2013) Further, there is no exploration of how that process should be conducted and how a broker may expand their knowledge base, or contextualise it to make it useful.

2.3.1 Brokerage and Technology Development

Research exploring the role of brokerage in support of technology development is an area growing in interest (Howells 2006). However, up until now, a large amount of the research conducted in this area has focussed on the early stages of technology development, specifically, the innovation stage (Hargadon 2002; Hargadon & Sutton 1997; Klerkx & Leeuwis 2009; Dodgson et al. 2014).

As earlier described, innovation involves the combination of resources and ideas, to create a novel service product or technology, which is successfully accepted (citation needed). The research exploring how brokers support this process, in the context of technology development has attracted significant attention in recent years. Howell identifies four key areas in which this research has been most prevalent: (a) literature on technology transfer and diffusion; (b) more general, innovation research on the role and management of such activities and the firms supplying them; (c) the systems of innovation literature; (d) research into service organisations and more specifically Knowledge Intensive Business Services (KIBS) (Howells 2006).

The power of brokerage to support innovation is in essence down to the fundamental purpose of what brokerage is about – using their position or experience to span gaps between actors and reduce “distance” (Nooteboom 1999; Nooteboom et al. 2007). Parjanen et al. identify 8 forms of gaps or distance detailed in the literature; cognitive, communicative, organisational, functional, social, cultural, geographic and temporal.

The premise of Parjanen et al.'s work is to highlight how the identification of gaps and distances in these eight areas, supports the identification of innovation opportunities. By subsequently reducing these distances through brokerage, they argue that the actors involved will be better positioned to work together and successfully proceed with otherwise "unreachable" innovations (Parjanen et al. 2011). They demonstrate their hypothesis through observation an analysis of an "innovation day". Here they document the key activities of actors involved, including the roles of the broker, highlighting when gaps are identified and reduced (Parjanen et al. 2011).

Similar research in this area has been conducted by Hargadon (Hargadon 2004; Choi & Hartley 1996; Hargadon 2002; Hargadon & Sutton 1997; Hargadon 1998). Hargadon focuses specifically on technology brokering, exploring the role of brokers in the early innovation process within technology companies. A large portion of Hargadon's research focuses on a design company called IDEO (Hargadon & Sutton 1997; Hargadon 1998).

In their research, Hargadon and Sutton Similar examine the role of IDEO consultants identifying gaps between the actor organisations they work with, in an attempt to create new products. However, unlike Parjanan et al., Hargadon and Sutton don't just explore the boundary-spanning role of brokers, but also examines the broker's role from the perspective that they are designers, who possess specific technical knowledge key to the context in which they are brokering. Here, they identify that as well as creating knowledge through connecting the customer actors with external actors; the broker also contributes their own explicit knowledge to the situation, actively contributing to the transformation of ideas and knowledge being transferred into innovations (Hargadon & Sutton 1997).

Hargadon's research has culminated in the development of a five-stage process model for knowledge brokering. Initially identified as access-acquisition-storage-retrieval-output (Hargadon & Sutton 1997) the process was later refined to access-bridging-learning-linking-building (Hargadon 2002). Essentially, the process model refers to the innovation process in technology brokering. Similar to the SECI framework proposed by Nonaka and Nishiguchi (Nonaka & Nishiguchi 2001), the premise of the model is that brokers access a new group or network, closely related to their experience and technical expertise. Through immersion in the new network, they assess current problem areas from the perspective of their own experience, subsequently linking ideas used in contexts external to the current group and applying them in that situation to novel effect. The result is an innovative proposition in the form of a technology, service or product (Hargadon & Sutton 1997; Hargadon 1998; Hargadon 2002).

The premise and application of the knowledge brokerage process model is well grounded and has displayed relative success. However, it also provides a glaring example of the limitations of research currently in this area. For instance, the focus of the broker here is solely on the innovation process. Research has thus far focussed largely on how the linking of unconnected actors and the introduction of new knowledge and resources can positively influence innovation. However, little research exists exploring the role of the broker past this point.

Indeed some scholars have questioned the role of brokers past the point of innovation. For instance, Fleming et al. (2007) suggests that not only are brokers of little use supporting the continued development of an innovation past it's initial inception, but that innovations, which occur with the input form an external broker have a reduced chance of being successfully developed and commercialised and thus are less likely to be accepted by the end consumer/system (Fleming et al. 2007). However, minimal research exists to appropriately validate this hypothesis.

One example, which does offer an indication of the usefulness of brokerage past the innovation stage of technology development, can be seen in Chesbrough's work on open innovation (2003). Here, Chesbrough refers to the role of an "innovation architect", which displays similar characteristics to brokers, in that they span gaps and support the flow of knowledge across boundaries (Chesbrough 2003). Chesbrough identifies that architects are usually deployed in highly complicated technology worlds. Here, the role of the architect is to partition the complexity to enable other organisations to provide pieces of the system, all while ensuring that the parts fit together in a coherent way. As an example, he cites Boeing as an example of a company who dictates the overall design of an aircraft but then utilise multiple other companies to support the development and construction of individual sections and technologies (Chesbrough 2003).

The example provided by Chesbrough can be viewed as a form of IOC network, governed by a lead organisation. Here, the innovation architects are responsible for developing the overall design of the aircraft – the network level problem. They are then also responsible for using their skills, knowledge and professional acquaintances to identify external partners to support the development of individual parts of the aircraft. As already identified in this review, both high-level coordination of problems and boundary spanning to solve said problems are two key facets of brokerage. As a result, the potential for brokers to provide value past the innovation stage is plausible, although considerable more research is needed.

Further examples of brokers being employed past the innovation stage is in the technology transfer literature. However, here brokers return to their limited role of "linking" and boundary spanning, connecting actors and organisations with early stage technology ideas, but lacking the commercial and technical expertise to develop the technology further, with specialist organisations who are capable of doing just that (Bessant & Rush 1995).

2.4 Gaps in the Literature

This section summarises the areas, which have been identified as under-addressed in this literature review.

2.4.1 Qualitative studies of collaborative technology developments

This review has highlighted that research exploring IOCs has up until now focussed largely on quantitative forms of analysis. Little research has been conducted seeking to explore the principles and functionality of collaborative technology developments from a qualitative standpoint.

2.4.2 A unified set of principles informing collaborative design

This review has highlighted the disjointed and fragmented nature of research pertaining to collaboration. Further, it has also illustrated that there is scant evidence of extant research seeking to define approaches to support collaborative technology developments. Specifically, there are no unified principles, from a qualitative standpoint, which inform the design and development of an IOC network, for the purpose of technology development.

However, whilst the review has not indicated the existence of a pre-defined framework to inform the design of a collaborative technology approach, several themes and sub-themes have been identified. Specifically, four themes have been identified in the literature review, which the authors considers important;

- Purpose and motivations for entering into a collaboration
- Governance
- Structure
- Partner identification and selection

The four themes illustrated above will serve as a basis for this research to develop a practical and unified set of principles, which can inform the design and development of collaborative technology developments.

2.4.3 A network level understanding of potential collaborative failure

Extant research has heavily referenced the prevalence with which collaborations currently fail. However, there has been no attempt to understand how or why this happens from a network level perspective. Specifically, there is scant evidence of any extant research, at the network level, seeking to understand how the likelihood of success or failure of collaborative technology developments may be assessed, based on the assessment of the collaborative composition or relationships of that network.

2.4.4 A unified set of principles defining the role and value of a broker in the context of technology development

The value of brokerage to span gaps and transfer knowledge has been well defined throughout the literature. However, at present there is no understanding relating to *how* the broker initially captures and contextualises such knowledge in order to make it of value. Further, whilst a wide array of literature has sought to define the principles of brokerage, they are currently significantly disjointed. Consequently, a unified framework advising on the principles of brokerage in relation to technology development and thus a true understanding of a broker's value in such a context, does not exist.

2.4.5 How the principles of collaboration and brokerage may be constructively applied in an industry context

This review has identified several tools and approaches, which are currently used within industry to facilitate collaboration. However, as illustrated earlier in this chapter, none of these approaches were developed for the explicit purpose to support collaborative technology developments. Further, of the frameworks which do exist to support collaboration, they are generally high level and do not indicate the best methods to apply them in a practical setting.

Chapter Three
Methodology

3.1 Introduction

This chapter describes the methodology applied to this research, to ensure a common approach throughout and produce a thesis of consistent quality. The methodology section presented has six key aims;

1. Provide an overview of the **key research questions** this research will address
2. Provide an understanding of the **context** in which the research is to be conducted, as so to appropriately inform the selection of research assumptions, strategy, design and methods.
3. Provide an indication as to the **philosophical perspective** of the researcher, taking into account the context in which the research is conducted
4. Provide a clear **strategy** for the research programme, to ensure each section of research is consistent to the overarching aim and delivers in the production of a single body of work
5. Provide an outline of the key **research methods** used to support the research and justifications for their inclusion.
6. Provide an overview of the **ethical** considerations

Through identifying the gaps in the literature review that this thesis seeks to address, this chapter initially presents the core research questions. These are, in summary;

- What are the key principles when designing collaborative approaches to support technology development?
- How can the principles of collaborative technology development be constructively applied in industry?
- How can the risk of failure of collaborative technology development be minimised from a network level perspective?

This chapter then continues to discuss the context in which the research is to be conducted, highlighting its impact on the research strategy and methods to be taken. It provides justification as to why the research takes a qualitative, subjective, interpretivist approach, addressing the ontological, epistemological and axiological assumptions of the researcher in turn.

This chapter then outlines the overarching research strategy to be taken, beginning initially with an in-depth review of the literature. Subsequently, two industry case studies are conducted, following the methodological approach of Yin (2014). The aim of the case studies is to better understand industry best practice towards collaborative technology development. The output of the case studies is a framework for collaborative technology development, which is subsequently tested and iterated through a more interventionist approach; three action cases (Vidgen & Braa 1997). An overview of the research strategy can be seen in Figure 4.

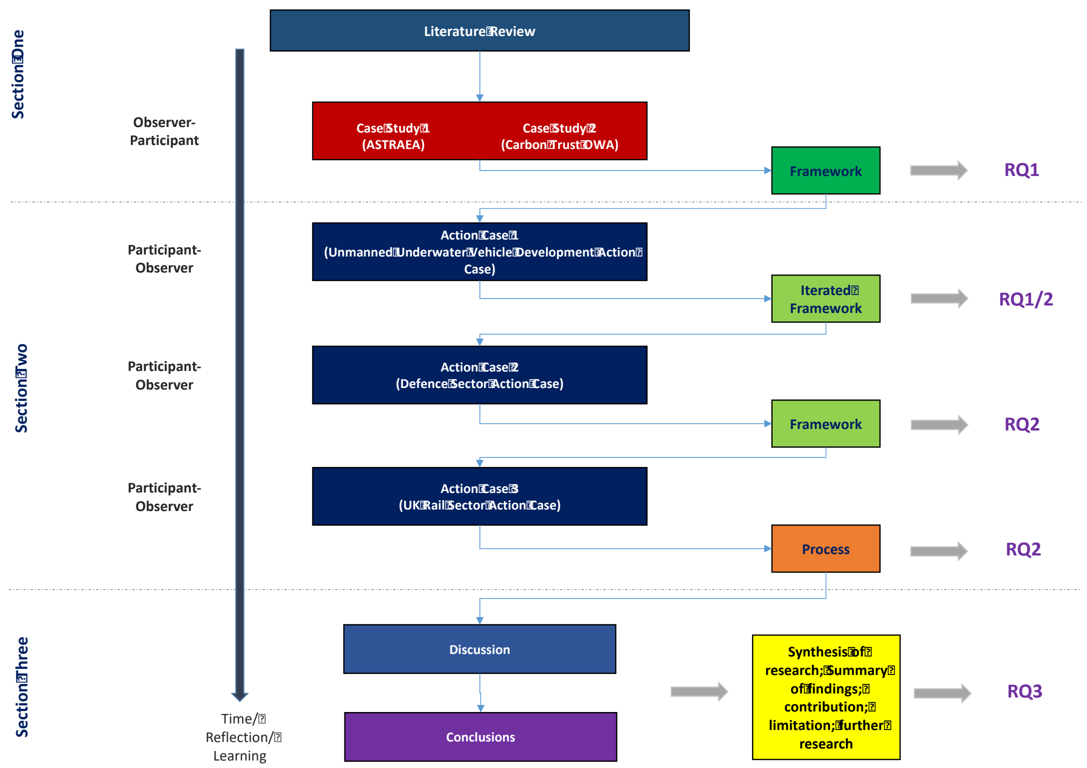


Figure 4 – Overarching Research Strategy

Finally, the chapter presents supporting research methods, which are to be used to support data collection. Ethical considerations of the research are also discussed.

3.2 Research Questions

The literature review has highlighted several gaps in extant research relating to collaborative technology development and brokerage. Whilst the review did identify that a significant body of literature exists, the multi-disciplinary nature of the field has resulted in much of the collaboration research becoming disjointed and lacking convergence, particularly in relation to technology development. There also exist significant gaps with regards to the methods of enquiry employed when studying collaborations. Specifically, there is a distinct lack of qualitative research exploring how collaborations are formed in industry from a network level perspective.

To effectively address these gaps and provide a basis for the thesis to contribute to areas of the literature currently lacking, the research will focus on three main research questions:

Research Question One: What are the key principles to consider when designing collaborative approaches to support technology development?

This thesis primarily seeks to understand the key principles of collaborative technology development. Through drawing together a critical analysis of the literature with two industry case studies, this thesis intends to develop a framework of key principles, to inform the design of future industry collaborations. Specifically, this research question seeks to understand;

- How are collaborations formed in industry currently?
- What approaches are used to support the formation and operation of collaborations?
- What factors and circumstances lead to the formation of collaborations?
- Is there a correlation between academic best practice and current industry best practice?

- What are the benefits of collaborative approaches to technology development, from a network perspective?
- What are the challenges of such collaborative approaches?

Research Question Two: How can the principles of collaborative technology development be constructively applied in industry?

The literature review has also identified that there is currently a gap with regards to the application of techniques to support industry organisations collaborate effectively for the purpose of successful technology development. To address this gap, the thesis explores the application aspect of the collaborative principles developed in response to question one. Through identifying several industry cases in which to apply the framework, the principles are tested and developed further. Particular attention is sought around the vehicle of delivery ie the process through which the collaborative principles are best applied. With this in mind, the role of brokerage in the support of collaborative technology development is a specific area of interest explored.

The ultimate intention of the thesis is to synthesise the learning in order to develop a practical understanding, which can better support organisations collaborate effectively, minimising the risk of developing technology. To support this, the second research question aims to understand the following core themes;

- How does the role of a broker compliment collaboration?
- How do brokers benefit technology development?
- What principles/assets should a broker possess to provide support to collaborative development?
- How can the principles of brokerage and collaborative technology development be formalised to support organisations in a useful way?

Research Question Three: How can the risk of failure of collaborative technology development be minimised from a network level perspective?

Finally, this thesis seeks to synthesise the learning of this research, through an evidenced based review of the cases conducted. The review seeks to build on the learning from the cases to understand how the likelihood of collaborative failure may be predicted based on the composition, distribution and typology of actors involved.

3.3 Methodological Considerations

This thesis adopts a qualitative approach to the investigation, utilising systems thinking principles to guide and shape the research programme. The approach has been developed based on the intention of the research, the context in which it is to be applied and the philosophical assumptions of the researcher. A qualitative approach has also been selected as a response to the literature review, which highlighted a distinct lack of qualitative research exploring collaborations.

3.3.1 Context

As illustrated in chapter one, the context within which this research is being conducted is Frazer Nash Consultancy (FNC), a project based engineering consultancy, which generates revenue through the delivery of client projects. It is therefore intended that, whilst the researcher will be conducting their research, they will also be required to contribute to the value generation of the firm. Further, the ultimate aim of the research from a commercial perspective is to support the development of a new business stream within the company, with the vast majority of data to support this originating externally of the business. These additional requirements mean the researcher will be expected to work on client-facing projects, which will simultaneously serve as “laboratories” in which to conduct research.

The selection of these projects, or “laboratories” becomes an important factor when ensuring appropriate opportunities for the researcher to address the research questions of this doctoral study. Consequently, to counter against the lack of consistency in project opportunities, a process will be developed, ensuring that projects are suitable for the research and guarantee access to all necessary data and material.

The involvement in active projects does present a great opportunity for the researcher to conduct research in contemporary, 'real-world' environments. However, it also constrains the approach one might take to address the research questions identified. For instance, working on live industry projects immediately positions the researcher as an active participant in the study. Consequently, pursuing an approach where the researcher is a 'complete-observer' would not be feasible in the context of this research. Instead, a strategy which favours a more interventionist approach will have to be considered.

Aside from the industrial context of this study, attention should also be paid to the academic perspective of the problem, when selecting an appropriate research approach. To this end, it is important to consider that the research questions identified have been developed in response to what can be characterised as a complex problem. Although complexity is a greatly debated facet of many problems, open to the subjectivity of individual perception, Jackson (2006) believes complexity stems from the nature of a problem; problems, which present themselves in relation to other problems in richly interconnected situations (Jackson 2006). This notion is somewhat shared by other notable academics such as Ackoff, Aldrich and Rittel and Webber, who characterise complex problems as 'messes', 'invisible' and 'wicked' respectively (Ackoff 1974; Aldrich 1976; Rittel & Webber 1973).

The impact of addressing a problem characterised as 'complex' is best highlighted by Rittel and Webber (1973) who explain that selecting an appropriate research approach when exploring 'wicked problems' has several core challenges;

1. You don't understand the problem until you have developed the solution
2. Wicked problems have no stopping rule
3. Solutions to wicked problems are not right or wrong
4. Every wicked problem is essentially unique and novel
5. Every solution to a wicked problem is a one-shot operation
6. Wicked problems do not have an enumerable set of principles

The core challenges identified by Rittel and Webber demonstrate that the research approach must take into consideration the unique aspects of each problem context the researcher is presented with. They also raise important considerations about the generalisability of findings and emphasise that 'absolute solutions' may not exist. For this reason, the research approach will be designed to produce outputs, which are deemed 'useful' in an industry context, but will not be considered 'silver bullet' solutions for all.

3.3.2 Philosophical Assumptions

Considering the philosophical assumptions of the researcher is an imperative first step to ensuring the selection of an appropriate research strategy (Huff, 2009; Cresswell 2009). Commonly referred to as paradigms (Mertens 1998), philosophical assumptions (Crotty 1998), alternative knowledge claims (Neuman 2000), philosophies (Saunders et al. 2003) or worldviews (Creswell 2009), they refer to four specific beliefs; ontology, epistemology, axiology and methodology. The various assumptions relating to this research are outlined below.

Ontology

Ontological issues relate to the nature of reality and its characteristics (Creswell 2013). Described by Johnson and Duberley (2000) as a branch of metaphysics dealing with the essence of existence, ontology ultimately refers to a person's perception of what is reality and what is not (Johnson & Duberley 2000)

The ontological assumptions of a person very much depend on a person's view as to whether the world is subjective and socially constructed, understood only through one's own experiences, or whether it is perceived as objective and external (Collis & Hussey 2003).

Due to its complex nature, this research takes a subjective ontological perspective, in which it is understood that each individual has their own socially constructed realities, which are to be interpreted by the researcher.

Epistemology

The epistemological assumption relates to the theory of knowledge; that is, how knowledge is developed and known (Creswell 2013). Saunders et al (2003) identify two main epistemologies; positivism and interpretivism.

Positivism reflects the traditional research philosophy of the natural scientist, where the researcher prefers to work in "an observable social reality" in which the end product can be a "law-like generalisation similar to those produced by the physical and natural scientists" (Saunders et al. 2003). Within this tradition, the researcher assumes a role of objective analyst and places significant emphasis on a highly structured, repeatable methodology, typically favouring a reductionist approach, which lends itself more appropriately to quantitative forms of analysis (Creswell 2009; Saunders et al. 2003).

Conversely, interpretivism views the world as a complex environment comprised of many social actors, to which the application of a positivist reductionist approach would not produce results of sufficient quality, as it would in the physical sciences (Saunders et al. 2003). Whereas positivism seeks generalisability of results, interpretivism views specific research contexts as unique, complex environments, within which generalisability adds little value. Instead, interpretivism is concerned with understanding the individual subjective realities of the people involved with the research. Advocating the theory of social constructionism, interpretivism considers knowledge and reality to be socially constructed by social actors and understands that each actor may have their own version of reality based on their experience (Saunders et al. 2003; Creswell 2013).

Due to the complex, wicked nature of the research questions identified for the research, the social context in which it is to be conducted and the general qualitative strategy that is being pursued, the research will adopt an interpretivist approach. Throughout, the research will seek to understand and interpret individual's perceptions of reality and construct discussions and conclusions based on that view.

Axiology

The axiological assumption is concerned with the values of research participants, as well as the researcher themselves. The philosophical assumptions and perspectives of the researcher underpin the selection of an appropriate research strategy and approach.

Although this research is concerned with exploring the principles of collaborative best practice, establishing techniques which can support organisations work more effectively together, it will not seek to determine absolutes. Instead, it will be understood that values are a definitive variable to when characterising 'good' progress.

3.4 Overarching Research Strategy

The primary aim of this thesis is to better understand how organisations may work together more effectively when developing technology collaboratively, in order to minimise the risk of failure. To explore this topic, the research adopts a qualitative approach. However, within this paradigm, the research adopts several research strategies and methods, to support the investigation. An overview of the strategy pursued can be seen in Figure 4 (page 74).

As is clear from Figure 4, the thesis is split into three sections. Commencing with a review of current literature, the study then moves on to explore the core problem through two industry case studies. The assessment of the case studies adopts an interpretivist approach and is informed from the literature review. Subsequently, the research becomes more interventionist through the application of three action cases, with the researcher an active participant in active industry projects. Throughout, the thesis attempts to strike a balance between interpretation and intervention, as it seeks to simultaneously understand and bring about change through the testing of ideas and techniques. In doing so, it does not try and reduce the complexity of the problem, nor make predictions. Such an approach may be better articulated with the support of Braa and Vidgen's (1999) research framework, present in Figure 5. Finally, the thesis moves into section three, where research findings are synthesised, discussed and concluded.

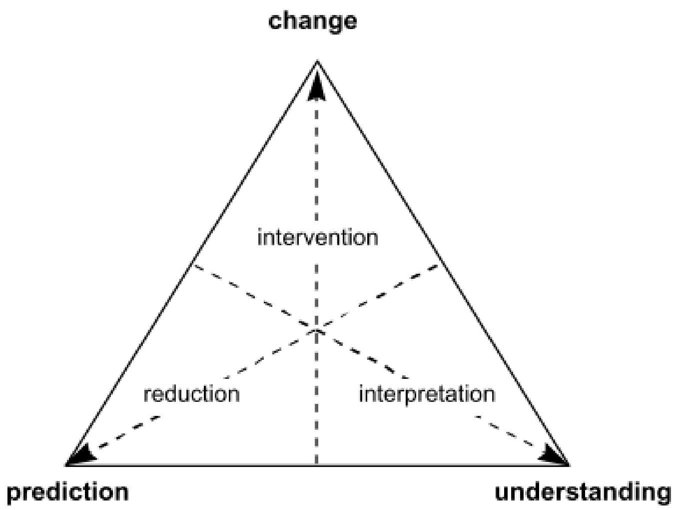


Figure 5 – Research Framework (Braa & Vidgen 1999)

3.4.1 Section One – Understanding Collaborative Technology Development

This section begins with a literature review, exploring extant literature in the fields of inter-organisational collaboration and brokerage, seeking to understand their role in the context of technology development. The review of the subject areas highlights key gaps in the literature including the current lack of convergence regarding collaborative technology development research. The rest of the section subsequently builds on the literature review through the analysis of two industry case studies, with the aim of formulating a better theoretical understanding of the principles of collaborative technology development. Greater explanation and justification for the selection of the case study approach employed is provided below.

3.4.1.1 Case Studies

A case study can be defined as "a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence" (Robson 2002). Classified as a scientific method by Galliers (1992), it has been suggested that case studies can be applied to support both positivist and interpretivist epistemological approaches, depending on the worldview of the researcher (Braa & Vidgen 1999).

Traditionally, case studies are used to investigate a single issue in great depth, in situations where the researcher has access to multiple data sources (Stake 1995). However, they can also be used in a comparative sense, in which multiple cases are conducted and subsequently cross-analysed (Bryman 2008; Saunders et al. 2003).

A key strength of the case study approach is that they enable the researcher to fully immerse themselves into the real-world context of a contemporary situation (Thomas 2011). This is of particular interest to this study, as the research seeks to gain a deeper, real world understanding of how industry collaborations are established, developed and governed, to support technology development.

A common criticism of the case study approach is that they cannot be used to form generalisations (Thomas 2011; Saunders et al. 2003). However, as Yin (2014) points out, this is not completely the case. For instance, whilst generalising from a single case is not possible, nor should it be pursued, the same is true for the traditional experimental approach. In these instances, the primary method to support generalisation is to conduct multiple experiments and compare the results. This is because an experiment, as a case study, should not be considered as a "representative sample". However, multiple experiments, and thus cases, may be used to further develop theories and hence generalise "theoretical propositions" (Yin 2014).

For the purpose of this research, this is an important distinction; one that makes the selection of the case study strategy a more appropriate research approach. For instance, the intention is to explore whether what is stated as academic best practice in the literature is true in industry application and subsequently infer a theoretical framework of key principles.

Further criticisms of the case study approach focus on a lack of control of variables and different interpretations by different stakeholders (Galliers 1992). However, such criticisms very much stem from the positivistic standpoint and as already

identified, the epistemological assumption of the researcher throughout this work is interpretivist.
Consequently, the first section of the research will adopt a comparative case study approach. Following Yin's methodological approach for case study design, the research in this first phase will consist of three main steps; Define and Design; Prepare, Collect and Analyse; Analyse and Conclude as depicted in Figure 6.

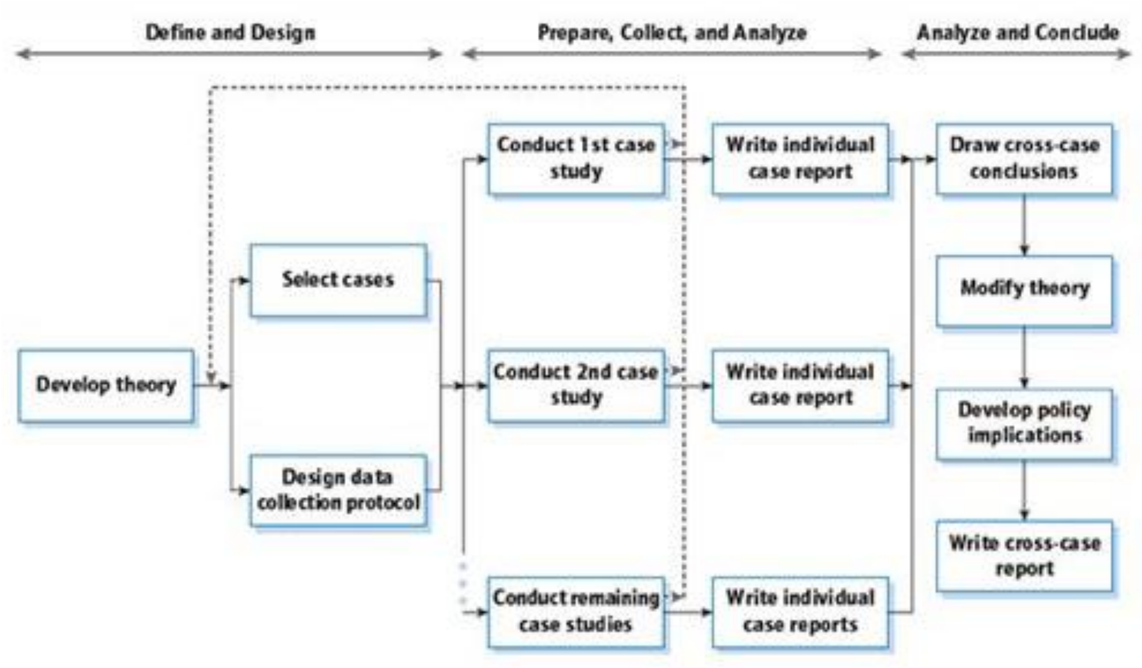


Figure 6 – Case Study Method (Yin 2014)

Define and Design

Develop Theory – The theory will be developed through conducting an in-depth literature review on the current agreed best practices relating to the principles of collaborative technology development.

Select Cases – The research is concerned with analysing cases where multiple organisations have collaborated in relationships greater than bi-partite formations, in order to develop a novel piece of technology. Consequently, in order to ensure appropriate cases are selected, multiple criteria must be satisfied. Specifically, building on the identified definition for collaboration developed in section 2.2.1, cases will be selected based on;

- the presence of three or more organisations

- collaborating to develop a piece of technology, which may be defined as a product or service
- The collaboration must be arranged in a formal way
- Researcher must have equal access to all artefacts and able to conduct semi-structured interviews with personnel of equal responsibility and seniority
- Collaborative development must be greater than 50% through the lifecycle of the project

Data Collection Protocol – To support the data collection, several techniques will be employed;

- Semi structured interviews with members of the collaborations. The themes and questions developed for the interviews are formed based on the findings from the literature review
- Desk research and analysis of document artefacts associated with collaborations

Prepare, Collect and Analyse

After an initial period, two case studies were selected, based on their suitability when assessed against the key criteria identified above. During this phase, one case was also discounted, as it did not fulfil the key criteria deemed a requirement. Further desk research was conducted on the two cases, in order to develop a more in depth understanding.

Subsequently, semi-structured interviews were conducted with the lead of the collaborations. The questions used to structure the interview sessions were developed based on the four key themes of collaborative technology development identified in the literature;

- Purpose and motivations for the collaborative model
- Partner identification and selection
- Network structure
- Governance processes

To support the cross-case analysis, both cases were written up as individual reports in a consistent format.

Analyse and Conclude

A cross case analysis is conducted, which compares the two cases with literature stated best practice. Subsequently, a second analysis is conducted to explore whether any other themes were present and consistent throughout the two cases, which weren't identified in the literature review. The output is presented as a framework for collaborative best practice when developing technology. The framework provides the basis for the subsequent action cases, where it is tested, validated and iterated.

3.4.2 Section Two – Supporting Collaborative Technology Development

This section seeks to build on the findings of section one. Through utilising the framework generated, the research looks to test, iterate and validate it through a series of action cases. Further, this section explores the application function of collaborative principles, using the action cases as intervention opportunities to test and develop a process of collaborative brokerage. Greater explanation and justification for the selection of the action case approach employed is provided below.

3.4.2.1 Action Case

As indicated earlier, the approach to this research seeks a balance between understanding and change due to the combined requirements of developing theoretical knowledge contributions whilst also positively intervening in client situations. In seeking such a balance, the researcher is caught between two traditional research paradigms, something noted by Braa and Vidgen (1999); "researchers finding themselves caught in an uncomfortable space, falling between research traditions that have different notions of relevance and rigor."

If the research were to focus solely on change, then action research would be a perfectly suited strategy to address the remainder of this study. Developed by Lewin in the 1940s, action research is a more interventionist approach to social science research (Vidgen & Braa 1997). It differs from traditional applied research due to its explicit focus on action and in particular, promoting change (Saunders et al. 2003). Traditionally requiring the direct involvement of the researcher within the situation (Eden & Huxham 1996), action research presents a way of building theories and descriptions within the context of practice itself (Braa & Vidgen 1999). Once developed, theories are subsequently tested through direct intervention within the organisational context; interventions which have a double burden of testing hypotheses as well as affecting positive change to the situation in question (Argyris et al. 1985).

Lewin's initial proposition for action research consisted of a six-stage model – (1) analysis, (2) fact finding, (3) conceptualisation, (4) planning, (5) implementation of action, (6) evaluation (Vidgen & Braa 1997). It is best summarised by Argyris et al (1985: 8-9) as follows;

1. Action research involves change experiments on real problems in social systems. It focuses on a particular problem and seeks to provide assistance to the client system
2. Action research involves iterative cycles of identifying a problem, planning, acting, and evaluating
3. The intended change typically involves re-education, a term that refers to changing patterns of thinking and acting that are presently well established in individuals and groups. The intended change is typically at the level of norms and values expressed in action. Effective re-education depends on participation by clients in diagnosis and fact finding and on free choice to engage in new kinds of action.
4. Action research challenges the status quo from a perspective of democratic values.
5. Action research is intended to contribute simultaneously to basic knowledge in social science and to social action in everyday life. High standards for developing theory and empirically testing propositions organised by theory are not to be sacrificed, nor is the relation to practice to be lost.

Since it's initial inception, Lewin's model has been developed considerably, garnering significant attention within the systems literature. Specifically, two approaches stand out; Susman's (1983) five phase action research cycle and Checkland's (1981) seven staged cyclical process. Whilst slightly different in terms of the number of stages, the two have distinct similarities. Most notably, both approaches support the establishment of a relationship between the researcher and participant (client), both strongly advocate the use of a theoretical framework to support a planned action approach "beginning the process of developing a legitimate rigorous alternative to positivistic research" (Checkland 1991) and both suggest a cyclic, iterative application of their model, each iteration building on the previous through evaluation and reflection (Braa & Vidgen 1999).

The similarities between the two approaches largely represent the core features of action research. That is, to plan an intervention, intervene in a situation, observe the impact, reflect and plan for the next intervention. This distilled version of action research is captured by Maclsaac and presented in Figure 7.

The principles of action research developed by Lewin, highlighted by Argryis et al (1985) and further developed by Susman (1983) and Checkland (1991) make action research an almost ideal approach for the second phase of this research. It's ability to support a non-reductionist approach mean it is perfect for dealing with real world 'messy' problems.

However, as earlier illustrated, the context in which this research is being conducted is an engineering consultancy. A primary characteristic of action research is the requirement to follow an iterative, repetitive cycle, something difficult to ensure is rigorously applied on fast-paced industry projects of varying durations. Resource and time limitations also pose significant challenges to adopting a traditional action research approach. More importantly though, action research does not provide a balance between understanding and change.

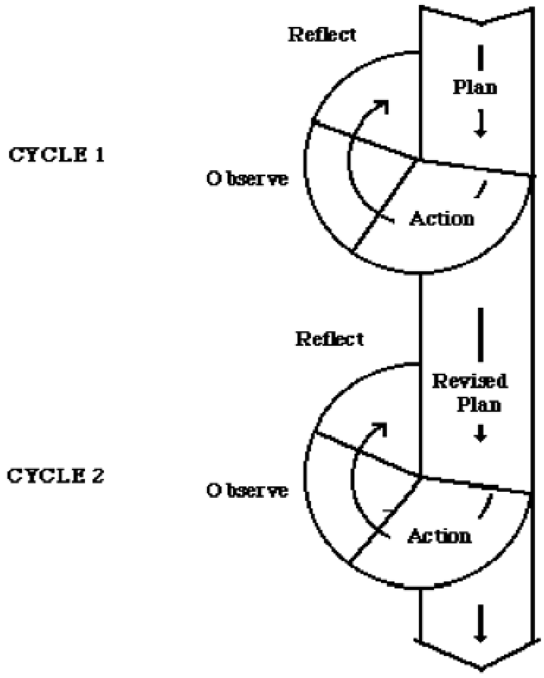


Figure 7 – Simplified Action Learning Loop

Instead, section two of the research will adopt an action case approach (see Figure 8). Developed by Braa and Vidgen (1999) as a "hybrid of understanding and change", action case is a mixed method approach providing "a trade-off between being an observer who can make interpretations (understanding) and a researcher involved in creating change in practice".

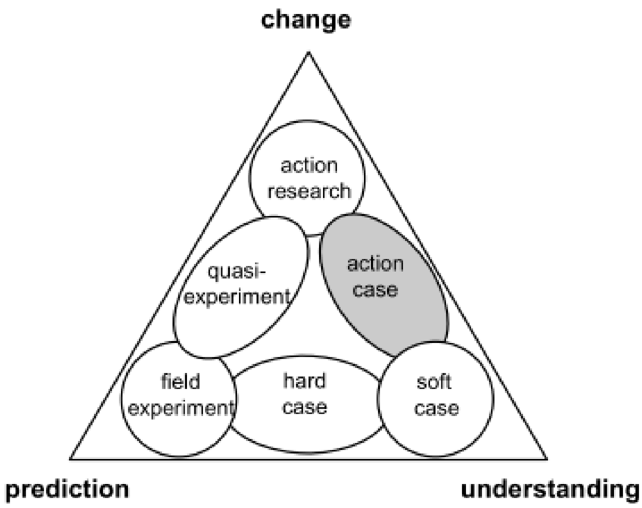


Figure 8 – Action Case method location framework (Braa & Vidgen 1999)

Section two then will consist of three separate industry based action cases. Although each case is a different industry project, there is a commonality between them in that they all involve organisations working collaboratively to develop technology. Each case will seek to build on the previous, further developing and iterating the framework for collaborative technology development generated in section one. Further, the cases will be used to better understand the role of brokerage in the application of collaborative technology development principles. Ultimately, the cases will be used to generate practical knowledge in the form of a process of collaborative brokerage, designed to support industry organisations collaborate more effectively and reduce the risk of technology development.

3.4.3 Section Three – Research Findings

Section three reflects on the research conducted in sections one and two. By drawing together the learning from the case studies and action cases, it seeks to synthesise the research to understand how the opportunity for failure in collaborative technology developments may be minimised. Referring back to the original research questions, the section discusses the implications of the research, highlighting the impact of the research upon both the literature and industry, presenting conclusions, limitations and areas for further research.

3.5 Research Methods

To support the application of the selected research strategies, several research methods will be utilised. Primarily focused on data collection, an outline of each of the methods is provided.

3.5.1 Observational Research

The observational research method is a form of ethnographic research, involving the systematic observations, recording, analysis and interpretation of people's behaviour (Saunders et al. 2003). Considered by some academics as an 'under-exploited' approach in business and management disciplines due to the 'quantification illusion' (Gummesson 2007), observational research provides an opportunity to better understand *why* certain phenomena occur.

In general, two types of observation exist; participant observation and non-participant observation (Saunders et al. 2003; Flick 2009). To provide a greater level of clarification Gold identifies four participant typologies; Complete participant, participant as observer, observer as participant, the complete observer (Gold 1958). These are evident in Figure 9.

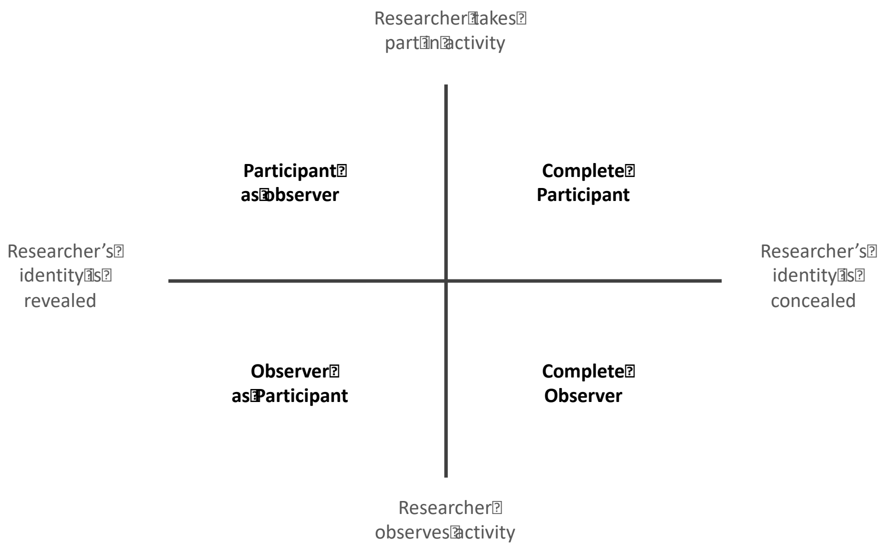


Figure 9 – Typology of participant observation researcher roles (Gold 1958)

This research employs two of Gold's four observation typologies, to complement the two overarching research strategies identified earlier in this chapter. The first of these methods, which will be used to support data collection for the compilation of the case studies, is observer-as-participant. By adopting this method, the researcher's role will be made clear to all involved, however the role will be limited to one of a 'spectator' (Saunders et al. 2003). The second observational method to be used is participant-as-observer, which will support the action case strategy. Similar to before, when adopting the participant-as-observer approach, the researcher's role will be made clear to all involved. However, the researcher will no longer be a 'spectator' but will be actively involved in the cases, complementing the more interventionist approach of the chosen strategy.

3.5.2 Semi-Structured Interviews

Described as a purposeful discussion between two or more people (Kahn & Cannell 1957), interviews are used to gather valid and reliable data that are relevant to the research (Saunders et al. 2003). The form in which the interview may take place can range from highly formalised and structured, to more informal unstructured conversations (Flick 2009). To provide further distinction, a common typology categorises the approaches in relation to their formality and structure, citing three interview approaches; structured, semi-structured, unstructured (Saunders et al. 2003; Bryman 2008).

This research adopts a semi-structured approach to interviews. In this approach, the researcher will generate a set of 'themes' or 'loose-questions' as a basis from which to conduct the interview. However, the researcher is not bound by the pre-identified questions. Instead, the aim is to use the question set as a guide, designed to encourage an open-ended conversationalist-like rapport with the interviewee about the topic in question. Such an approach allows for a more exploratory, wide-ranging conversation about a topic than perhaps a structured interview would support and allows the interviewee to express their personal perspectives in more detail (Bryman 2008). All interviews will be recorded, subject to the interviewee's approval. Further, the researcher will take notes throughout each interview.

3.5.3 Archival Research

Archival research relates to research conducted based on documentary secondary data, ie documents containing data not generated by the researcher (Saunders et al. 2003). Such data can include written documents, such as reports, meeting minutes, transcripts and emails and can refer to either recent or historical artefacts (Bryman 2008; Saunders et al. 2003). Documentary secondary data can also include non-written documents such as video, drawings and digitally sored information.

For the purpose of this research, archival research will be used to support both research strategies, in the following ways;

- Case Study – any available archival document will be analysed to develop a richer understanding of each case and validate findings of primary data collection through triangulation
- Action Case – Any available archival document relating to the project will be consulted as a means to attain a suitable level of knowledge of the context of the case. They will also be used to validate the findings of primary data through triangulation.

3.6 Ethical Considerations

Throughout the process of the research, the researcher will be cognisant of the various ethical considerations, which may materialise. The main areas in which ethical issues may arise is during the data collection and reporting stages. The researcher is aware that, unless the research is conducted in an appropriate and professional manner, there is potential to cause harm to participants.

To ensure no harm is caused and the research observes a rigorous process throughout data collection and reporting, the researcher will individually address the six areas of ethical consideration, as outlined by Polonsky (2010).

3.6.1 Voluntary Participation

All potential research participants will be accepted on a voluntary basis only. There will be no provision of financial compensation for participation, nor will participants be unduly coerced.

3.6.2 Informed Consent

Prior to formal engagement, all participants will be contacted directly by the researcher to be informed of the requirements and expectations of their involvement. Should the participant be par-taking in an interview which is to be recorded, this will be done so only with the explicit consent of the participant, which will be obtained at least 48 hours before the interview is to take place. Recordings and transcripts will be accessed only by the researcher. Any data emanating from discussions will be treated as confidential and not included in the research without the explicit consent of the participant.

3.6.3 Confidentiality and Anonymity

All participants, both individual and organisational entities, will remain anonymous throughout the research. Exceptions will only be made when referring to organisations taking part in the study, although this will only be with the explicit consent of said organisation. Further, although individuals will remain anonymous by name, a profile may be constructed detailing their position, skills and experience, should it benefit the context of the research.

3.6.4 Potential for Harm

Diener and Crandall (1978) identify several ways in which harm may be brought to participants; physical harm; harm to participant's development; loss of self-esteem; stress; and inducing subjects to perform reprehensible acts (Diener & Crandall 1978). The researcher will take measures to ensure no category of harm is experienced by any participant.

3.6.5 Communicating the Results

Before public dissemination, all research results will be primarily communicated to the participants of the study. Further, any publication of research will be done only with the explicit consent of participants, in a way which does not bring about harm or embarrassment to that individual or their host organisation.

3.6.6 Conflicts of Interest

The research programme is sponsored by the researcher's host company, Frazer Nash Consultancy. Consequently, the researcher will take steps to ensure there are no conflicts of interest throughout the duration of the research. Further, when approaching potential participants, the researcher will be completely transparent as to their employment status, representing both the University of Bristol and Frazer Nash Consultancy. Any commercially privileged information the researcher is made aware of throughout the course of any participant interaction, which may be of particular competitive advantage to Frazer Nash Consultancy will not be reported.

Chapter Four
Industry Case Studies: A Review of Collaborative Technology Developments in Practice

Aspects of research in this chapter have been presented at and published in the proceedings of the 8th Annual IEEE International Systems Conference, SysCon 2014, Ottawa, Canada

4.1 Introduction

This chapter follows on from the theoretical grounding of collaboration, established in chapter two. It presents an assessment of two industry case studies, selected for their application of collaborative principles to support technology development, with the aim of developing a practical framework of best practice. Specifically, the research in this chapter seeks to explore the following lines of enquiry;

- How are collaborations to support technology development formed in industry currently?
- Is there a correlation between academic best practice and current industry best practice?

Case study A presents an industry case study of a collaboration designed to accelerate the development of Unmanned Air Vehicles.

Case study B presents a case study of a collaboration designed to increase innovation in the offshore renewables sector by reducing the cost associated with the production of offshore wind turbines.

Both case studies have been selected based on satisfying the key criteria identified in chapter three. That is, they both represent collaborations of 3 or more organisations, arranged in a formal way for the purpose of developing technology, which are more than 50% through their projected life-cycle. Further, access to all necessary archival information as well as the programme director of both cases has been guaranteed.

To support a structured assessment of each case and ensure a common platform for a cross-case comparison, both case studies are analysed across four main themes. Identified in the literature review as four academic principles of collaboration, the four themes are; Purpose and motivations for the collaborative model; Partner identification and selection; Network structure; Governance processes. Greater detail as to descriptions of each theme and relevant sub-themes are evident in the assessment framework, presented in table 6.

The information, which has informed the development of both case studies, has been obtained from several sources. Archival documents and data were made available from organizations involved in both case studies. This was used to build up an initial overview of each case and provide the researcher with a foundational understanding as to the premise of each program. Subsequently, semi-structured interviews were conducted with the programme directors of both IOC programmes. The themes discussed and the questions posed in the interviews were informed from the academic principles of collaboration, identified in table 6.

Key Themes	*Overview*	*Sub-Themes*
Purpose and motivations for collaborative model	Understand the rationale and strategy behind decision to collaborate. What goals are set individually and collectively for development of tech.	Rationale for collaboration Initial strategy – proposed duration etc… Stakeholder buy in process – collective goal/objective agreements
Partner Identification and Selection	Understand the process of identifying and selecting relevant organisations to participate in the collaborative model.	Method for relevant organization/stakeholder identification and selection – capability. Appreciation for capacity to work in collaborative model.
Network Structure	Understand how the collaboration is structured to deliver against the agreed strategy and objectives.	Collaboration structure and management Facilitator? Individual enterprise? Methods of communication Infrastructure
Governance Processes	Understand what governance processes were used to facilitate the organisations collaborating in reality, highlighting drivers and barriers along the way.	Barriers and drivers throughout process How roles of differing organisations complimented each other through out Organization hierarchy – affect collaboration? Line of command? Problem structuring – which organization tackles what? Coping with shifting requirements?

Table 6: Assessment Framework

4.2 Case Study A: ASTRAEA

4.2.1 Introduction

ASTRAEA (Autonomous Systems Technology Related Airborne Evaluation & Assessment) is a collaborative civil aviation initiative aimed at enabling the routine operation of unmanned air vehicles (UAVs) in non-segregated airspace. The fundamental aim of the programme is to support the integration of UAVs into the existing manned aviation environment, without compromising current levels of safety.

Developed in 2005, ASTRAEA primarily consists of seven industry partners. However, at it's peak, the ASTRAEA programme has comprised over 70 organisations from an assortment of industrial backgrounds, working collaboratively to mature UAV technology.

In March 2013, ASTRAEA achieved their primary goal, when for the first time, an unmanned air vehicle flew in UK manned airspace, above the skies of Scotland. The case study is set out according to the assessment framework outlined in table 6.

4.2.2 Purpose and Motivations for Collaborative Model

The primary purpose of the ASTRAEA programme was to develop UAV's to a point where they can be successfully, commercially integrated into an existing manned aviation environment, without compromising the current levels of safety. At the time of the formation of the collaboration, the technology to support unmanned aerial vehicle flight existed at a proof of concept stage, or TRL 5. The aim then was to mature this technology to TRL 8/9 through a collaborative model of technology development.

To support the maturation of the appropriate technology, three key objectives were developed;

- Enable routine use of Unmanned Air Systems in all classes of airspace, without the need for restrictive or special conditions of operation

- Develop and demonstrate key technologies and operational procedures required to open up the airspace
- Develop key areas of regulatory framework

The initial concept for ASTRAEA stemmed from industry. Representatives of the seven core industry partners, connected through already established professional relationships and networks, held informal discussions across a timeframe of six months. During this period, they each recognised that the immaturity of UAV technology was negatively impacting the UAV market in the civil aerospace sector. Further, at the time it was predicted that within 5 – 10 years, the demand for UAV technology was set to increase dramatically. However, it was also noted that UAV technology was not maturing at an appropriate rate to meet that anticipated demand. Specifically, the technology was not close to being commercially available.

As a result, the seven partners concluded a way to accelerate the maturation of UAV technology was to form a collaboration; ASTRAEA. Through such a model, the partners noted they could 'pool' their resources and technical expertise to accelerate the commercialisation of UAV technology, whilst also reducing the financial risk to each of their individual businesses. They were further motivated by the notion that the strong market positions held by each of the core partners would likely support a 'technology push' of the technology, further driving up demand.

"A huge motivation for everyone to be involved with this was the understanding that developing this technology collectively would not only reduce individual exposure to risk, but also make it significantly more likely that the technology would become commercially desirable by utilising the market positions of all the companies involved." (ASTRAEA Programme director)

The formal arrangement of ASTRAEA originated when the partners addressed the theme of financial funding. It was recognised that as a future growth area, UAV's represented a potential benefit for both the private and public sector.

Consequently, as a condition of the consortium progressing, it was decided the programme should be part funded by the UK government. An application to the UK government was subsequently made, requesting for 50% match funding to be granted.

The initial request was for £70m, which was to be spent over a period of eight years and split between the seven core partners. As part of the request, each partner guaranteed to match any contribution they received. Whilst the UK government accepted the terms of this 50% funding model, realising the benefits that would stem from the UK being associated with pioneering UAV development within the civil market, they suggested a £35m contribution for four years. This would then be reviewed towards the end of the four-year period and should suitable progress have been made, a further £35m would be provided for the remainder of the programme.

Without the financial input from the UK Government, it is highly unlikely the ASTRAEA programme would have ever progressed past the concept stage. Similarly, it was recognised that if any of the seven partners had approached the UK Government individually, in an attempt to secure funding for their own personal development of UAVs, the chances of securing funding would have been significantly reduced. Consequently, a prime motivation for the formation of ASTRAEA was to further reduce the risk of UAV technology development through the support of public funding.

"We recognised the power we had. We were seven large, global organisations, offering to collaborate in the pursuit of a new technology. If we had approached the Government individually, we could never have justified that we possessed the necessary technical skills or even the resources to attempt such a programme. They would have laughed us out the door. However, together, we absolutely could…….If we hadn't have been granted funding, we still would have pursued UAV technology development - it was and is an emerging market – but we wouldn't have done it collaboratively. It would have continued as it was, each company working individually, unlikely communicating with each other in any sensible way to protect

IPR. We would not have made the progress we have made through that approach." (ASTRAEA Programme Director)

4.2.3 Partner Identification and Selection

The core collaborators which comprised the ASTRAEA model consisted of seven main industry partners; AOS, BAE Systems, Cassidian, Cobham, QinetiQ, Rolls-Royce and Thales. To identify and select these partners, no formal process was utilised. Instead, the partners assembled based on pre-existing relationships, predominantly professional and the shared aspiration of further developing UAV technology.

Aside from the core technical collaborators, ASTRAEA also benefited from public funding partners. As stated earlier, ASTRAEA received £70m funding from the UK Government, across an eight year, two-phased period. Initially, the financial partners consisted of several local community partnerships, Scottish Enterprise and the Welsh Government. However, between phases one and two, the local community partners became victim of a UK governmental change in the UK. This partner was subsequently replaced by the Technology Strategy Board (TSB), a UK government organisation, designed specifically to support the development of innovative technology in industry.

The change of partners caused significant problems for ASTRAEA. The relationships established with the local community partners were no longer present and thus the previously agreed continuation funding for phase two was now subject to a new approvals process. This was also set against a backdrop of the global recession and a UK Government, focussed on a mandate of austerity and severe spending reductions. Further, the development of ASTRAEA throughout phase one had not progressed as anticipated.

Although the programme had made significant technical advances, ASTRAEA was struggling to demonstrate the impact of the developments due to existing aviation regulations. Specifically, testing of UAVs was significantly restricted. Consequently, ASTRAEA were not meeting their ultimate goal of integrating UAVs into manned airspace. From the UK Government's perspective, this meant they were not satisfying the conditions of acceptable progress and thus were not to receive further funding.

To address this issue, ASTRAEA contracted an eighth "core collaborator", the civil aviation authority (CAA). The CAA are the UK's regulatory body for civil aviation. Although they had already been part of the ASTRAEA programme for the previous four years, this had been working in a sub-contractor capacity. Further, they were only consulted once technical changes and developments had been made. The new proposal was that ASTRAEA would work collaboratively with the CAA, ensuring any future developments would correspond to existing legislation, or where not possible, legislation could be addressed at a much earlier opportunity. The anticipation was this would maximise the chances of the developed UAV technology being allowed to be tested in manned airspace. The inclusion of the CAA was a success and the revised consortium were granted £35m for phase two.

"…I can't remember who exactly had the idea, but we were at an almost crisis point half way through. We hadn't made a tremendous amount of progress in terms of demonstrating impact and were trying to secure the next phase of funding. On top of that, the local government partnerships, who originally invested in us ceased to exist due to the change in government – who were cutting funding left, right and centre due to the recession. We needed a new approach to demonstrate how exactly we were going to ensure maximum impact of UAV integration. That's when we realised that the technical challenge was no longer the problem – it was now a regulatory issue. As a result, we approached the CAA to have them on board to assist with the next phase of development. This ultimately secured our second round of funding" (ASTRAEA Programme Director)

ASTRAEA also benefited from many other organisations throughout the eight-year period. At it's peak, ASTRAEA consisted of 77 organisations, from an assortment of backgrounds, all working towards the single aim of progressing UAV technology. However, rather than forming part of the core collaboration, these other collaborators represented "secondary" partners. They were identified and selected in a much more traditional way, usually directly through individual primary collaborators ie BAE.

4.2.4 Network Structure

The structure of the ASTRAEA collaborative model was very specific, intentionally designed to support the key aims of the programme. Consisting of seven core industry partners, the general structure was one of a "hub and spoke" model (see figure 10). At the centre of this model was the programme director, who's responsibility it was to oversee the programme from a non-bias, objective standpoint. Immediately adjacent to the director were the seven core partners. Forming the "hub" of the model, the seven partners were governed through a facilitative process, led by the programme director.

To support a more effective delivery of the key objectives, the collaborative model was split into four specific technical streams; Autonomy and Decision Making (ADM); Ground Operations & Human Systems Interaction (GOHSI); Communications, Security and Spectrum (CSS); and Sense and Avoid (SA). Each of the technical streams represented a particular technical area, which required specific attention to support the continued development of UAVs. To maximise efficiency of the approach and minimise disagreements between the collaborating organisations, each of the partners were permitted to occupy only one of the technical streams. Consequently, the ADM, CSS and SA streams comprised of two organisations in each, whilst the GOHSI stream was represented by the remaining partner.

The aim of creating four distinct technical streams was to enable "dedicated development paths" for specific aspects of the technology. It was also intended to allow each organisation to focus on a technical aspect, which was most suited to their core business. This had two benefits. Primarily, it would support the ASTRAEA model in developing key areas of UAV technology deemed 'immature' by allowing industry experts in each technical field to address the key problems. Second, it would allow each core partner to focus on developing an aspect of the technology which also complimented their core business objectives, enhancing their own market position in that area and thus maintain their commitment to the programme.

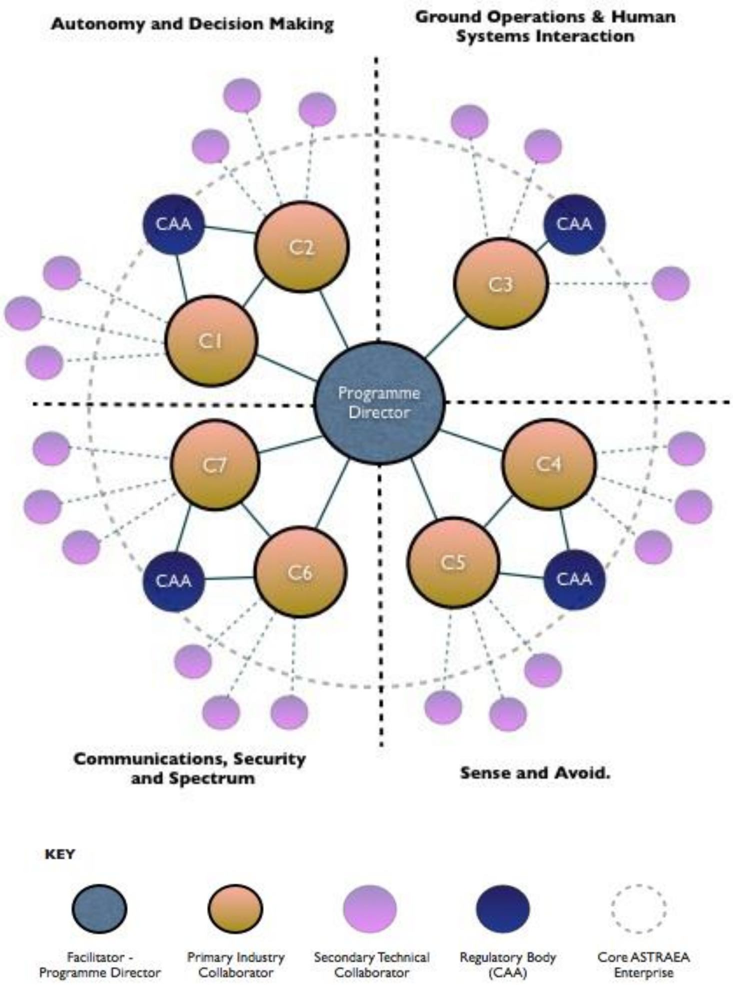


Figure 10: Overview of ASTRAEA Collaborative Structure

A further purpose for separating the model into independent development paths was to ensure specific aspects of each technical problem could be addressed. To support this, decisions as to the direction each technical stream could pursue were allowed, to a certain extent, to be taken at the technical stream level as each organisation were allowed to lead their own technical projects. As a result, each partner could more easily sub-contract specialist support from industry, supporting a much wider engagement of secondary collaborators. Further, it also allowed each partner to protect their intellectual property rights (IPR), constituting a further benefit of the approach and something deemed crucial to the successful continuation of the collaborative model, as noted by the programme director.

"there were many reasons why we chose the four technical streams. Ultimately though, they represented the four key areas, which needed to be addressed. They also represented key areas, which our core collaborators had individual incentives to pursue. Consequently, we deemed it a win-win to structure the model in this way….By allowing each organisation to only focus on an individual stream, it allowed each company to maintain a level of 'secrecy' about their technical developments and protect their individual intellectual property rights." (ASTRAEA Programme Director)

Whilst the spoke aspect of the model undoubtedly supported the tactical delivery of the technical requirements of the programme, the central hub model provided the strategic direction. Through structuring the model around a central facilitator figure, it maintained possible to consistently engage with each of the seven core partners, meeting regularly to discuss progress and development issues. Further, although tactical delivery decisions could be taken at the technical level, key strategic decisions had to be taken at the central level, with unanimous agreement from all parties. Such an approach was designed to prevent individual organisations pursuing technical issues not deemed a 'priority' to the ASTRAEA programme, maintaining the 'balance of power'.

The central hub of the model also provided a platform for innovation to flourish, by enabling partners from across the aerospace industry to exchange knowledge and ideas. Further, it also fostered the building of trust between the core organisations, firms traditionally highly protective of sharing information with entities they would naturally perceive as potential competitors.

4.2.5 Governance Processes

The key governance process adopted by the ASTRAEA programme was the use of a central programme director, complementing the chosen structure. Responsible for setting the overarching strategic direction and ensuring progress was maintained, the PD acted more as a central facilitator figure, than an authoritarian leader. Maintaining an un-bias, independent perspective, the PD provided a central point of contact, responsible for establishing and maintaining communication between the primary collaborators, as well as providing independent views on paths forward and development stream decisions.

Adopting such an approach to governance enabled all strategic and tactical objectives of each technical stream to be discussed and agreed with all seven partners, ensuring consistent adherence to the overarching ASTRAEA goals. Further, by acting as a facilitator, the PD was able to effectively govern and mediate the balance of power within the group. Specifically, to protect against any one company using the ASTRAEA programme for personal strategic gain, specific development objectives had to be discussed and agreed by the majority of partners. In situations where two partners competed over responsibility for leading a single development objective, the programme director would mediate a suitable solution. Once agreed, each organisation were then able to lead their own technical projects individually, responsible for selecting and managing appropriate sub-contractors as part of their technology development stream.

As illustrated earlier, utilising this independent approach for specific technical development ensured that each of the partners were the centre of their own development area, enhancing the potential for innovation to occur. It also enabled intellectual property to be contained within each company, easing tensions and fostering trust, further aiding the collaborative effort.

Whilst each technology stream followed its own development path, the high level goal meant all were progressed with airspace integration of UAVs in mind. Consequently, communication between the partners proved key throughout the ASTRAEA programme. Review meetings were held by phone every two weeks, whilst face to face progress meetings held quarterly. A responsibility of the PD to organise and chair, the meetings proved to be imperative to the continued success of the collaborative model. Specifically, the quarterly meetings proved to be or particular significance. Rotating the location each time, enabling a different partner to host the session, the face to face meetings became opportunities for building relationships between key actors within each organisation, fostering the growth of trust. The change of location also promoted a transparency between otherwise incredibly secretive organisations. To safeguard against the host company, non-disclosure agreements (NDAs) were signed by all partners. However, the simple act of each partner 'opening the doors' of their 'home' had a significant positive effect on the collaboration, something noted by the ASTRAEA PD.

"We would change the location of the quarterly meetings each time. Initially, we decided on this to reduce the travel burden of our partners and also balance the responsibility of hosting. However, it had a much more significant impact. After several sessions, people began to become much more open. Hosting organisations took it as an opportunity to show case other projects they were working on, stimulating discussion. The topic of discussions became much more honest and I had several people remark they couldn't believe that company x or company y had invited them into their offices. I mean these were companies that historically have fallen out over the smallest of things, working in an industry infamously secretive. Hosting the meetings at the offices of each partner changed that mentality; it had an incredibly positive bonding effect, which strengthened the collaborative." (ASTRAEA Programme Director).

Establishing over-arching objectives provided a top-down strategic approach to identifying key areas to address in order to maximize the chances of UAV integration. It also ensured all research contributed to the primary ASTRAEA objectives, providing added security to investors.

4.3 Case Study B – Carbon Trust Offshore Wind Accelerator Programme

4.3.1 Introduction

The second case study assesses the Carbon Trusts Offshore Wind Accelerator (OWA) program, a joint industry project with the objective of reducing the cost of offshore wind by 10%. The fundamental aim of the programme was to enhance the development of offshore wind technology by encouraging innovation across five key technical areas to a point as so it can support the delivery of a 10% reduction in cost.

Developed in 2010, OWA consisted of nine industry partners and was led by the Carbon Trust, although in total the number of organisations working on the programme has exceeded 100.

Although this case study was undertaken in early 2013, it is understood by the author that in late 2015, the OWA programme realised it's vision across the five technical areas, managing to reduce the associated cost of offshore wind technology by the targeted 10%. The case study is set out according to the assessment framework outlined in table 4.1.

4.3.2 Purpose and Motivations for Collaboratve Model

The primary purpose of the CT's OWA project was to reduce the cost associated with offshore wind energy by 10% by the year 2015. It was commissioned in response to the UK Government's (now defunct) Department for Energy and Climate Change's (DECC) growing concerns regarding the resilience of the UK's power supply and the associated benefits of moving towards a more diverse, renewable energy future. The project was considered of "strategic importance" in the UK's pursuit to meet the EU's 15% renewable energy target, viewed as a catalyst to support further innovation in the offshore wind sector, facilitating the 9-fold increase required in offshore energy production over the subsequent decade.

The project was led by the Carbon Trust, an independent, not-for-profit organisation, who were both motivated and selected to be involved based on their core mission; to accelerate a move to a sustainable, low-carbon economy. Specifically, the CT envisioned the OWA project as a way of accelerating the move towards this future, supporting the delivery of three key benefits;

- A 7% reduction in UK carbon emissions versus the 1990 levels
- 250,000 UK jobs created by 2050
- Annual revenues of £19 billion by 2050

The CT identified offshore wind as the most effective and efficient way to deliver the above benefits. However, they also noted that order to do so, specific risks associated with the development of the technology would need to be reduced along with the cost of offshore wind turbine production. As a result, the OWA project was initiated.

"The OWA project came about as we recognised the potential of offshore wind to significantly and positively impact the renewable energy make-up of the UK's energy supply. Based on our assessments there was so much untapped energy just off the coast, which was not being captured effectively. However, we also realised that in order to increase offshore wind supply, there were significant improvements to be made regarding the current risks and costs associated with development. Consequently, we set up the OWA programme to specifically address these issues" (CT Programme Director)

The motivations to pursue offshore wind development as a collaborative venture stemmed from the CT's status as a not-for-profit advisory organisation and not an engineering organisation. Specifically, the CT lacked the capabilities and necessary resources to pursue this alone. Consequently, they identified that through a collaborative model, they could provide support to industry organisations who did possess the necessary skills and experience, benefiting from the pooling of their resources.

Although the primary driver behind the formation of a collaborative model was to address environmental concerns and the pooling of resource, the CT also had a further motivation; return on investment. Specifically, in order to encourage industry organisations to partner with them, the CT were offering to part-fund the venture in a 33% : 66% split. In this funding scenario, the CT would provide 33% of the necessary funding, on the premise that the industry partner would provide the remaining 66%. However, far from being an altruistic move on behalf of the CT, the CT calculated that they would eventually benefit from this investment in an ROI ratio of 12:1.

4.3.3 Partner Identification and Selection

The core collaborators which comprised the OWA programme consisted of nine developers; Dong Energy, E-On, Mainstream Renewable, RWE, ScottishPower Renewables, SSE Renewables, Statkraft, Statoil and Vattenfall. To identify and select these partners, no formal process was utilised. Instead, partners were assembled based on the knowledge and pre-existing relationships of CT senior management. Specifically, senior members of the CT approached the majority of core organisations, based on their involvement with prior CT projects. The only metric used to assess their suitability for partnership was the presence of a shared common goal focussed around enhancing the development of offshore wind technology.

"Formally, we didn't really use any sort of approach to identify who we wanted to work with. We had decided our goal was to improve the opportunities for renewable energy development. We knew of several large companies who worked in that area and had worked with us previously and so approached them. We thought we were in a pretty good position in terms of what we were offering. All we sought in return was that the organisation shared in our vision; that they were motivated to innovate in this area and wanted, like us, to enhance to development of offshore wind technology." OWA Programme Director

Aside from the core collaborators, the OWA programme also utilised the skills and resources of other, more technically focussed organisations, to support the development of specific technical streams. In these instances, a more formal approach to partner identification and selection was employed, specifically through a traditional tendering process. Whilst less emphasis was placed on the need to buy into the "shared vision" here, an external technical consultant was employed to manage the process, in order to ensure technical quality.

4.3.4 Network Structure

The structure of the OWA collaborative model was intentionally designed to support the key aims of the programme, based on the composition of organisations collaborating. Consisting of nine core industry partners, the general structure was one of a "hub and spoke" model (see figure 11). At the centre of this model was the Carbon Trust, who assumed the role of programme director and facilitator. It was their responsibility to oversee the programme from a non-bias, objective standpoint. Immediately adjacent to the director were the nine core partners. Forming a primary steering committee grouping or the "hub" of the model, the nine partners were governed through a facilitative process, led by the Carbon Trust.

To support a more effective delivery of the key objectives, the collaborative model was split into five key technical streams; Foundations; Access Systems; Wake Effects; Electrical Systems; and Cable Installation. Each of the technical streams represented a particular technical area, which required specific attention to support the enhancement of offshore wind technology. As each of the core partners had a vested interest in the technical development of each stream, a second steering committee was developed in each technical area. This was formed of technical representatives from each of the nine organisations, specialists in that technical discipline. It also comprised of a CT member and an employed external technical consultant, who would take responsibility for the delivery of the stream objectives.

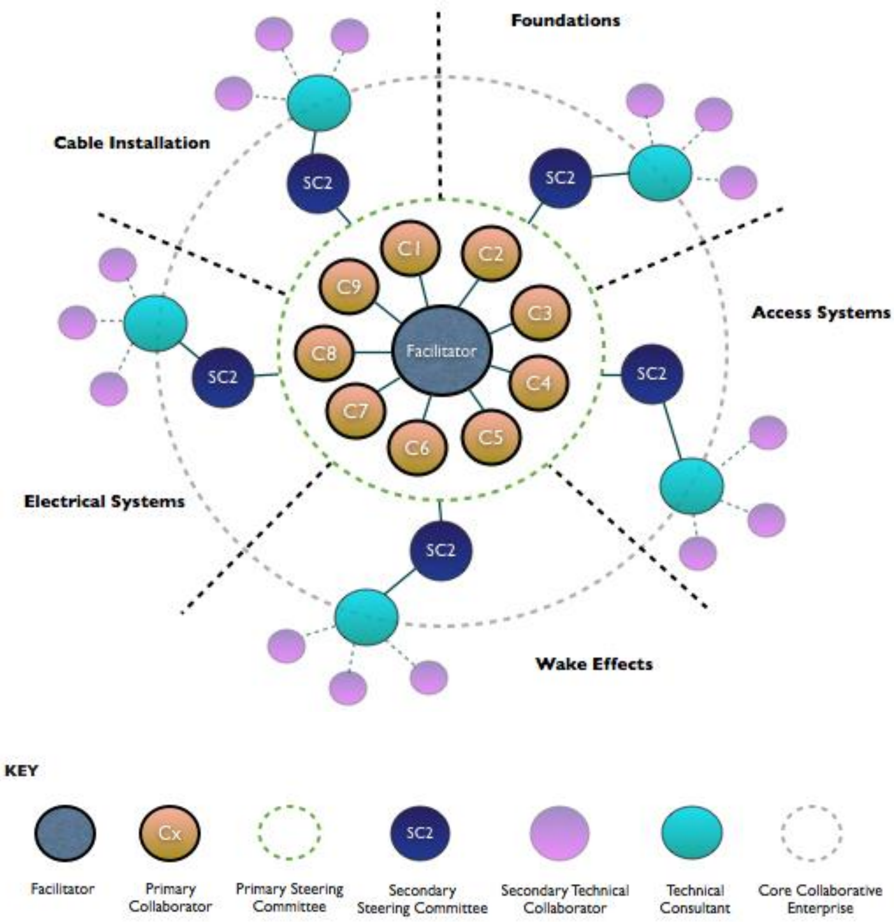


Figure 11: Overview of OWA Network Structure

The intention behind this design was to ensure all core members maintained motivation for involvement and had access to the technical innovations occurring, as to not give one particular company an advantage. The creation of five technical streams, led by a second steering committee enabled several benefits. Notably, it enabled each of the technical areas to benefit from the input of nine developers , fostering greater discussion around the development of objectives and specific projects that should be sanctioned in order to enhance the technology in each of the areas. Once a project had been decided upon, a technical delivery consultant was employed to manage the process enabling technical issues to be addressed efficiently, maximising engagement across industry and ensuring the "most appropriate people" were employed to support. Essentially, the structure was designed to promote communication and trust centrally, whilst allowing the programme to deliver efficiently when addressing specific technical concerns, as explained by the OWA PD.

"The structure was developed based on who we had as part of the collaboration and the issues we thought needed to be addressed. At the centre was ourselves and the nine organisations we were working with. Together we formed the central leadership group. Out side of this, we identified five technical areas, which we needed to focus technical skills on. As each of the nine companies had an interest in all five technical areas, we created a second steering committee. This was formed of a CT representative but also a technical expert from each of our core collaborators. They then set the direction for each stream, passing on the directions to a technical consultant, who was employed to manage the supply chain and coordinate the project based on that guidance. We thought the structure simplified our approach and made sure everyone was happy and retained some level of involvement. From our perspective (CT) it also ensured that people who knew what they were doing were allowed to address the technical issues….because that definitely would not have been us"

4.3.5 Governance Processes

The key governance process adopted by the OWA programme was the use of a central programme director, supported by two programme officers, all of which were employed by the Carbon Trust. The three CT members occupied a position at the centre of the collaborative approach and formed part of a steering committee, which was also has representation from a single member of each of the nine core partners. Responsible for setting the overarching strategic direction and ensuring progress was maintained, the steering committee was led by the PD who acted more as a central facilitator figure. Maintaining an un-bias, independent perspective, the PD provided a central point of contact, responsible for establishing and maintaining communication between the primary collaborators across the steering committee.

Adopting such an approach to governance enabled all strategic objectives of how the OWA programme could best progress to be discussed and agreed with all nine partners, ensuring consistent adherence to the overarching OWA goals.

As each of the nine core partners had a vested interest in the technical development of each of the five streams, five second steering committees were also created. Sitting just outside of the primary steering committee, the second steering committees were comprised of a CT representative, a technical expert in that area from each of the core partners and a technical delivery consultant (TDC), who was external to the OWA programme and an expert in that specific technical area. The secondary steering committees were led by the TDC, which ensured they progressed in way which could not be manipulated by any of the core partners for individual gain. Further, the use of a TDC permitted a more expansive exploration of each technical area and the inclusion of a wider stakeholder group in terms of second and third tier suppliers, which were managed through the TDC, minimising the risk to the core partners. The OWA PD described the approach to governance as follows;

One of the issues we had early on was that each of the core partners wanted to be involved in the development of each of the technical streams. As there were five key technical areas identified, all of which focussed on a separate technical aspect, we were unsure as to how it would work. Eventually, we decided to form secondary steering committees, on which, each partner could have a single representative to advise on the approach that stream should take. To avoid any one company trying to use a stream to their advantage, we agreed that the secondary technical streams should be led by an external technical delivery consultant; someone who did not have an investment in the strategic development of the programme, but who possessed the appropriate skills and experience to lead that particular technical stream. The partners were happy with this approach and it allowed for each stream to better explore the specific problems encountered by each technical aspect as well as effectively govern themselves, with updates provided back to the primary steering committee to ensure they we were all moving in the right direction" OWA PD

4.4 Cross Case Analysis

This section looks to compare the two case studies through an analysis of the key themes. It seeks to understand if the themes identified in the literature have played a significant aspect in the development of the industrial collaborations. It also identifies themes not highlighted from the literature review.

4.4.1 Purpose and Motivations of Collaboratve Model

The literature review indicated that considering the purpose of a collaboration should be a primary consideration when deliberating such an approach. Upon reviewing the two cases here, it becomes clear that this proposition stood true. For ASTRAEA, the purpose considered was to develop UAVs to a point they are commercially incorporable into existing manned airspace. For OWA, the primary purpose was to advance offshore wind technology sufficiently, as to bring about a 10% reduction in the associated production price. From this it becomes apparent that, although clearly different in their detail, both cases shared a generic reason for adopting a collaborative model; to accelerate the maturation of a technology, in order to enhance its commercial viability. Such a reason reflects much of the extant academic theory identified in chapter 2 (Hagedoorn 1993; Powell et al. 1996; Dodgson 1993), providing further evidence to support such propositions.

Furthermore, the identified purpose of both cases was "bought into" and "agreed" by all core partners. This is something noted by both programme directors as an important step to building a collective understanding of the value of the collaborative model.

"The purpose was agreed with all of the core partners. Everyone agreed on this focus, which allowed us to move forward on a collective front." (ASTRAEA Programme Director)

"All of the core partners were invested in addressing the problem of climate change. They were passionate about reducing carbon emissions and wanted to support the evolution of renewable energy. (Consequently) they bought into our identified purpose and were happy to work towards our goals. This was important." (OWA Programme Director)

Buying into a shared purpose and sharing this notion is again identified in the literature as important to ensuring a successful collaboration (Huxham 1996; Gray 1985; McCann 1983).

In terms of motivations for pursuing a collaborative approach, both cases shared several. Notably, both identified the benefit of pooling the technical resources of multiple organisations to support the increased opportunity for innovation and reducing the individual risk associated with development. Such motivations were again evident in the literature review. However, closer analysis reveals several motivations not identified in the literature as well as differing reasons across both cases.

Specifically, the motivation of a financial 'gain' was a prominent driver behind the formation of ASTRAEA. In fact, as stated by the programme director, ASTRAEA was "highly unlikely" to have ever progressed in any formal capacity, should it not have received public funding. Further, the programme director states that each of the seven core partners were "aware" of their market position and thus negotiating "power" when talking to the UK Government collectively, whilst understanding the likelihood of "being laughed out the door" should they have requested financial support individually. Such a statement raises significant questions. Not least, it questions whether access to public funding was a motivator for all partners, or just some. Further, if the promise of financial gain was a motivation for all partners, could this then constitute the primary purpose of forming a collaborative approach?

Answering this question definitively in this study is not possible as interviews with each partner were not conducted as deemed out of scope of a network-level analysis. Consequently, offering conjecture as to which one is more likely would not be useful. However, what this analysis does identify is there was a positive financial driver, which undoubtedly played a part in the formation of the collaborative approach. This is something not explicitly identified in the literature. Further, the question of whether accessing such a funding mechanism was a motivator or purpose of the collaborative approach highlights the interplay between the two. It also raises questions around the individual perception of motivation ie from the ego-level and the impact this could have on the network level outcomes. For instance, do the motivations of all egos have to align for a successful network outcome? Or is it sufficient for each ego to agree on the purpose of a collaboration but retain individual motivations?

The motivation of financial gain was also present in the OWA case. Similar to ASTRAEA, OWA was partly funded by the UK Government. However, whereas ASTRAEA funding was split 50:50, OWA was split 33:66, with the Carbon Trust responsible for the third. It should be noted that there were key contextual differences which underpinned this financial model. For instance, OWA was formed by the CT as a response to the UK Government's commitment to reduce carbon emissions by 2020, an environmental goal, and subsequently approached industry for support, which is the opposite to ASTRAEA. However, what is common is that the CT were similarly motivated by a financial return. Specifically, although offering industry partners 33% of the cost, they expected to receive, at minimum, a "12:1" return on that investment.

Consequently, it should be considered that the funding mechanism and perceived economic return play significant motivational roles in the establishment and design of technology development collaborations. However, the influence of the financial driver should not detract from ensuring understanding of purpose is aligned.

4.4.2 Identification and Selection of Partners

The methods and approaches adopted by each collaborative programme to identify and select the core industry partners differed considerably in terms of execution and formality. Whilst ASTRAEA was industry led, with an inner core of collaborators comprised through informal conversations and pre-existing professional networks of individuals, OWA was formed through a public sector tender, led by the Carbon Trust (CT), a governmental organisation. Although there were pre-existing professional relationships present in OWA, they were used as 'marketing' pathways through which the premise of the programme and existence of the tender were communicated. They were not used to informally establish the collaborative approach, as was the case with ASTRAEA.

Despite the differences in terms of formality of the partner selection approach, the requirements and reasons underpinning the selection of collaborators were remarkably similar in both cases. Specifically, the selection of core partners in both cases revolved around satisfying two general requirements;

- That each partner shared in the purpose and objectives of what the collaboration was formed to do; and
- Each partner was willing to contribute the necessary resources and financial funding, in order to secure

The insistence on all core partners sharing in the purpose and objectives of the collaboration is well established in the extant literature (Huxham 1996; Gray 1985; McCann 1983), as highlighted in section 4.4.1. However, the requirement for core partners to consider and agree upon a fixed financial model, whereby each must contribute a stipulated value, or indeed consideration of the impact a financial model may have upon the selection of partners, is not something explicitly explored within the current body of knowledge.

Similar to the selection of core partners, the approach to selecting secondary collaborators also differed in both cases. ASTRAEA allocated the responsibility to each of the core partners, to individually identify and select secondary partners as they deemed appropriate. Such a move complimented their structure whereby each partner occupied an individual technical stream. However, the OWA approach differed. In the OWA case, a technical consultant was primarily recruited to lead each of the technical streams. This is because the core partners each had a vested interest in the development of each technical stream. Consequently, each organisation were represented in all of the five OWA technical streams, not just one. To maintain a collective approach and protect against individual partners taking advantage of a specific stream, a technical consultant was identified to lead. Acting as an objective, informed lead, it was then the technical consultant's role to contract secondary partners to assist with the collective development of each technical stream objectives.

However, despite the differences in approach, there were again strong correlations between the requirements and reasons underpinning the selections. Consequently, with such strong correlations across both cases one may theorise that, whilst the approach or 'method' of identifying and selecting partners may take multiple forms, the reasoning and requirements used to evaluate the potential partners must remain consistent, in order to maximise the opportunity for a successful collaboration.

The distinction of approaches to the selection of core partners and secondary partners highlights a further similarity between the two cases. That is, the categorisation of partners. Specifically, from analysing both cases, it is clear there were four types of partner; Core technical partner; Secondary technical partner, Financial partner; and Regulatory partner.

Whilst the importance and role of multiple technical partners within a collaboration has been explored in the current literature (Hagedoorn 1993; Hagedoorn 1995; Ortiz-Gallardo et al. 2010), categorising partners in terms of their financial or regulatory contribution has not. The researcher finds this of particular interest, given the pivotal role both category of partners played in each of the cases presented. In particular, the regulatory partners were instrumental in the development of ASTRAEA and OWA. For ASTRAEA, the regulatory partner was the CAA, whose inclusion secured the second phase of funding as well as advising on the development of technical streams as so to ensure the technology complied with current regulation. A similar role was played by OfGem in the OWA programme, who ensured that any new technological developments were in line with UK regulations. The role of the financial partners in both cases has already been highlighted earlier in this section and in section 4.4.1.

Consequently, it must be considered that, in the context of developing technology collaboratively, there should be some consideration given to partners falling under the four categories, in order to maximise the opportunity for success.

4.4.3 Network Structure

The literature review indicated that extant research into the formation of collaborative structures to support technology development has largely focussed on quantitative forms of analysis (Provan et al. 2007). Traditionally, such analyses have been conducted on well established collaborative networks, concerned with how characteristics such as density and centralisation impact upon the effectiveness of said network. Minimal research exploring the approach taken in the early stages to *design* and *establish* such collaborative structures exists. Consequently, in terms of informing the analysis, the literature does not offer much theoretical guidance in terms of a preferred structural approach to the design of a collaborative structure.

Interestingly then, both cases seemed to adopt a remarkably similar approach. That is, both cases sought a structure, which supported the collaborative delivery of their key objectives and designed it through a series of formal workshops with the input of all core partners. Such input was deemed vital in ensuring that all key members were actively engaged with the chosen structure.

The output of the workshops specified the requirements for the structure and outline design. The key requirements identified were for a structure which had the capacity to be "flexible" and "adaptable", promoted "central leadership" of the programme but not in a way which inhibited the relevant "experts" addressing specific problems with a degree of "freedom" and "autonomy". Both programme directors also indicated that they desired a structure, which promoted transparency and communication as they viewed this as imperative in the development of trust between partners and ultimately, the success of the programme.

The resulting structure, in both cases, was one, which largely resembled a hub and spoke model. In this model, the "hub" acted as the central leadership team, providing strategic direction for each programme and maintaining the development and attainment of objectives. Closely mirroring what the literature describes as a cohesive network (Burt 2004; Nooteboom 1999; Granovetter 1983; Nooteboom 2004), the central hub also facilitated a consistent level of communication between the core partners. In the ASTRAEA case, this allowed the seven core partners to meet regularly, briefing each other of progress and discussing the best paths forward to support the continuation of the programme. As a result, trust between the partners began to develop as the transparency of progress was maintained. Similarly, in OWA, the central hub provided the core partners with a focussed agenda to develop the strategic direction of the programme, with input from all involved.

Whilst the central hub was pivotal in supporting the development and overarching direction of both programmes, it was the allocation of specific technical streams, or "spokes", which allowed for the concentrated development of individual technologies. In both cases several technical streams, identified by the partners in the "hub" as important to the collective cause, enabled the overarching problem to be compartmentalised into specific technical challenges. The categorisation of the problem into distinct technical challenges meant that specific technical issues could be addressed with a greater degree of autonomy, increasing the efficiency with which solutions were generated. In essence, "bridging networks" were created, providing each case with further, unique benefits. In the ASTRAEA case, this benefit stemmed from the core partners being able to independently lead a technical stream. As a result, they became "gatekeepers" of any information generated in their stream, naturally facilitating the protection of intellectual property – an important tenet of the network design. In the OWA case, the benefit of "gatekeeper" did not lie with any of the core partners, but instead with an independent technical consultant, specifically recruited for the role. The impact of this though did have a broader benefit on the programme itself, as it enabled the supply chain of technical experts to be widened significantly, whilst offloading the financial and technical risk associated with addressing complex technical problems from the core partners.

The impact of the collaborative structure in both cases appears to have been positive. As illustrated, the central, cohesive hub allowed for the strategic direction to be outlined and maintained, whilst also promoting communication and trust between the core partners. The spoke aspect of the design facilitated the deconstruction of the overarching problem into manageable technical challenges, enabling a more autonomous pursuit of the solutions. Whilst the benefits of this approach were different in each of the cases, the overarching impact was similar – to increase the efficiency of solution generation in the delivery of the programme objectives.

In terms of informing theory pertaining to the general formation of collaborative structures, although both cases adopted a very similar structure, the researcher does not believe that this should be considered a “silver-bullet” solution for all collaborative technology development ventures. However, the approach taken to develop the structure in each case does lend itself to be generalised theoretically. Specifically, the consideration of the collaborative purpose, defining the leadership strategy, understanding the key technical delivery challenges and involving all key partners in a formal collective decision process would appear to be key factors when designing a collaborative structure. The development of trust and maintaining communication also seemed to be important factors to consider, resonating with a large section of extant literature (Hibbert & Huxham 2010; Huxham 1996; Vangen & Huxham 2003; McCann 1983). Of particular contemplation here is whether communication and trust are to be maximised or contained, as alternative structures will impact such factors in different ways, as illustrated in the mixed structural hub and spoke model adopted here.

A final observation from analysing the two structures is the relationship between the developed structure and the complimenting governance model. This is something expanded upon in section 4.4.4.

4.4.4 Governance

The literature review indicated that, typically, collaborations are governed by one of three mechanisms; self-governance, lead organisation governance and network administrative organisation governance (NAO) (Provan & Kenis 2008). The choice is influenced by several factors, most notably the structure.

From analysing the cases, it’s clear that in both instances, the NAO governance model was applied. Described by McEvily et al as a form of governance in which an independent entity is employed in the role of a facilitator to govern the network

(McEvily et al. 2003), it is a form of governance which promotes communication between collaborators and reduces the complexity associated with shared governance in terms of power dispersal and decision making (Provan et al. 2004).

The role of the lead facilitator in both cases was assumed by the Programme Director. An independent role, this position was responsible for maintaining development of the programme. It also provided a central point of contact, responsible for establishing and maintaining communication between the primary collaborators, as well as providing independent views on paths forward and development streams.

The approach to the choice in both cases stemmed largely from the proposed structure each case had outlined. In each case there was also a secondary governance structure, positioned "lower down" the hierarchy. In ASTRAEA, this was led by a technical team from each organisation. In OWA, this took the form of a secondary steering committee, who informed the development of specific technical streams. The purpose for these secondary mechanisms was to compliment the combined structural approach of the hub and spoke model. It benefited both programmes by providing more detailed guidance and governance by more informed experts in each technical stream, allowing for solutions to be pursued more effectively.

However, the choice was also influenced by the funding structure – something not mentioned in the literature. As both were part publicly funding, there was more of a need to balance the approaches with an independent lead and prevent any one organisation taking advantage of the programme for their own strategic needs.

The independent aspect of the role is something which appears to have been of significance in both cases. Specifically, having an objective leader, in such a large, complex venture allowed for balance to be maintained between otherwise mis-matched organisations and a level of clarity in the direction

Similar to the structure, just because both programmes adopted a very similar approach to governance, it is not to say that this is *the* approach, which should be taken in such contexts. However, it does highlight the key benefits such an approach brings. Specifically, it allowed the central director to strategically lead the programme. It also allowed for them to manage disagreements and maintain the balance of power between the core partners. Further, by remaining objective and independent, they did not have a vested interest in any particular commercial development and so could be counted on to provide objective leadership, again maintaining power balance and trust in the group. Similarly, the management of the technical streams by more interested parties allowed for more focused development to occur. Individual objectives and aims, which complimented the overarching goals but also satisfied the independent needs of secondary collaborators and technical leads allowed the programmes to progress in a much more efficient manner.

A further emergent theme was the formality with which the PD's governed. Regular meetings, both face to face and by phone fostered the development of trust between core partners, supporting the development of the "team".

4.4.5 Other Factors

Several other factors were noted. Some have already been drawn out, but will be summarised below in bullet points

- ***Funding Mechanism*** **–** As illustrated throughout the cross case analysis, the funding mechanism used by each of the cases played a pivotal role in the development and ultimate success of each programme. Specifically, the motivation of financial gain was a significant driver behind the development of ASTRAEA, whilst a return on financial investment also factored heavily in the CT OWA case. Further for the organisations working together, there was the incentive of matched funding; 50% in the ASTRAEA case and 33% in the OWA case. The importance of funding in the development of collaborative approaches is something which does not receive much attention in the extant literature, with even less ascribing significant value to its role in the development of collaborations. Indeed some scholars, such as Hagedoorn and Schakenraad (1993) believe that funding has minimal to no impact upon the development of a collaboration.

However, the author believes the two cases presented here highlight the important role the funding mechanism has in not only the design of a collaborative approach to technology development, but the structure, governance, motivations and maintenance of that collaboration too. Therefore, the author considers this to be an important principle to consider.

- ***Success Requirements*** **–** In both cases, an important approach in the development and maintenance of the collaborative approaches was the development and defining of success requirements. Importantly, this provided the organisations involved with a metric, which could be used to measure the performance and progress of the collaboration. It also created a vision of what the partners were collectively working towards allowing them to “buy into a shared vision”. Further, the identification of individual success requirements by actors involved, enabled them to identify the value of entering into the collaboration and maintained their motivation to remain involved.
- ***Definition of Risk*** **–** Similar to the success requirements, both cases illustrated the importance of defining risks, from a collective and individual perspective. In conversations, both PD’s referenced the importance of being aware of risks to development and effectively mitigating them in order to ensure the collaboration did not suffer.
- ***Collaborative Objectives*** **–** The importance of collaborative objectives is clear throughout both the ASTRAEA and CT OAWA case studies. Specifically, the definition of collective objectives set the tone for both programmes, serving as the barometer to subsequently select partners to support the work. For instance, both PDs mentioned that when selecting partners to become part of the collaborative approach, the key metric used was whether they bought into the vision and identified collaborative objectives of the programme. If they did not then they were not selected.

4.5 Development of a framework for collaborative technology development

Through reviewing the industry case studies, several common principles and key factors to consider when forming a collaborative network were observed. By compiling these factors with those identified from the literature a best practice framework to guide the design and development of collaborative technology development (CTD) has been produced (see figure 12).

The framework consists of eight elements; purpose definition, funding mechanism, partner identification and selection, definition of collaborative objectives, agreement of network structure, selection of governance processes, definition of risks and outline of what constitutes success. Each phase is outlined in the remainder of this section.

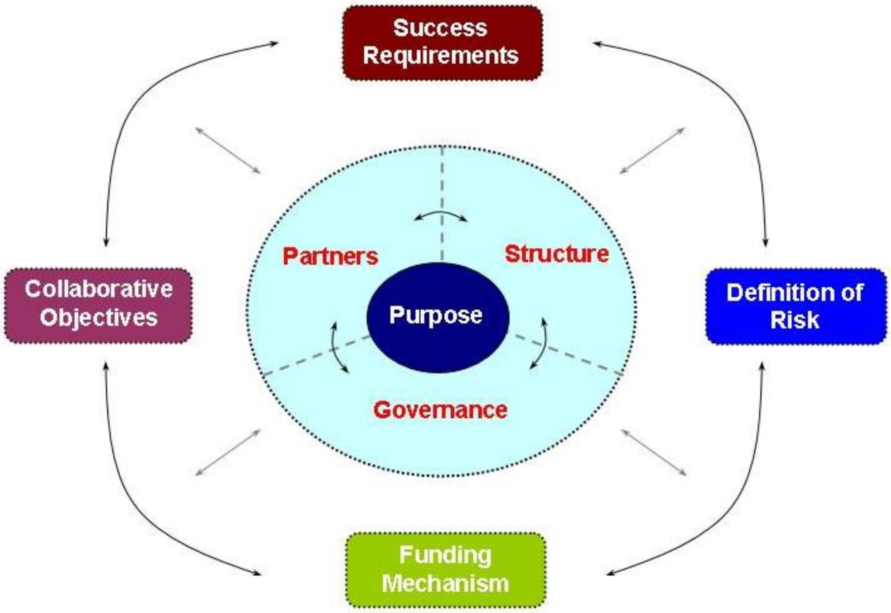


Figure 12: Overview of Framework for Collaborative Technology Development

4.5.1 Purpose

As indicated from the literature and evidenced in the case studies, the primary principle to consider when establishing a collaborative network to facilitate technology development is a collective definition of purpose. Having a clear sense and definition of the problem the collaboration is being formed to address will provide a better indication of the value a collaborative approach will provide. The more nuanced and complex the defined purpose, the greater the impact upon the collaborative design. To maximise the opportunity for success, the defined purpose *must* be accepted by all core partners involved in the collaborative venture.

Within the theme of purpose, consideration should also be given to the key drivers, benefits and motivations of pursuing a collaborative model. Having an understanding of such factors will provide further justification for pursuing a collaborative approach and help to inform further stages of development.

4.5.2 Partners

The partners principle refers to the identification and selection of appropriate collaborators who will support the development of the technology. The approach to selection need not be prescribed, however, for a partner to be useful in the context of a collaborative approach, they must share in the common understanding of what the collaboration is being formed to achieve. Further, they must identify a value in pursuing such an approach and be happy to work in a collaborative environment. Should a proposed partner not meet these two requirements, it is strongly recommended they are not involved as part of the core group of developers.

Aside from the approach to partner selection, consideration should also be given to the type of partner to be selected. Specifically, a partner should be identified in each of the following four categories;

- *Core Partner* – A collaborator who takes on a central role throughout the lifespan of the collaboration. Must be aligned as to the purpose of the collaboration with fellow core partners and see value in a collaborative approach.
- *Technical Partner* – Should be considered a technical expert in the area which they are required to support. Such a partner may be a core partner or a secondary partner, sub-contracted for a specified period of time and not necessarily required for the duration of the collaboration. They should

however be willing to work within the structural model of the proposed collaboration.

- *Financial Partner* – The partner(s) who fund the collaborative technology development venture. This may be a core, or selection of core partners. It may also be an independent partner(s), with a vested interest in the development of the technology.
- *Regulatory Partner* – The regulatory partner represents the body responsible for current legislation in the proposed area the developed technology is to be integrated. Their involvement should be sought to ensure the developed technology may be integrated with minimal *negative* disruption.

Whilst each category of partner must be identified, it is possible for the same partner to assume multiple roles. Further, whilst only four roles are identified here, that is not to say further roles aren't required. For instance, should the technology being developed be more consumer focussed, one would expect a user role to be included. Instead, these four roles are understood to be the absolute minimum required, in order to appropriately reduce the level of risk associated with collaborative technology development.

4.5.3 Structure

Designing an appropriate collaborative structure is imperative to ensuring success when developing a technology. This research has highlighted the differing impacts alternative structures may have on the development of a technology. Consequently, whilst a preferred structure is not prescribed, consideration should always be given to several key factors. These are;

- Collaborative purpose – Although perhaps obvious, the structure needs to complement the identified collaborative purpose. For instance, should the purpose be more focused around the latter phases of development ie commercialisation, an alternative structure may be selected as opposed to if the development were in earlier, more innovative stages.
- Partners – Consideration of the number of partners, as differentiated by their category. A high number of core partners may lend a need for a

greater emphasis on designing in specific communication channels into the structure, in order to promote trust.

- Governance strategy – The structure and governance are inherently inter-linked. Therefore, an understanding of the governance approach to be applied needs to be considered when designing a complimenting structure.
- Technical complexity – Consideration of whether the technical challenges are of sufficient complexity to require separation into specific streams will impact the structure.

Aside from considering the above key factors, efforts to maintain communication and promote trust between partners should be made, as well as avoiding dispersions of power within the core group. To support this, decisions should involve all core partners in a collective decision making process.

4.5.4 Governance

As with the structure, there is no prescribed best fit governance model, which can be applied to all collaborative technology development ventures. Instead the governance model should, first and foremost, complement the chosen structure. Ideally, both the proposed structure and governance for the collaboration will be designed in tandem, minimising the risk of a mis-match. When pursuing this, consideration should be given to the following factors;

- Structure – The governance should take into account the proposed structure and seek to complement.
- Collaborative purpose – As with the structure, the governance approach needs to complement the identified collaborative purpose. For instance, should the purpose be more focused around the latter phases of development ie commercialisation, an alternative governance model, prioritising hierarchy and command may be selected, as opposed to if the development were in earlier, more innovative stages.
- Partners – Consideration of the number of partners, as differentiated by their category. A high number of core partners may lend a need for a

greater emphasis on designing a governance model which supports a greater level of communication.

- Technical complexity – Consideration of whether the technical challenges are of sufficient complexity to require separation into specific streams will impact the governance model. There may be a need for multiple layers of direction and management, in order to promote efficiencies in tactical delivery, whilst allowing for discussion around strategic direction.

Ultimately, the governance model will be chosen based on its ability to satisfy the above key factors. It should also seek to facilitate communication throughout the duration of the collaborative endeavour, fostering the growth of trust between partners and managing tensions and disagreements through the balancing of power between all.

4.5.5 Funding Mechanism

Appreciation of how the collaborative model is to be funded is vital to all phases of the framework. Although not indicated in the literature, a constant theme throughout the case studies was the source of funding and the added motivation various funding models provided. Of particular consideration here is the source of the funding and the structure through which it is to be made available. Divergent funding mechanisms will influence and motivate partners differently.

4.5.6 Collaborative Objectives

An important finding from the research was the benefit of collectively defining objectives. This will set the scope for various aspects of subsequent work and so it is important that the objectives are clearly defined and bounded appropriately.

4.5.7 Success Requirements

From the industry case studies, this was an important factor in the successful collaborative models. Defining success is important to validate the performance of the collaborative model; something not explicitly covered in the literature. It is also important to note that meeting or failing to meet specific objectives may not constitute success. Consequently, care should be taken to refrain from being too prescriptive in criteria. Further, consideration of both collective and individual partners success criteria should be sought – if possible.

4.5.8 Definition of Risk

From the case studies, it is clear that acknowledgement of risk is key to a successful collaborative model. When several partners work together, the opportunity for risks is increased due to the increased complexity of the CTD. Consequently, understanding risks that can be of detriment to the success of the project is an imperative aspect of any technology development program and should be considered as a key component of CTD.

Theme	*Overview*	**Sub-Theme**	*Description*
Purpose	*The purpose forms the core theme when designing a collaborative approach to technology development. Having a clear sense and definition of the purpose the collaboration is being formed to address will provide a better indication of the value a collaborative approach will provide.*	***Complexity of purpose***	Relates to the key drivers and reasons for entering into the collaboration and the interdependencies between them. The greater the complexity of the purpose the greater the impact upon the design and development of the collaboration, specifically around the structure and governance aspects
		Collective acceptance	To maximise the opportunity for success, the defined purpose must be developed and accepted by all core partners
		Motivations	Building on the complexity aspect, the core motivations for pursuing a collaborative approach should be defined, in order to ascertain whether value will be delivered and to influence the design of subsequent themes
Partners	*The partners principle refers to the identification and selection of appropriate collaborators who will support the development of the technology. The approach to selection need not be prescribed, however, for a partner to be useful in the context of a collaborative approach, they must share in the common understanding and perceived value of what the*	***Value perception***	Partner must identify with the value of the collaborative approach and share in that value.
		Common understanding	Partners should demonstrate a common understanding as to the purpose of the collaboration.
		Partner category;	Whilst each category of partner illustrated below should be identified, it is possible for the same partner to assume multiple roles. Further, whilst only four roles are identified here, they are considered the minimum requirement for collaborative technology development. They should not be considered the *only* partners required.

	collaboration is being formed to achieve.	- ***Core***	A collaborator who takes on a central role throughout the lifespan of the collaboration. Must be aligned as to the purpose of the collaboration with fellow core partners and see value in a collaborative approach.
		- ***Technical***	Should be considered a technical expert in the area which they are required to support. Such a partner may be a core partner or a secondary partner, sub-contracted for a specified period of time and not necessarily required for the duration of the collaboration. They should however be willing to work within the structural model of the proposed collaboration.
		- ***Financial***	The partner(s) who fund the collaborative technology development venture. This may be a core, or selection of core partners. It may also be an independent partner(s), with a vested interest in the development of the technology.
		- ***Regulatory***	The regulatory partner represents the body responsible for current legislation in the proposed area the developed technology is to be integrated. Their involvement should be sought to ensure the developed technology may be integrated with minimal *negative* disruption.

Structure	Designing an appropriate collaborative structure is imperative to ensuring success when developing a technology collaboratively. Whilst there are no prescribed structures one should follow, attention should be given to the sub-themes identified here	*Collaborative purpose*	The structure should seek to complement the identified collaborative purpose. For instance, should the purpose be more focused around the latter phases of development ie commercialisation, an alternative structure may be selected as opposed to if the development were in earlier, more innovative stages.
		Partners	Consideration of the number of partners, as differentiated by their category. A high number of core partners may lend a need for a greater emphasis on designing in specific communication channels into the structure, in order to promote trust.
		Governance	The structure and governance are inherently inter-linked. Therefore, an understanding of the governance approach to be applied needs to be considered when designing a complimenting structure.
		Technical complexity	Consideration of whether the technical challenges are of sufficient complexity to require separation into specific streams will impact the structure
		Collective decision making	To ensure the collaborative approach develops in a way agreeable to all partners, the structure should

			enable core partners to be consulted and involved with key decision making
		Communication; trust; power	Structure should understand it's relationship with the power of stakeholders and be aware that certain approaches will create differing imbalances
Governance	*As with the structure, there is no prescribed best fit governance model, which can be applied to all collaborative technology development ventures. Instead the governance model should, first and foremost, complement the chosen structure. Ideally, both the proposed structure and governance for the collaboration will be designed in tandem, minimising the risk of a mis-match.*	*Structure*	The governance should take into account the proposed structure and seek to complement.
		Collaborative purpose	As with the structure, the governance approach needs to complement the identified collaborative purpose. For instance, should the purpose be more focused around the latter phases of development ie commercialisation, an alternative governance model, prioritising hierarchy and command may be selected, as opposed to if the development were in earlier, more innovative stages.
		Partners	Consideration of the number of partners, as differentiated by their category. A high number of core partners may lend a need for a greater emphasis on designing a governance model which supports a greater level of communication.
		Technical complexity	Consideration of whether the technical challenges are of sufficient complexity to require separation into specific streams will impact the governance model. There may be a need for multiple layers of direction and management, in order to promote efficiencies in tactical delivery, whilst allowing for discussion around strategic direction.

		Collective decision making	To ensure the collaborative approach develops in a way agreeable to all partners, the governance should enable core partners to be consulted and involved with key decision making
		Communication; trust; power	The governance should understand it's relationship with the power of stakeholders and be aware that certain approaches will create differing imbalances
Funding Mechanism	*The funding mechanism relates to how the collaborative approach is financially supported. It is of great importance to consider this principle when developing a collaborative approach to technology development*	*Source and structure*	Understanding where the finance is coming from and under what arrangements is particularly important. Consideration should also be given to the relationship between the source and actors identified as funding partners
Collaborative objectives	*Defining collaborative objectives will support the collaboration develop collectively towards a single set of goals and enable all actors to agree on common goals*		
Success Requirements	*Defining success is important to validate the performance of the collaborative model, although care should be taken to refrain from being too prescriptive in criteria.*	*Individual*	Each core partner should define what success looks like individually to them to ensure they remain focussed and motivated throughout the collaboration
		Collective	Collective definitions of success should be defined to allow the collaborative leaders to assess whether the approach has delivered value once the project is finished

Definition of Risk	*When several partners work together, the opportunity for risks is increased due to the increased complexity of the CEN. Consequently, understanding risks that can be of detriment to the success of the project is an imperative aspect of any technology development program*	*Individual* *Collective*	Risks of individual partners should be sought to better understand the risk appetite of the collaboration Risks should be identified from a network collaboration level to understand key issues which may arise throughout the collaborative lifecycle and allow them to be managed through mitigation

Table 7: Detailed framework displaying principles for Collaborative Technology Development

Section Two:
Supporting Collaborative Technology Development

This sections consists of the following chapters;

- Chapter Five: Unmanned Underwater Vehicales Action Case
- Chapter Six: UK Defence Sector Action Case
- Chapter Seven: UK Rail Sector Action Case

Chapter Five:
Unmanned Underwater Vehicle Action Case

This chapter is based on work conducted by Frazer Nash Consultancy for a client in the Marine sector; the Maritime Autonomous Systems Group. Aspects of this research have therefore been included in a client report as well as presented at several conferences, notably; The Undersea Defence Technology Conference, 2013, Hamburg, Germany; Maritime Autonomous Systems Annual Conference, 2013, London; European Defence Agency Annual Conference, 2014, Brussels.

5.1 Introduction

This chapter seeks to test and validate the principles of the CTD framework identified in chapter four and explore the functionality of the framework by applying it in a consultancy setting. Through the utilisation of an action case approach, the primary aim of the research is to appraise the appropriateness of the framework to support the *design and establishment* of a technology development collaboration.

As an overview, this chapter addresses the following research questions;

- Are the identified principles of the CTD Framework valid and accurate?
- How can the principles of collaborative technology development be constructively applied in industry?
- What are the challenges and limitations of the application of the framework in its current format?

The research in this chapter has been conducted on a consultancy project. The client for whom the work was conducted; the Marine Autonomous Systems Group (MAS) operates in the marine sector. The purpose of the project was to assist the client design and establish a collaborative approach to accelerate the development of Unmanned Underwater Vehicles (UUV). Specifically, the client wanted to understand how the maturation of UUVs may be aided through a collaborative approach, similar to how ASTRAEA accelerated the development of UAVs.

5.2 Objectives

The objective of this research was to support the client design and establish a collaborative network to accelerate the development of UUVs through the application of the CTD Framework. Specifically, the work sought to address the following key objectives;

1. Understand the current approach to UUV development and current limitations
2. Identify a suitable collaborative structure and governance model, which may support UUV development
3. Identify key partners who could positively contribute to the collaboration.
4. Explore the opportunity of matched government funding and understand the benefit a collaborative approach may provide in attaining this
5. Identify the general benefits a collaborative approach may provide

5.3 Approach

The research in this chapter adopts an action case approach, as outlined by Braa and Vidgen (Braa & Vidgen 1999). The format of the research follows the four phases of the action research loop as defined by MacIsaac; Plan, Act, Observe, Reflect. However, due to time constraints, only one application of the action research loop is conducted.

As indicated in the introduction, the primary focus of the research is to test and validate the principles of the CTD Framework developed in chapter four and understand its applicability in a consultancy context.

To appropriately address the research questions of this study, the plan phase will consist of two phases. The first phase will involve a desk study, exploring the current approaches to UUV development, identifying limitations. The second phase will identify suitable professionals who work in the marine sector, who possess key knowledge and experience of developing UUVs, to take part in a day long workshop as part of the act phase.

In order to accurately test and validate the CTD framework, it will be applied as part of the "act" section. As the focus here is on understanding the applicability of the framework and validating its use to support establishing a collaborative model, the act will focus solely on the application outputs. It is not concerned with the subsequent development of the collaboration. The observation phase will detail the response of the client and the acceptance of the work. The reflect phase will appraise the success of the application and identify limitations.

5.4 Plan

The planning for this research is split into two phases. Phase one consists of a desk study, exploring the current approach to UUV development. The second phase identifies key stakeholders who will take part in a workshop, in order to appropriately apply the framework.

5.4.1 Phase One – Desk Study Exploring Current Approaches to UUV Development

The desk study indicated that UUVs have experienced significant development in technical maturity over the past fifty years. Early development started in 1957 with the production of the 'Self Propelled Underwater Research Vehicle' (SPURV) by the University of Washington. Designed to study three things; diffusion, acoustic transmissions and submarine wakes, its success illustrated the potential of autonomous underwater vehicles, and led to several further development initiatives. Throughout the latter part of the 20th century, UUV development continued to be predominantly led by American academic institutes such as the Massachusetts Institute of Technology and the University of New Hampshire and later by the Russian Academy of Applied Sciences.

The combination of such development initiatives has facilitated the maturation of UUV technology. Specifically, technical capability has matured significantly, with UUV's now recognisably capable of offering services in over 20 commercial areas, operating across three main markets; Defence, Energy and 'Big Science' Research. Advances across technical areas such as communications and navigation have allowed Examples of use include Mine countermeasures by the Navy, Oil and Gas exploration and sea bed mapping for large energy firms and marine exploration and oceanographic surveys for the science community.

Despite significant advances in the capability of autonomous underwater technology, several 'technology longpoles' still exist, particularly around the areas of communications, energy storage, propulsion and localisation (Manii, 2012). Consequently, the current development focus is centred on the technical issues of UUV operation. Specifically, eight areas are being targeted; energy systems, communications, launch systems, navigation, propulsion systems, sonar, sensors and software.

The European Unmanned Maritime Systems (UMS) for mine countermeasures initiative is one such example, focusing specifically on developing the technical aspects of UUVs. It represents the first major technology programme directly connected to Maritime Mine Counter Measures (MMCM). Established by the European Defence Agency's (EDA), it is part of their capability development plan, developing the next generation of MMCM technologies for 2018. Similar technically oriented programmes are also being run in the energy and science sectors of the industry. The UMS initiative is one of many programmes focussing on technical development of UUVs. Across the defence, energy and science markets, development paths are being pursued to further enhance the technical capability of UUVs.

As well as the technical challenges, activities to address the safety and regulatory aspects of unmanned underwater vehicles are also being pursued, albeit in significantly lower numbers. Work groups such as SARUMS (Safety and Regulation for European Unmanned Maritime Systems), established by the EDA do however represent one such example. Its focus is to enhance interoperability of autonomous unmanned vehicles (AUVs) throughout maritime operations. Specifically, the primary objective of SARUMS is to provide European Navies a best practice framework for Unmanned Maritime Systems that recognises their operational usage, legal status and the needs of the Navies. Consisting of an assortment of European defence institutes, they are currently working towards a document, expected to deliver significant improvement in interoperability and standardisation in design and operation of AUVs.

Although it's evident UUVs are benefiting from the current development approaches being employed, the current approaches to technical and regulatory issues are being addressed independently of each other. Specifically, the researcher can find minimal evidence of any joint initiatives, which seek to address both the technical and safety/regulatory challenges together. Such a silo'd approach would seem to characterise the industry as a whole, which appears significantly disjointed and lacking an overall strategy in the delivery of UUVs. Further, there currently does not appear to be a common strategy when developing specific technology areas, with minimal communication between projects. Ultimately, it would appear that the integration of UUVs into the manned environment is suffering as a result.

5.4.2 Phase Two – Identifying Experts / Defining the approach for application

To accurately validate the principles of the CTD framework and in order to test its applicability in a consultancy setting, the framework is to be applied in a one-day workshop. The workshop will be attended by five industry representatives, selected based on their experience and current positions in the marine sector. The attendees are outlined below;

- *Attendee 1* - Business Manager, Frazer Nash Consultancy
- *Attendee 2* - Technical Director, Frazer Nash Consultancy
- *Attendee 3* - Senior Business Manager, Frazer Nash Consultancy
- *Attendee 4* - Technical Director, Babcock
- *Attendee 5* – Director, Marine Autonomous Systems Group (Client)

Before the date of the workshop, each attendee will be introduced to the CTD framework via an introductory email. The framework will again be explained at the start of the workshop, which will be led and facilitated by the researcher. The intent is for the framework to be applied in a similar manner to the Business Model Canvas (Osterwalder and Pigneur, 2010), whereby the attendees will be systematically taken through each theme of the framework, using the sub-theme as specific discussion points and prompts, in order to validate the CTD and generate a detailed collaborative model.

5.5 Act

This section details the application of the CTD framework to design and establish a collaborative set up for the development of UUVs. As the primary focus of the research is around the validation of the framework principles, the framework is applied as per table 7, with each theme split into sub themes, where key outcomes of the application are summarised here. The acceptance of the framework application is then described in section 5.6 whilst the success of the framework as a tool to support the design and establishment of collaborative approaches is discussed in section 5.7.

5.5.1 Purpose

The key outcomes relating to the purpose of the collaborative design are as follows;

- ***Define*** – Discussions within the group agreed that defining the overarching purpose of the collaborative would be beneficial to frame and structure the challenge moving forward. It was discussed and agreed that the aim of the collaboration was to alter the current development approach for UUVs and to bring a greater sense of strategic unity to the sector, in the belief this would support the acceleration of product maturity and expose new revenue models. Further, there was an aspiration to attract a wider supply chain base than was currently evident as well as uniting those that existed. To achieve this, it was agreed that the definition should remain high level as to not constrain thinking and so the core purpose of the MAS collaboration was defined simply as "to support the accelerated development and integration of maritime autonomous systems".
- ***Complexity*** **–** As the purpose centred around "development" and "integration" and also sought to include a wide array of stakeholders, it was noted that the complexity of it was significant. Specifically, all stakeholders present agreed that there should be a balance to the collaborative approach between technical development and commercial integration.
- ***Collective acceptance*** **–** All stakeholders present agreed with the defined purpose. However, as the framework was tested in a single workshop, with a minimal number of people, the acceptance did not extend further. It was agreed however, that moving forward, partners would be included on the basis they were "on board" with the defined purpose.
- ***Motivations*** **–** Similar to collective acceptance, understanding the motivation of all who might be involved in this collaboration was not possible, given the early stages of its design and the limited opportunity for involvement. However, all present held similar motivations, with only one member differing in their priority.

5.5.2 Partners

The key outcomes relating to partners of the collaborative design are as follows;

- ***Core partners*** – It was agreed that the collaboration should consist of several core partners, who would form the primary fulcrum of the collaborative. Given the purpose of the approach was balanced between technical and commercial requirements, it was decided that such partners should be characterised by their capability to enhance both aspects. Whilst several potential partners were identified, non were confirmed in this session.
- ***Technical partners*** **–** Several technical partners were identified during the session. These consisted of core partners and several smaller firms. It was agreed that all potential technical partners should be characterised against their capability to support the technical challenges of the problem *and* their complicity with the approach/purpose of the programme.
- ***Financial partners*** **–** It was agreed that as one of the core motivations to pursue a collaborative approach was to expose new financial models in support of UUV development, that the primary candidate for a financial partner should be the Technology Strategy Board; a UK Government funded NGO. The aspiration was for the TSB to contribute up to 50% matched funding. The other financial partners would be the core partners.
- ***Regulatory partners*** **–** As part of the discussions, it was agreed that in order to achieve the integration and commercialisation aspects of UUV development, the inclusion of regulatory partners would be imperative. However, it was noted that the marine sector has many regulatory bodies and it became evident that the regulatory environment was somewhat more complex than previously anticipated. Consequently, while regulatory partners were identified and agreed important to liaise with as part of the collaboration, no decisions were taken as to which to include and when.
- ***Value perception*** **–** As partners were only discussed and not approached, it was not possible to identify if they held the same value perceptions as the group.

However, it was agreed that this should form an important aspect of the selection criteria.

- ***Common understanding –*** Similar to value perception; as partners were only discussed and not approached, it was not possible to identify if they held a common understanding with the group. However, it was agreed that this should form an important aspect of the selection criteria.

5.5.3 Structure

The key outcomes relating to the structure of the collaborative design are as follows;

- ***Collaborative Purpose*** - Whilst discussing a possible structure for the collaborative approach, referring to the collaborative purpose proved important. Specifically, as the intent was to form a collaboration to support both the technical development and ultimate integration of UUVs, it was decided that the structure needed to accommodate both in an agile way.
- ***Partners –*** It was noted that there would likely be numerous partners in the final collaboration, occupying differing levels of responsibility. Given the inclusion of core partners, it was suggested that the structure of the collaboration should be one which promoted closer ties between these, whilst allowing for other partners to be involved as and when needed.
- ***Technical complexity –*** The technical complexity of the proposed collaboration perhaps had the most significant impact upon the proposed structure. Specifically, eight technical "streams" were proposed. Based on current development areas in UUV technology, the eight streams were; energy systems, communications, launch systems, navigation, propulsion systems, sonar, sensors and software. The intention was for each of the technical areas to provide an opportunity for core partners to communicate in a more direct way with technical and other partners on specific technical challenges. It was proposed that this would then allow technical issues to be addressed in a more efficient manner. Further, it was identified that many civil and defence organisations who would likely be involved in the collaboration already had active programmes addressing issues in each of the streams. The collaborative model would look to capitalise on this existing

capability and enable easy transitions for such companies. To ensure that each stream addressed challenges specific to the development and integration of UUVs, it was proposed that each should receive strategic direction from a central governing body, consisting of all core partners.

To ensure the technical challenges were addressed with UUV integration in mind, it was also proposed that there should be a regulatory presence in each of the streams. The purpose for their inclusion at this level was to ensure the necessary requirements are identified to maximise the chances of successful UUV integration.

- ***Governance* –** As is detailed in section 5.5.4, the intended governance model also had a significant impact on the proposed structure, ultimately leading to the selection of the hub and spokes model evident in fig 13. Discussions in the group identified that the collaboration should be centrally driven, with core partners responsible for the strategic direction, ultimately forming the hub. The spokes would be comprised of secondary partners such as technical and regulatory partners, with certain core partners potentially taking a tactical lead in individual streams. It was envisaged that such a structure would support the promotion of trust and communication centrally, leading to a more holistic approach to UUV development, whilst not detracting from the already proven and established silo'd approaches to the technical challenges, which would be allowed to thrive in the streams, albeit under the direction of the core partners.
- ***Collective decision making; communication; trust* –** As indicated, discussions identified that the central part of the collaboration should be designed to promote trust and communication in order to support a more collective strategic approach to UUV development.

An overview of the proposed structure is provided in figure 13.

5.5.4 Governance

The key outcomes relating to the governance of the collaborative design are as follows;

- ***Collaborative Purpose* –** Similar to discussions when proposing the structure, relating back to the identified purpose of the collaboration was a useful reference tool. Specifically, the notion that one of the primary drivers of forming a collaborative approach was to alter the traditional development model of UUVs and bring a more synergistic approach to the strategic development significantly influenced the identification of the proposed governance model.

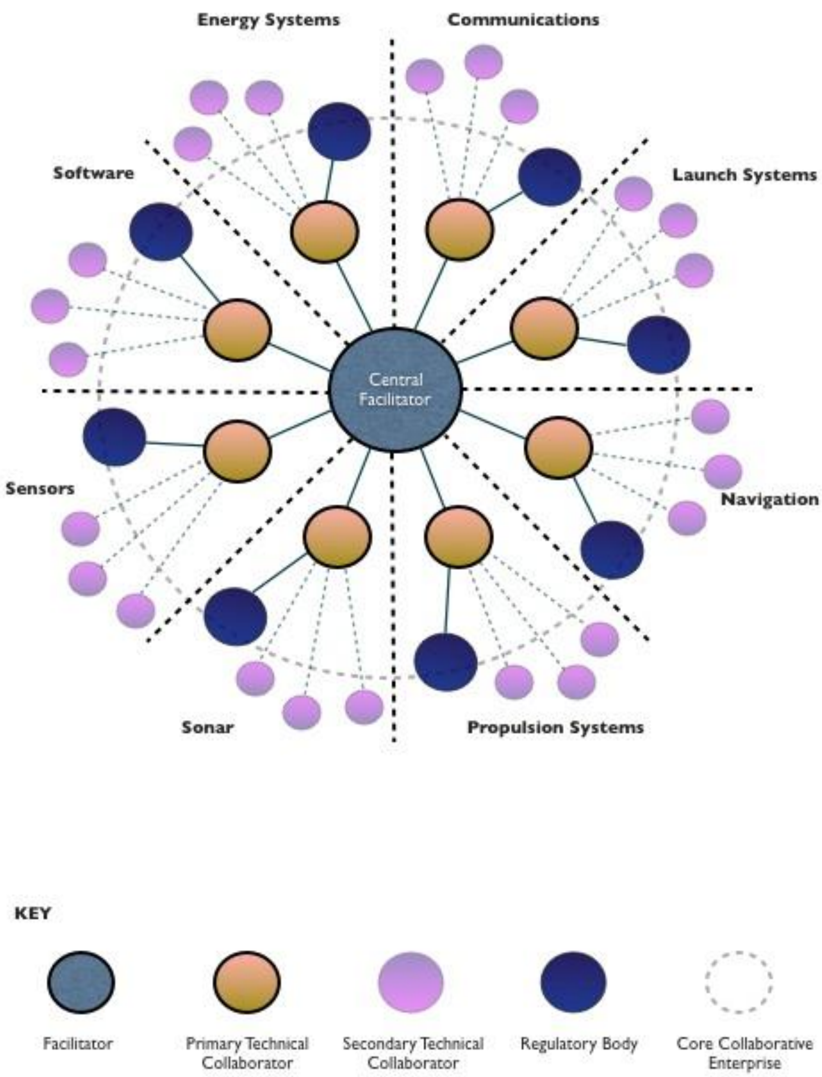


Figure 13: Overview of proposed collaborative structure

- ***Structure*** **–** The proposed structure of a hub and spokes model considerably impacted the discussion around how the collaboration should be governed, with agreement that a traditional hierarchal model would not be appropriate and ultimately leading to the proposition of a central facilitator/broker. Positioned at the centre of the model, as illustrated on fig 13, it was proposed that the role of facilitator would assume responsibility for maintaining the development of the collaboration and provide a central focal point for communication. An independent role, the facilitator would essentially manage the collaborative approach, responsible for establishing and maintaining communication between the collaborators, as well as providing independent views on paths forward and appropriate development streams. It is also responsible for helping to shape an overarching strategy to integrate UUVs into the current environment, my managing power dispersals in the central group and mediating discussions relating to tactical technical decisions.

Whilst the facilitator would assume responsibility for the core, "hub", aspect of the collaboration, their oversight would not directly reach into the streams. Instead, it was proposed that each stream would be governed by one of the core partners, chosen based on their technical capability in that area. The core partner responsible for that stream would then assume responsibility for engaging with technical partners and ensuring technical challenges were addressed in accordance with the strategic decisions set centrally.

- ***Partners* –** The discussions around how the partners would influence the governance model proved useful and provided added justification for the selection of an independent facilitator. Specifically, it was noted that the core partners would most likely be formed of several large organisations, who didn't have a great reputation for collaborating effectively. However, it was proposed that the inclusion of an independent mediator would mitigate against any attempt by any one partner to disproportionately influence the strategic decisions of the collaborative.
- ***Technical complexity* –** As the technical complexity influenced the structure, it had a similarly strong influence on the chosen governance model. Specifically, one of the prime reasons for the suggestion that core partners should manage technical streams individually was to enable the technical challenges to be addressed efficiently. Further, it was also proposed that such a model would promote the protection of intellectual property, enabling individual partners to retain IP, whilst continuing to contribute to the strategic development of UUVs.
- ***Collective decision making; communication; trust* –** Discussions within the group again agreed that the choice of an independent facilitator would be the most

appropriate to maintain power equality throughout the group, promote trust and encourage communication; all aspirations of the end collaboration.

5.5.5 Funding Mechanism

The key outcomes relating to the funding of the collaborative design are as follows;

- ***Source and structure* –** Potential funding for the collaboration was discussed at length, with a consensus eventually agreeing that the primary source should originate from the UK government. Specifically, the TSB were to be targeted and would be asked to support the collaboration in a 50% matched-funding model. The remaining 50% would be provided by the core partners. Whilst specific figures weren't identified, the sum was in the region of £15-£20m over a four-year period.

5.5.6 Collaborative Objectives

The key outcomes relating to the collaborative objectives of the collaborative design are as follows;

- As the framework was applied in a single workshop, with a limited number of stakeholders, it was deemed that defining the collaborative objectives, outside of overarching purpose, would not be beneficial or useful at that time. However, it was agreed that should the development of the collaboration proceed, it would be of most importance to identify such objectives, once the core partners had been identified.

5.5.7 Requirements for Success

The key outcomes relating to the success requirements of the collaborative design are as follows;

- ***Individual* –** Due to the limited application of the framework, individual success requirements were not defined.
- ***Collective* –** Collective requirements for success were discussed briefly, although it was deemed that at this early stage they could not be defined in any great detail. However, it was agreed that one metric of early success should be that within an

18-month period, the collaboration should be well established, with public funding secured and core partners in place. A further metric identified was that the collaboration should positively impact the demand for UUVs over the subsequent 10-year period. Aside from this, only the generic success requirement of advanced UUVs integrated into the existing environment was also identified.

5.5.8 Definition of Risks

The key outcomes relating to the definition of risks of the collaborative design are as follows;

- ***Individual -*** Due to the limited application of the framework, individual risks were not defined.
- ***Collective –*** Due to the limited application of the framework, collective risks were not defined.

5.6 Observe

The desk study identified that currently, the approach to UUV development is disjointed and lacks any holistic or strategic oversight. As a result, UUVs have not progressed to the same operational level as other autonomous vehicles.

The application of the CTD framework was intended to stimulate a discussion around this topic, providing some structure around how a collaborative approach to UUV development may be generated to support a more focussed development programme and what such a collaboration may look like. In fact, by applying the CTD framework and systematically working through the themes and sub themes, a detailed, albeit draft, understanding of what such a collaborative approach could look like was able to be generated, garnering significant positive feedback from both the client and all workshop attendees

The model was very well received by the client and other industry partners. Subsequent to the initial scope of work, the client requested that the draft collaborative model was presented at two industry conferences; *The Marine Autonomous Systems Conference in London (2013)* and at the *European Defence Agency Annual Conference in Brussels (2014)*.

The premise of the framework used to generate the model as well as the outputs were presented to audiences and in each situations, both the framework and the draft collaborative model were widely accepted, serving as a platform for significant discussion. The researcher considers this an indication of success.

5.7 Reflect

This section reflects on the application of the CTD framework, discussing its suitability to support the design and establishment of a collaboration and exploring whether the identified principles have been appropriately validated. Further, the approach to the application is also discussed and limitations of the framework identified.

5.7.1 Validation of Framework Principles

The CTD framework was developed in chapter four based on the identified best practices of industry and extant academic research. In this chapter, it was applied to support the design and establishment of a collaboration seeking to develop UUVs. In general, the application of the framework in this context seems to have been a success.

Of the eight principle themes identified in the CTD framework, all were agreed important by the stakeholder group involved in the workshop. Specifically, several stakeholders commented that the structured approach of the framework, supported by the identification of the sub-themes, provided an excellent foundation from which to think about and frame how to design a collaboration for the purpose of technology development. A prime example of this was the first theme – “Purpose”. Initially, most of the stakeholders thought this a simple exercise and assumed a common purpose was already known. However, upon discussing some of the sub-themes such as “complexity” and “motivation”, they began to realise that even within a small group of five people, differences in understanding and characterisations of what the collaboration was intended to support were appearing. Having the sub themes there then to generate discussion enabled the stakeholders to arrive at a common consensus around the purpose, which subsequently framed the rest of the day’s discussions.

Throughout the application of the framework, none of the principles were called into question and all were explored with similar enthusiasm. More pertinently, all stakeholders appeared to agree on the value of each of the principles and benefitted from approaching the design in a phased and structured way.

Although there was a general consensus as to the value of the identified themes and sub-themes, there was some confusion when identifying partners. Specifically, the regulatory partner sub-theme led to the identification of five different regulators. Whilst this wasn't a problem initially, it quickly became apparent that the lack of appreciation for the potential of multiple regulatory partners was something the framework struggled to accommodate in other areas; notably around structure and governance. It exposed a larger problem with the framework; that it was not as agile as it could be and, perhaps more importantly, that it currently failed to consider the context in which the collaboration was seeking to be developed.

This limitation was further identified in a subsequent presentation of the framework and draft collaborative model, where it was noted that whilst the framework considered several key principles, it had not taken into account market or customer demand for the product. Again, the researcher views such a consideration as a contextual condition; to understand how a collaboration may be appropriately designed to deliver a successful collaboratively developed technology, the market environment and necessary contextual conditions should be fully explored and understood. This would include nuances relative to individual sectors such as a complex regulatory environment as well as perceived market demand for the technology that is being developed. Consequently, upon reflection the researcher considers context to be another key principle, which should be part of a revised CTD framework.

5.7.2 Applicability of Framework

The CTD framework was applied in a one-day workshop with five stakeholders. The workshop was led by the researcher and whilst the application of the framework can be considered a success, the ease of applicability in a consultancy setting most certainly represents another significant limitation. Further, it is noted by the researcher that the framework was applied by the developer, ie the researcher. If the aim is for the framework to be more generally applied by a wider audience, significant more attention needs to be placed on understanding the best methods by which to do this as currently it offers little guidance and relies heavily on the applicators knowledge of collaborative best practice.

Despite the issues with the general applicability of the framework, it did serve as a useful tool to structure the workshop and focus stakeholder's attention around the key principles of collaboration. The structured approach, already highlighted for its positive reception in section 5.7.1 very much benefited the creation of a detailed draft collaborative model. However, applying the framework in such detail was not without its drawbacks. Specifically, by exploring every sub theme with such a small group of stakeholders, there were several instances of significant repetition when discussing the structure and governance design. The researcher noted that as a consequence, a couple of stakeholders taking part grew weary and seem to become slightly exasperated when discussing the same point for a third time. In the context of this workshop, the reactions were manageable by the researcher, but it should be noted for future applications that the current prescriptive nature of the framework may need to be addressed.

Finally, it should also be recognised that the framework itself is limited in its use and relies significantly on a collection of "experts" or well informed stakeholders in order to be applied effectively.

5.8 Revised CTD Framework

Based on the learning from this case, it is proposed that the CTD framework should be revised to include a further principle; system context. The importance of the system context in which the collaboration is occurring was overlooked in the initial development of the CTD framework as the author had not understood its importance. Further, whilst conducting the literature review, they did not come across any extant research which explicitly drew a correlation between the principles of collaborative design and the impact the contextual conditions may have on this.

Upon reflection, this was a distinct oversight by the author. Re-visiting the two case studies explored in Chapter 4, it is clear that contextual conditions impacted the design and development of both approaches. Specifically, a key contextual influence which impacted the OWA case was the desire of the UK government to reduce carbon emissions by 7% when compared to 1990 levels. In the case study, this is captured under the purpose and motivations of the programme, but it would be more accurately characterised as a contextual influence. Similarly, the ASTRAEA case was impacted by wider contextual conditions, specifically around a global shift towards autonomous vehicles across the aerospace, marine and land vehicle sectors. Again captured as a motivation to pursue the approach, the author feels this would be better characterised as a contextual consideration.

In reference to the UUV action case, the absence of a contextual consideration principle led to confusion when trying to characterise the various regulatory partners who would be involved in the development, as there were multiple. The complexity of this context could not be captured, rendering the framework less agile and negatively impacting its applicability.

The revised framework then should include the following theme;

System Context

The system context principle refers to the external environment in which the collaborative approach is occurring and should be considered when identifying the core purpose of the collaboration. Specifically, attention should be given to the contextual conditions which may be acting as drivers or barriers to the collaborative approach and the potential they have to influence the various other aspects of collaborative design. Within this, the context should be characterised based on its complexity. The more complex the context is perceived to be, the higher the likelihood it will impact the collaboration throughout the design and maintenance of the approach. A revised framework overview is presented in figure 14, with a more detailed description provided in table 8.

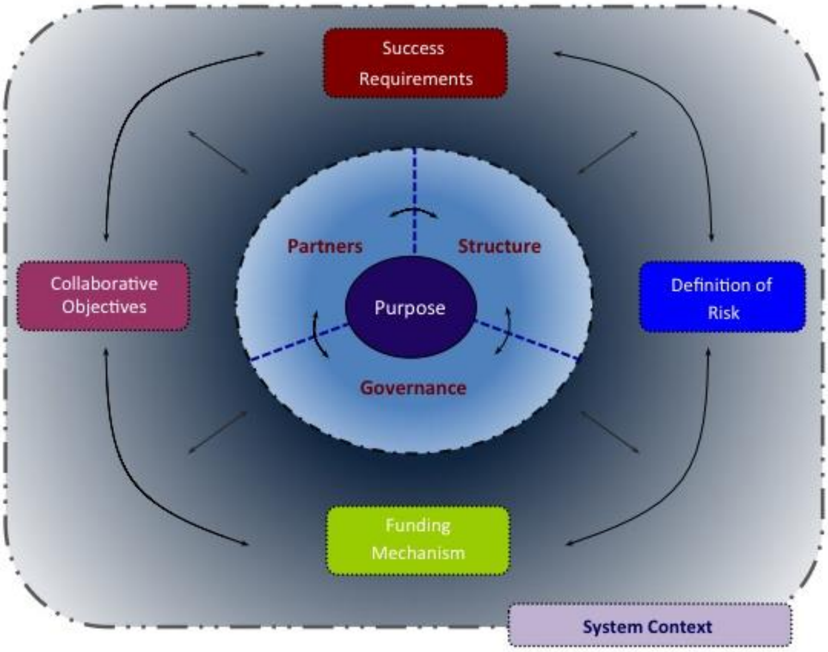


Figure 14: Overview of Revised CTD Framework

Theme	*Overview*	Sub-Theme	*Description*
System Context	The system context refers to the external environment in which the collaboration is occurring and should be considered concurringly with the purpose.	***Contextual Conditions***	The contextual conditions relate to the key drivers and barriers which demonstrate the capacity to influence the collaborative design and other principles of the CTD framework. The context should be characterised based on its complexity.
Purpose	*The purpose forms the core theme when designing a collaborative approach to technology development. Having a clear sense and definition of the purpose the collaboration is being formed to address will provide a better indication of the value a collaborative approach will provide.*	***Complexity of purpose***	Relates to the key drivers and reasons for entering into the collaboration and the interdependencies between them. The greater the complexity of the purpose the greater the impact upon the design and development of the collaboration, specifically around the structure and governance aspects
		Collective acceptance	To maximise the opportunity for success, the defined purpose must be developed and accepted by all core partners
		Motivations	Building on the complexity aspect, the core motivations for pursuing a collaborative approach should be defined, in order to ascertain whether value will be delivered and to influence the design of subsequent themes
Partners	*The partners principle refers to the identification and selection of appropriate collaborators who will support the development of the technology. The approach to selection need not be prescribed, however, for a partner to be useful in the context of a collaborative approach, they must share in the common understanding and perceived value of what*	***Value perception***	Partner must identify with the value of the collaborative approach and share in that value.
		Common understanding	Partners should demonstrate a common understanding as to the purpose of the collaboration.
		Partner category;	Whilst each category of partner illustrated below should be identified, it is possible for the same partner to assume multiple roles. Further, whilst only four roles are identified here, they are considered the minimum requirement for

the collaboration is being formed to achieve.

collaborative technology development. They should not be considered the *only* partners required.

-	***Core***	A collaborator who takes on a central role throughout the lifespan of the collaboration. Must be aligned as to the purpose of the collaboration with fellow core partners and see value in a collaborative approach.
-	***Technical***	Should be considered a technical expert in the area which they are required to support. Such a partner may be a core partner or a secondary partner, sub-contracted for a specified period of time and not necessarily required for the duration of the collaboration. They should however be willing to work within the structural model of the proposed collaboration.
-	***Financial***	The partner(s) who fund the collaborative technology development venture. This may be a core, or selection of core partners. It may also be an independent partner(s), with a vested interest in the development of the technology.
-	***Regulatory***	The regulatory partner represents the body responsible for current legislation in the proposed area the developed technology is to be integrated. Their involvement should be sought to ensure the developed technology may be integrated with minimal *negative* disruption.

Structure	Designing an appropriate collaborative structure is imperative to ensuring success when developing a technology collaboratively. Whilst there are no prescribed structures one should follow, attention should be given to the sub-themes identified here	*Collaborative purpose*	The structure should seek to complement the identified collaborative purpose. For instance, should the purpose be more focused around the latter phases of development ie commercialisation, an alternative structure may be selected as opposed to if the development were in earlier, more innovative stages.
		Partners	Consideration of the number of partners, as differentiated by their category. A high number of core partners may lend a need for a greater emphasis on designing in specific communication channels into the structure, in order to promote trust.
		Governance	The structure and governance are inherently inter-linked. Therefore, an understanding of the governance approach to be applied needs to be considered when designing a complimenting structure.
		Technical complexity	Consideration of whether the technical challenges are of sufficient complexity to require separation into specific streams will impact the structure
		Collective decision making	To ensure the collaborative approach develops in a way agreeable to all partners, the structure should enable core partners to be consulted and involved with key decision making
		Communication; trust; power	Structure should understand it's relationship with the power of stakeholders and be aware that certain approaches will create differing imbalances

Governance	*As with the structure, there is no prescribed best fit governance model, which can be applied to all collaborative technology development ventures. Instead the governance model should, first and foremost, complement the chosen structure. Ideally, both the proposed structure and governance for the collaboration will be designed in tandem, minimising the risk of a mis-match.*	*Structure*	The governance should take into account the proposed structure and seek to complement.
		Collaborative purpose	As with the structure, the governance approach needs to complement the identified collaborative purpose. For instance, should the purpose be more focused around the latter phases of development ie commercialisation, an alternative governance model, prioritising hierarchy and command may be selected, as opposed to if the development were in earlier, more innovative stages.
		Partners	Consideration of the number of partners, as differentiated by their category. A high number of core partners may lend a need for a greater emphasis on designing a governance model which supports a greater level of communication.
		Technical complexity	Consideration of whether the technical challenges are of sufficient complexity to require separation into specific streams will impact the governance model. There may be a need for multiple layers of direction and management, in order to promote efficiencies in tactical delivery, whilst allowing for discussion around strategic direction.
		Collective decision making	To ensure the collaborative approach develops in a way agreeable to all partners, the governance should enable core partners to be consulted and involved with key decision making
		Communication; trust; power	The governance should understand it's relationship with the power of stakeholders and be aware that certain approaches will create differing imbalances

Funding Mechanism	*The funding mechanism relates to how the collaborative approach is financially supported. It is of great importance to consider this principle when developing a collaborative approach to technology development*	*Source and structure*	Understanding where the finance is coming from and under what arrangements is particularly important. Consideration should also be given to the relationship between the source and actors identified as funding partners
Collaborative objectives	*Defining collaborative objectives will support the collaboration develop collectively towards a single set of goals and enable all actors to agree on common goals*		
Success Requirements	*Defining success is important to validate the performance of the collaborative model, although care should be taken to refrain from being too prescriptive in criteria.*	*Individual* *Collective*	Each core partner should define what success looks like individually to them to ensure they remain focussed and motivated throughout the collaboration Collective definitions of success should be defined to allow the collaborative leaders to assess whether the approach has delivered value once the project is finished
Definition of Risk	*When several partners work together, the opportunity for risks is increased due to the increased complexity of the CEN. Consequently, understanding risks that can be of detriment to the success of the project is an imperative aspect of any technology development program*	*Individual* *Collective*	Risks of individual partners should be sought to better understand the risk appetite of the collaboration Risks should be identified from a network collaboration level to understand key issues which may arise throughout the collaborative lifecycle and allow them to be managed through mitigation

Table 8: Revised Detailed Framework for Collaborative Technology Development

Chapter Six
UK Defence Sector Action Case

This chapter is based on work conducted by Frazer Nash Consultancy for a client in the Defence sector, who for security reasons have requested anonymity be retained. Aspects of this research have been included in a client report as well as presented at the annual Operational Research conference OR56, 2014, London.

6.1 Introduction

This chapter continues to explore the functionality of the CTD Framework established in chapter four and through the utilisation of an action case approach, seeks to build on the work conducted in chapter five. Whilst the previous chapter sought to appraise the appropriateness of the framework to support the *design and establishment* of a technology development collaboration, this chapter focusses on a slightly different context. Specifically, this chapter seeks to understand the value of the framework to support the assessment of an *already established and functioning* collaboration.

Further, as indicated in chapter five, a limitation of the current framework is its applicability in a consultancy setting. Specifically, whilst the framework provided an overview of the key principles of collaborative technology development, it did not provide the user with a guide of how best to apply it or define the principles such a user should possess. Consequently, this chapter also explores *how* the framework is applied.

As an overview, this chapter addresses the following research questions;

- How may the principles of collaborative technology development be used to assist already established collaborations?
- How may the role of a broker assist in the application of the framework?
- What principles / assets should a broker possess to provide support to collaborative technology developments?

The research in this chapter has been conducted on a consultancy project. The client for whom the work was conducted operates in the defence sector. The purpose of the project was to assist the client assess the current set up of a collaboration, which had been designed to facilitate the development of a technology. Specifically, the client wanted to understand if the collaborative set up was working well, or if changes were required in order to ensure maximum efficiency and results.

6.2 Objectives

The objective of this research was to support the client assess the current operational capability of a collaborative approach to technology development. Specifically, the work sought to address the following key objectives;

1. Assess the current collaborative approach to the management of technical developments
2. Appraise current working arrangements in terms of structure and governance
3. Understand the Tier-one supplier's perspective of the collaboration
4. Clarify the accuracy of data held relating to progress and financial management of programme

6.3 Approach

The research in this chapter adopts an action case approach, as outlined by Braa and Vidgen (Braa & Vidgen 1999). The format of the research follows the four phases of the action research loop as defined by MacIsaac; Plan, Act, Observe, Reflect. However, due to time constraints, only one application of the action research loop is conducted.

As indicated in the introduction, the focus of the research is two-fold;

- Validate the value of the Collaborative Framework to support the assessment of an established and functioning collaborative technology development

- Appraise the approach through which consultants apply the framework, with specific attention being paid to the concept of brokerage.

Consequently, the approach to the Plan section will be split into two phases. Phase one will consist of the researcher re-visiting two projects they worked on in the previous six months; “The Dementia Mug Project” and “The Radical Train Project”. Both of these projects represent examples whereby the researcher’s organisation acted as “brokers” in order to aid collaborative approaches to technology development. The intent is for each of these cases to provide the researcher with contextualised data regarding the role of brokers in the technology development process, with a specific focus on interaction techniques. Phase two will involve the researcher establishing the current approach the client is taking to collaboratively develop technology.

In order to accurately test the value of the CTD framework, it will be applied as part of the “act” section. This will be carried out by the researcher and an FNC colleague with 40 years of consultancy experience specific to the defence sector and will take place over a 4-month period.

The “Observe” section will look at the method used to apply the framework and look to establish brokerage traits employed. The “Reflect” will look to appraise the success of the approach and draw out some common themes from previous projects and the literature on brokerage.

To support the research, data will be collected through semi-structured interviews, workshops, observations and access to archival client data.

6.4 Plan

As illustrated in section 6.3, the plan consists of two phases. Phase one explores two examples of brokerage, employed in a consultancy setting to facilitate technology development. Phase two establishes the current “as-is” approach to technology development taken by the client.

6.4.1 Phase One

In order to effectively evaluate how brokerage may support the implementation of the CTD framework, it was deemed that further contextual examples where consultants had brokered collaborative approaches to technology development were required. Consequently, the researcher conducted semi-structured interviews with two FNC colleagues who had managed such projects. A brief outline of each project is provided below, followed by a summary of key learning lessons, which will provide useful insights to the planning of this research.

6.4.1.1 Dementia Mug Project

The dementia mug project was a 6-month project aimed at increasing hydration opportunities for patients with dementia. Specifically, the primary objective of the project was to design and develop a hydration vessel which would actively encourage patients to consume water at regular intervals.

To satisfy this objective, the project manager (PM) decided to take a collaborative approach, enlisting the support of a wide-reaching stakeholder group to define the requirements for such a technology. This included nurses, doctors, specialist dementia carers, family members of patients who suffered from dementia, mechanical engineers, product designers, electrical engineers and representatives from a local dementia charity. The aim was to collate the expertise of all stakeholders into a "best-fit" technology product. However, the best approach by which to do this proved difficult, as illustrated by the PM;

"Initially, we thought if we got all the experts into a room, we could talk about the problem and begin to define some requirements for the product. Perhaps foolishly, we believed the medical professionals would share the same opinion of what was important or at least there would be a general sense of consensus regarding the best way forward. Unfortunately, this was not the case. Whilst the nurses and carers shared a similar concern with the practicality and usability of the device, the doctors seemed more pre-occupied with recording volume of liquid consumed and the charity representative with the cost of the product. Also, once the doctors made clear their opinions, the nurses and carers seemed to change their mind slightly. We

realised that pursuing development through group workshops would not be the most constructive process. Instead, we decided to speak with each of the stakeholders individually – to try to better understand their perspectives. We then assembled all of the individual requirements, analysed them and working with our engineers, produced three prototype products. The prototypes were then presented to the group in another workshop setting, where we discussed the benefits and dis-benefits of each and eventually came to a unanimous decision as to which to pursue." Dementia Mug PM

Ultimately, the project was a success and the chosen prototype continued to be developed into a fully functional product, which was to undergo a 9-month trial period. When asked what key skills she thought were important to the process of brokering such a development, the PM responded with the following;

"In terms of lessons learned there were quite a few. Looking back, trying to get everyone in a room and just going for it was probably a big mistake. We hadn't accounted for the dynamics of the group and managing the stronger opinions of some, whilst encouraging some quieter ones. That's why speaking with people individually, although it took longer, was such a good approach for us. Also, having worked in the health sector many times before, we had the confidence to understand what each of the professionals were saying and then piece together the problem ourselves. It was then much easier to relay this information to our guys and engineer some prototypes." Dementia Mug PM

6.4.1.2 Radical Train Project

The radical train project was a 9-month project designed to increase collaborative innovation in the rail sector. The primary objective of the project was to support the client (the now defunct Enabling Innovation Team [EIT], part of the Rail Safety and Strategy Board [RSSB]) identify, assess and develop potential industry collaborations, which demonstrated the capacity to positively innovate within the rail sector. Once identified, the EIT wanted to invest up to £4 million in the most promising propositions.

To identify potential collaborators, the project began with a competition, designed and run by the radical train PM. The premise of the competition was to advertise the call by the EIT that it was looking to support collaborative innovation in the rail sector. To support the advertisement, several engagement events were hosted, designed to communicate the requirements of the competition, provide an opportunity for Q&A and enable potential collaborations to form between industry partners. The PM explained the events as follows;

"The first stage of the project was to set up and advertise the competition. The client wanted to interact with the widest range of partners possible and so, using all avenues possible, we advertised the events to industry. The events were held at the National Space Museum in Leicester, mainly because we thought this would be a good back drop to the innovation theme. We also thought a physical event would be a good opportunity for people to network face-to-face. The events themselves were really successful. I think we had over 200 people turn out each day. Due to a significant amount of pre-planning (before attending, organisations were asked to briefly outline their innovation proposition including area it addressed, likely budget, timeframe to delivery and what type of company it was looking to work with), we were able to introduce lots of different organisations to each other, most of which went on to submit a proposal. In fact, of the 8 successful collaborative proposals, 7 of them were formed at one of those events." Radical train PM

After the event, the competition received 83 proposals, detailing innovative technology propositions. Each of these had to be assessed, against a set criteria defined in conjunction with the client. The assessment, reduced the proposals down to 15, each of which were then invited to present their ideas to a 6 person board, which included technical and strategic leads from across various aspects of the rail sector. The presentations lasted 45-minutes each and would include questions from the board. At the end of each presentation, the board members were asked to individually rank the proposal, against several pre-defined criteria. At the end of the two-day session, all the proposals were compared based on the collated individual assessments, with 8 eventually being appraised worthy of receiving funding for continued development.

When asked what key skills he thought were important to the process of brokering such a development, the PM responded with the following;

"This project required quite a few different skills in order to make it a success. Early on, it was all about making connections between people and identifying potential contributors. This required such a huge amount of work prior to the events and relied on our consultants having a vast knowledge of the rail sector – I think that was quite important. During the events it felt at times we were acting as dinner party hosts; we were basically conduits facilitating introductions between organisations we thought would complement each other and between potential collaborations and the client. When it came to the assessment, the skills there were more traditional for engineering consultants; we identified what was important to the client, created a standard methodological assessment and appraised the proposals. The assessments themselves though required quite a broad technical knowledge as well as sector specific knowledge – we were having to decide not only if these propositions were plausible, but in what timeframe and within what budget and to what sort of impact. Once we had whittled them down to the final 15 the skills then were more acting as an independent arbitrator – basically collecting the individual assessments of the board for each proposal and analysing them collectively to minimise any bias towards a particular proposal." Radical Train PM

6.4.1.3 Key Lessons

The two projects described above have clear lessons, which can be positively applied to this project;

- ***Effective stakeholder management*** **–** In both instances, the PM's refer to the need to manage the wide range of stakeholders involved with the process. They both adopt an approach of seeking out the individual understanding and perspectives of many stakeholders, subsequently combining into a collective understanding of the situation.
- ***Sector specific knowledge*** **–** In both projects, the PMs referred to the benefit of possessing sector specific knowledge to support communicating effectively with stakeholders. There is also evidence to suggest this

supported stakeholder “buy-in”, providing the PMs with an aura of authority and credibility amongst the stakeholders.

- ***Technical competency*** – This theme was evident in both instances described above, enabling the PM’s and their team to more effectively garner the trust and with buy-in of the stakeholders they were working with. It also supported the assessment phase of the radical train project.
- ***Conduits of information*** – Possessing the capacity to unearth important information and requirements and then communicate them effectively to others was a thee common through both projects.

The key lessons learned will be used to influence the approach taken to this action case and support the application of the CTD framework.

6.4.2 Phase Two

The second phase of the planning involved building up an understanding of the client’s current approach to collaborative technology development as well as defining the approach to the project. Initially, it was agreed that in order to ensure the project has sufficient experience and sector knowledge, it was to be led by a principal consultant (PC) FNC colleague. The PC had 40 years of experience providing consultancy support within the defence sector, something which the phase one planning suggested would be important to the success of the project. Further, Mike also had technical experience developing the technologies we were assessing, again providing a further key requisite identified in the previous section.

To expand our knowledge of the client’s approach, we were invited to attend three project review meetings over a 6-week period. During this time, we were also able to immerse ourselves for several days at the client’s site, providing the opportunity to hold informal conversations with several staff members as well as review archival data relating to the strategic approach and current progress of the collaboration. Figure 15 outlines the high-level structure of the approach

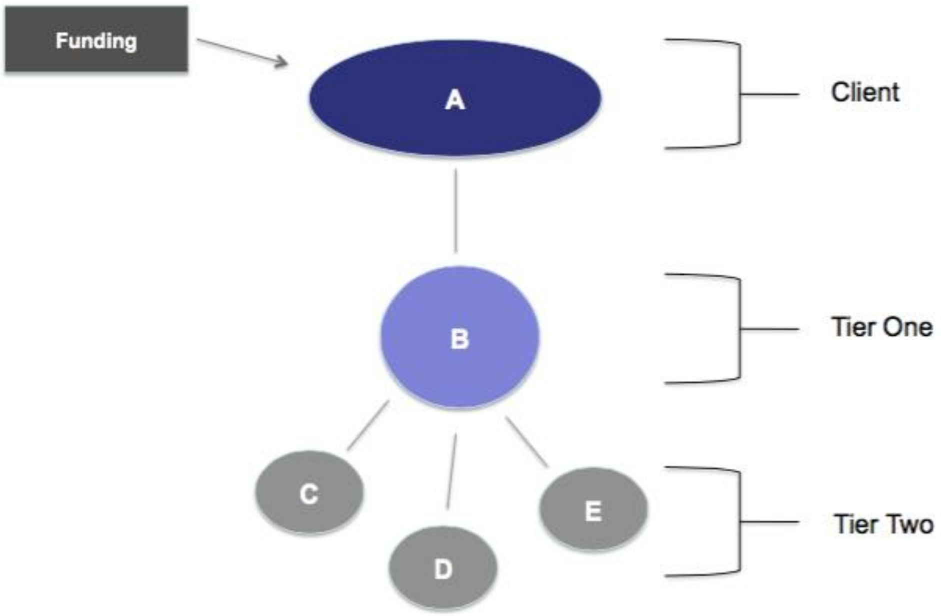


Figure 15 – Overview of Collaborative Structure

From the initial 6 week period, the following key things were learned;

- The client (organisation A) is leading two collaborative approaches to develop two similar pieces of technology
- The funding for the projects originates from outside of the client organisation, provided by an external source. The source is out of scope for this project and not available to provide input to the investigation. However, this does not appear to pose any significant barrier to the research.
- The client has contracted organisation B to lead the technical delivery of the collaborations.
- The client provides organisation B with the funding and technical requirements for the technology developments.
- Organisation B is responsible for managing and contracting all second tier collaborators.

- Although organisation A is the “customer” for the technology developments, they are not the “user”. Organisation B is responsible for ensuring the users are involved with the developments where possible.
- The client is in the process of undertaking a significant organisational transition. This appears at first instance to be impacting negatively on the collaboration.
- There is particular confusion, from the client’s perspective, around two aspects of the collaboration
    - Financial management of budgets
    - Definition of technical requirements

The information uncovered during the 6-week planning phase subsequently enabled a more detailed plan for the research project to be defined. For instance, as there was particular confusion regarding the approach to financial management as well as defining technical requirements, the researcher and PC decided that they should form the focal point of the enquiry. Further, to gain a full understanding of the various perspectives of the “as-is” collaborative approach, four interviewees were identified; two from organisation A and two from Organisation B. To fit with the previous requirement, in each organisation, one interviewee would be a senior employee responsible for the financial management of the project, whilst the other would be a senior technical project manager. It was envisaged that by following this approach, a more well-rounded and un-biased understanding of the approach could be generated.

To ensure each interview accurately assessed the collaborative “as-is”, the CTD framework would be used to structure the session and generate the question themes. Further, building on the lessons learned from phase one of the planning, it was decided that each interviewee would be interviewed individually and their identity protected from the client. The reason for this was to encourage participants to be as candid as possible to maximise the opportunity to attain an accurate, uncensored understanding of the “as-is”. Once the interviews were conducted, the researcher and PC would analyse the transcripts of each, identifying key themes using the CTD framework. A collective understanding of the “as-is” would then be generated into a technical report and presented to the client, identifying any areas of the collaboration which required particular attention.

6.5 Act

This section details the application of the CTD framework to assess the collaborative set up of the client. As the focus of the research is around the applicability of the framework to be successfully applied in such a context as well as the approach to application, only key findings are presented. The approach to application is then described in section 6.6 whilst the success of the framework as a tool to support such an assessment is discussed in section 6.7.

6.5.1 Context

The key findings relating to the context of the collaborative set up were as follows;

- The assessment identified that wider contextual cultures of both Organisations A and B were seriously impairing the ability of the collaboration to function. Specifically, both organisations employed a structure and governance which favoured hierarchy. As a result, this made it difficult for more junior individuals to identify problems effectively – something which had in one instance led to a circa £5 million delay.
- The ongoing change management programme occurring within Organisation A was negatively impacting the ability of the collaboration to function effectively. Specifically, the change programme involved a revision to the roles and responsibilities of senior members of organisation A. Consequently, confusion emanated as to who was responsible for certain decisions, impacting the delivery timeframes of key decisions.

6.5.2 Purpose

The key findings relating to the purpose of the collaborative set up were as follows;

- The assessment demonstrated there was a general acceptance across the collaboration as to the high-level purpose of the collaborative set-up. However, understanding of personnel as to more specific objectives and responsibilities of the various partner organisations proved to be inconsistent.

6.5.3 Partners

The key findings relating to the partners of the collaborative set up were as follows;

- Due to the complex context in which the collaboration was occurring, poor governance and minimal communication, there was no common understanding between organisation A and B regarding programme progress or status.
- There was a confusion of partner roles. Notably, Organisation A had, in places, employed people to perform the same role as they had contracted Organisation B to fulfil. This led to an immense level of confusion and in places a complete breakdown of relationships between the two organisations. Organisation B felt it was continuously undermined and unable to manage the technical delivery of the programme, whilst organisation A felt it was not being listened to.
- There was a lack of consistency in the management of second tier partners. Although Organisation B had responsibility for liaising with second tier suppliers and the end-user of the technology, Organisation A would often "interfere". Specifically, on numerous occasions, Organisation A approached second tier suppliers directly and without informing Organisation B, would alter requirements and request new deliverables. This has caused significant delay to the programme and substantial damage to the relationships between Organisation A and B.
- The capability of the partners in Organisation B appeared of a high quality and reasonably experience. However, the same did not appear true for those in Organisation A, many of which were new to their roles and had limited experience of technology development programmes.

6.5.4 Structure

The key findings relating to the structure of the collaborative set up were as follows;

- The current structure does not support formal communication channels between Organisations A and B. Instead, the effectiveness and success of the programme to date appears overly reliant upon individual relationships of key personnel, rather than a complimentary structure or governance process.
- Organisation B has established a suitable structure to compliment the technical delivery of the programme. However, this is being undermined by Organisation A and poor governance processes.

6.5.5 Governance

The key findings relating to the governance of the collaborative set up were as follows;

- The governance mechanisms currently in place are inadequate and are responsible for a large proportion of problems. Specifically, there is no one "lead person" in Organisation A who is responsible for overseeing the programme and ensuring the relevant partners are delivering to time, cost and quality. Instead, there are at least six personnel occupying this role, causing confusion as to individual responsibility and rendering all devoid of accountability. This is a huge source of tension both internally within Organisation A and between Organisations A and B.
- The lack of leadership has resulted in difficulty when defining collective objectives and monitoring progress of various partners.
- Decisions across both organisations are being made on an "ad-hoc" basis, with minimal evidence being used to support important financial and technical decisions. This has caused significant delay and programme cost overrun.

- The mechanisms used to record progress of the programme and measure the key performance metrics such as time, cost and quality are not consistent within or across the two organisations. Specifically, organisation A has two databases, which are being used to monitor progress, whilst organisation B has three. Whilst each database has been designed for slightly different purposes, there is significant overlap and hence redundancy in the information contained throughout. Further, more detailed analysis of each database highlighted that each contain different "versions of the truth". That is, no two databases gave the same "snapshot" of current progress of the programme. With various personnel using the different data management tools across the programme, it is little surprise that a collective, consistent understanding of current programme delivery progress exists.
- Despite a process being in place in which each data base should be updated monthly, closer analysis identified that several were not current.

6.5.6 Funding Mechanism

The key findings relating to the funding of the collaborative set up were as follows;

- The assessment identified that Organisation A and B have completely different understanding of current programme spend. This relates to overall budget, the allocation of funds to the various technical work streams and how much has been spent to date. Similar to the governance issue, this stems from the existence of several database tools, being used to manage programme spend. As a result, there is no consistent understanding as to the current spend of the programme.
- Further, from speaking with both organisations, there are clear discrepancies regarding the process of cost data entry and evaluation.

6.5.7 Collaborative Objectives

The key findings relating to the collaborative objectives of the collaborative set up were as follows;

- The assessment highlighted that collaborative objectives for the programme had only vaguely been identified and defined. This had occurred very early on in the collaborative set-up. However, since then, significant changes had been made to the requirements of the technology and hence many of the objectives. However, such changes had not been documented or communicated in a formal manner. Consequently, no two personnel encountered throughout this study had a consistent understanding of their objectives.

6.5.8 Success Requirements

The key findings relating to the success requirements of the collaborative set up were as follows;

- As no objectives had been accurately defined, success requirements were non-existent.

6.5.9 Definition of Risk

The key findings relating to the risk of the collaborative set up were as follows;

- The approach to risk management was inconsistent and poorly actioned across the two organisations, resulting in a reduced understanding of risks and issues.

6.6 Observe

This section explores the approach taken by the researcher and PC whilst applying the CTD framework to this project. The interaction techniques, depicted visually on a project timeline in figure 16, are summarised and reviewed. Specifically, the intent here is to understand *how* the researcher and PC applied the CTD framework, and to identify any forms of brokerage that may have occurred at each stage of the project.

6.6.1 Planning Phase

The planning phase consisted of six weeks, in which the researcher and PC were invited to base themselves at the client's base of operations for several days a week. As indicated in section 6.4.2, it also provided an opportunity to attend several client review meetings discussing the current status of the collaborative programme, access archival data pertaining to the programme and communicate with members of the team.

In terms of brokerage, this phase does not fall under any traditional category. However, it did provide the opportunity for the researcher and PC to expand their knowledge of the technology being developed, the internal organisational conditions in which it was being developed and external contextual considerations, which were impacting and driving development. This could be considered as both the researcher and PC reducing their "cognitive, social and cultural distances" relating to the collaborative programme (Parjanen et al. 2011). Further, it allowed the researcher and PC to begin to develop relationships within the two Organisations, in an informal manner, building trust with key personnel – two key tenets of successful brokerage and stakeholder engagement (Gray 1985). It also proved instrumental in forming a first-hand, non-biased understanding of the current "as-is" of the collaborative set-up. All of these activities proved to be vital in preparing for the latter stages of the project.

6.6.2 Client Kick-off meeting

The client kick-off meeting took the form of a four-hour session, with the researcher, PC, senior member of Organisation A and two support members, also from Organisation A. The purpose of the session was to clarify project objectives and convey how the project would be delivered to the client. It was also an

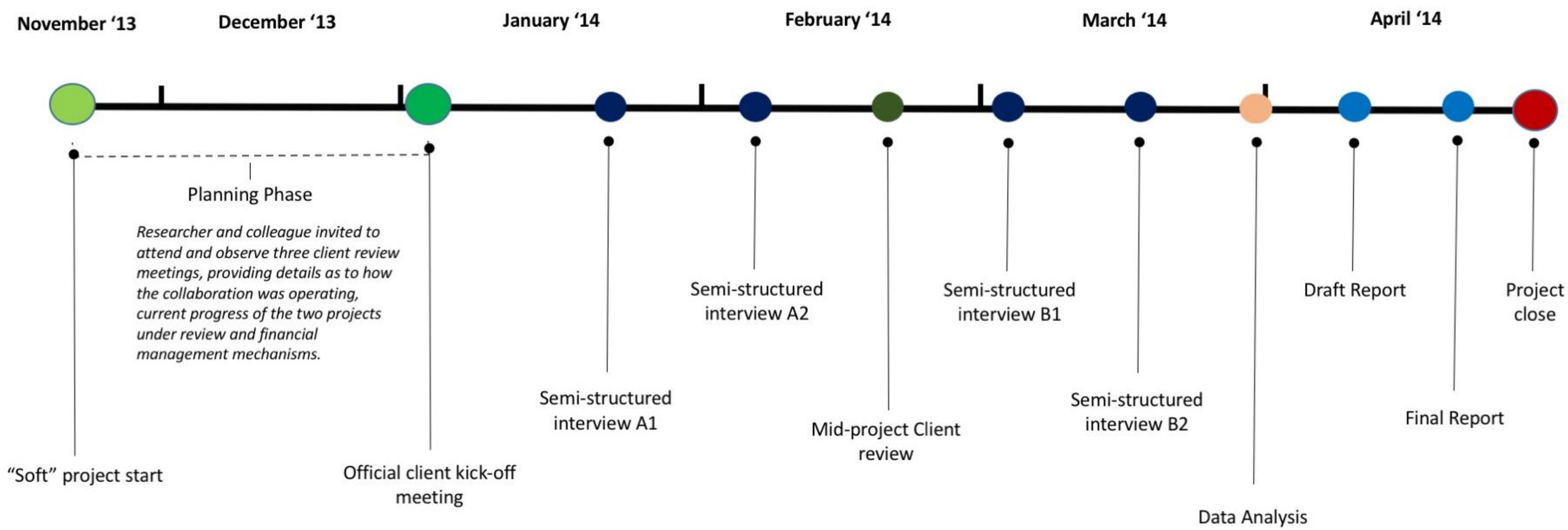


Figure 16: Overview of approach taken to UK Defence Action Case

opportunity to introduce the CTD framework to the client and develop a formal working relationship between the key point of contact.

In terms of brokerage, this phase again would not fall under a typical classification. However, it did prove to be an opportunity for specific types of knowledge to be “brokered” to some extent; albeit for reasons of gaining stakeholder buy-in and confidence rather than to deliver immediate value to the client. Specifically, this occurred in two forms. Firstly, the PC spoke at length about their 40 years’ experience in the defence industry, citing examples of similar technology development programmes they had been involved with. Leading the conversation and conversing in a manner which was familiar to the client, the PC successfully demonstrated their technical competency relating to the development of similar technologies. This had a significant positive impact upon the relationship with the client, and appeared to support the development of trust. Similarly, the researcher used this opportunity to convey their technical competency, although as they had limited experience supporting defence focussed technology developments, this centred around the CTD framework and collaborative technology developments in general.

6.6.3 Semi-Structured Interviews

Throughout the project, four semi-structured interviews were conducted. Two of these were with employees of Organisation A and two were from Organisation B. The purpose of the interviews was to provide the researcher and PC with a well-rounded understanding of the current collaborative setup from multiple perspectives, with a key focus on the technical and financial management approach.

The interviews were structured using the CTD framework, which ensured each interviewee were asked pertinent questions relating to the pre-identified principles of collaborative technology development. It also enabled comparisons of responses across a common framework.

In terms of brokerage, the interview stages perhaps represented what is most characteristically considered "traditional brokerage". Specifically, throughout each interview, both the researcher and PC interacted with each interviewee in a rather informal conversational manner. Consequently, whilst the primary aim of each session was to "download" information from the interviewee to the interviewer, there was a significant element of transferring knowledge the opposite way too.

In the initial interview, the knowledge transferred between interviewer and interviewee centred around the researcher and PC's interactions with the client, as well as their time spent on site throughout the planning phase. Whilst the interviewee found the information received useful, it highlighted the lack of communication and inadequate structural procedures and processes currently in place within the collaboration; the interviewee was supposed to have a direct line of communication with the client and worked for the same organisation. Instead, the interviewers found themselves acting as an "itinerant" broker, or "mediator" (Gould & Fernandez 1989) between the two, apparently already connected, actors, supporting the process of "transfer brokerage" (Spiro et al. 2013).
With each subsequent interview, the interviewer's knowledge and understanding of the collaborative setup expanded. Interestingly, this led to an increase in dialogue with each new interviewee and hence, an increase in knowledge transferred. Specifically, as the interview sessions moved to focus on Organisation B, both the researcher and PC found themselves transferring a significant amount of knowledge. A large proportion of this focussed on communicating the perceptions of current progress held my members of Organisation A. In both interviews, the corresponding interviewee from Organisation B did not recognise the beliefs and perceptions held by their Organisation A counterpart. Gould and Fernandez characterise this type of brokerage as "liaison" (Gould & Fernandez 1989).

Throughout the interview sessions a particular observation of interest was the relationship development and interchange between the PC and interviewee. In each session, the PC took the lead, establishing the premise of the session at the outset and taking charge of the questions, supported by the researcher when a query relating to collaborative theory arose. Such an approach proved extremely effective and was significantly enhanced by the PC's vast technical knowledge and experience. Specifically, in three of the four interviews, the PC was able to provide technical advice to the interviewee pertaining to a different challenge they were experiencing. The advice in each instance was positively received and seem to support the development of a positive relationship between interviewer and interviewee. Further, the PC's familiarity with contextual acronyms and phrases again supported the development of a positive relationship, helping to secure more candid perspectives and richer data responses to the questions.

6.6.4 Mid-Project Review

The mid-project review presented an opportunity to feed-back to the client what the researcher and PC had learned at the mid-way point of the project. It allowed for progress to be measured and reassure the client that expectations and objectives were on course to be met. In terms of brokerage it again can be characterised as the classic process of "transfer brokerage" (Spiro et al. 2013).

6.6.5 Data Analysis

The data analysis phase occurred after the completion of all semi-structured interviews. To analyse the data, the researcher transcribed all four interviews and, together with the PC, analysed them across the CTD framework, identifying key themes in the process. The assessment was further informed by notes and observations taken by both the researcher and PC.

Although data analysis is not traditionally considered a key part of brokerage, without conducting the analysis neither the researcher or PC would have been able to communicate accurate findings to the client.

6.6.6 Report and Project Close

The production of the report provides an illustration of transfer brokerage, albeit through an alternative medium. The recommendations made were well received.

6.7 Reflect

This section reflects on the application of the CTD framework, discussing its suitability to support the assessment of an established collaboration and identifying whether it was applied successfully. Further, the approach to the application is also discussed, drawing out the key tenets of collaborative technology brokerage and contrasting them against extant literature.

6.7.1 Applicability and Success of CTD Framework

The CTD Framework was initially developed to support the design and establishment of collaborative technology developments. Although the principles of collaboration identified should be constant throughout all collaborative technology endeavours, the framework was not developed to be applied in the assessment of an established collaboration. However, upon reflection, it's clear that the application of the framework as a tool to support the assessment of an established collaborative technology development was a success. This view is supported by the PC who applied the framework and the client, who accepted the findings and subsequently acted upon them.

The framework was particularly effective at providing a structured, informed guide for the PC and researcher to follow and conduct their assessment. It enabled key limitations of the collaborative approach to be identified, such as the inadequate structure that had been developed and the impact that was having on governance and communication. Further, as well as identifying key issues under each of the core principles, the framework allowed for the identification of "transversal" issues; problems which impacted more than one aspect of the collaborative set-up. An example of this is the context in which the collaboration was occurring, which had influenced the development of an inadequate structure and governance model. A further example is the governance model itself, which was negatively impacting the functionality of the collaboration and prohibiting the identification of objectives, risks, success criteria and the effective communication of partners.

Although the application of the framework can be considered a success, a significant part of the success can be attributed to the PC and researcher, ie the people who applied it. Specifically, the knowledge and experience of the PC drove a large amount of the interviews and sessions with the client. Further, whilst the principles of collaborative best practice were a useful tool to support the assessment, they were significantly supported by the planning phase and the expanding of knowledge of the brokers who applied it. This is something, which is often quite lost when discussing the principles of collaborating effectively.

6.7.2 Application Approach and the Role of Technology Brokerage

As illustrated in 6.7.1 a significant portion of the success of the applicability of the CTD Framework was due to the people, or "brokers" that applied it. Consequently, this section attempts to draw out common tenets, principles and behaviours relating to technology brokerage, which proved integral to the application and where possible, contrast these to extant literature on brokerage.

Relationship Building and Trust:

The development of trust and it's application to support the building of relationships is something well noted in the collaboration and brokerage literature (Gray 1985; Fernandez & Gould 1994; Currie & White 2012a; Haas 2015; Burgess & Currie 2013; Vangen & Huxham 2003; Vangen 2016). It is perhaps of little surprise then that it played such a pivotal role throughout the application of the CTD framework. Specifically, the relationship building during the semi-structured interviews proved to be of significant importance as it encouraged more candid responses and thus a richer data set to be generated from interviewees.

The development of trust in the interview sessions was supported significantly by the technical competency and sector knowledge of the PC. The importance of both sector knowledge and technical competency was noted in the lessons learned from previous projects in section 6.4.1.3 and is also noted in the extant literature (Lee Fleming et al. 2007; Parjanen et al. 2011; Hargadon & Sutton 1997).

Development of Knowledge:

Much of the extant literature on brokerage emphasises the importance and various approaches through which brokers (Gould & Fernandez 1989; Brown & Duguid 2001; Burt 2004; Hargadon 1998), boundary spanners (Levina & Vaast 2005) and gatekeepers (Spiro et al. 2013; Haas 2015) seek to span gaps and reduce distance by transferring knowledge (Parjanen et al. 2011). However, little research explores how brokers develop such knowledge in order to provide value. Specifically, the researcher could find no examples of research which explores how brokers develop their contextualised knowledge of particular situations, in which they intend to add value.

The researcher finds this of particular interest, given the importance of the planning phase in the application of the CTD framework. The opportunity for the researcher and PC to immerse themselves in the client's organisation provided an excellent opportunity to expand their knowledge of the existing collaboration. Without this knowledge, communicating with key stakeholders vital to the successful completion of the project would have been difficult.

Indeed, the expansion of knowledge of the two brokers did not stop after the planning phase, but continued throughout the interview sessions up until the analysis phase. This is demonstrated by the increased dialogue between the interviewers and each subsequent interviewee, as the contextualised knowledge of the brokers continued to increase.

Such an observation causes the author to re-assess the "process" of brokerage as specific to each to each phase identified in section 6.6. Instead, the author believes that this action case demonstrates that the process of brokerage in fact occurs throughout the project life-cycle (see figure 17); from the planning phase through to delivery, and should incorporate the expansion and contextualisation of knowledge.

A further point of interest here was *how* the brokers expanded and contextualised their knowledge. Whilst the two brokers entered the project with

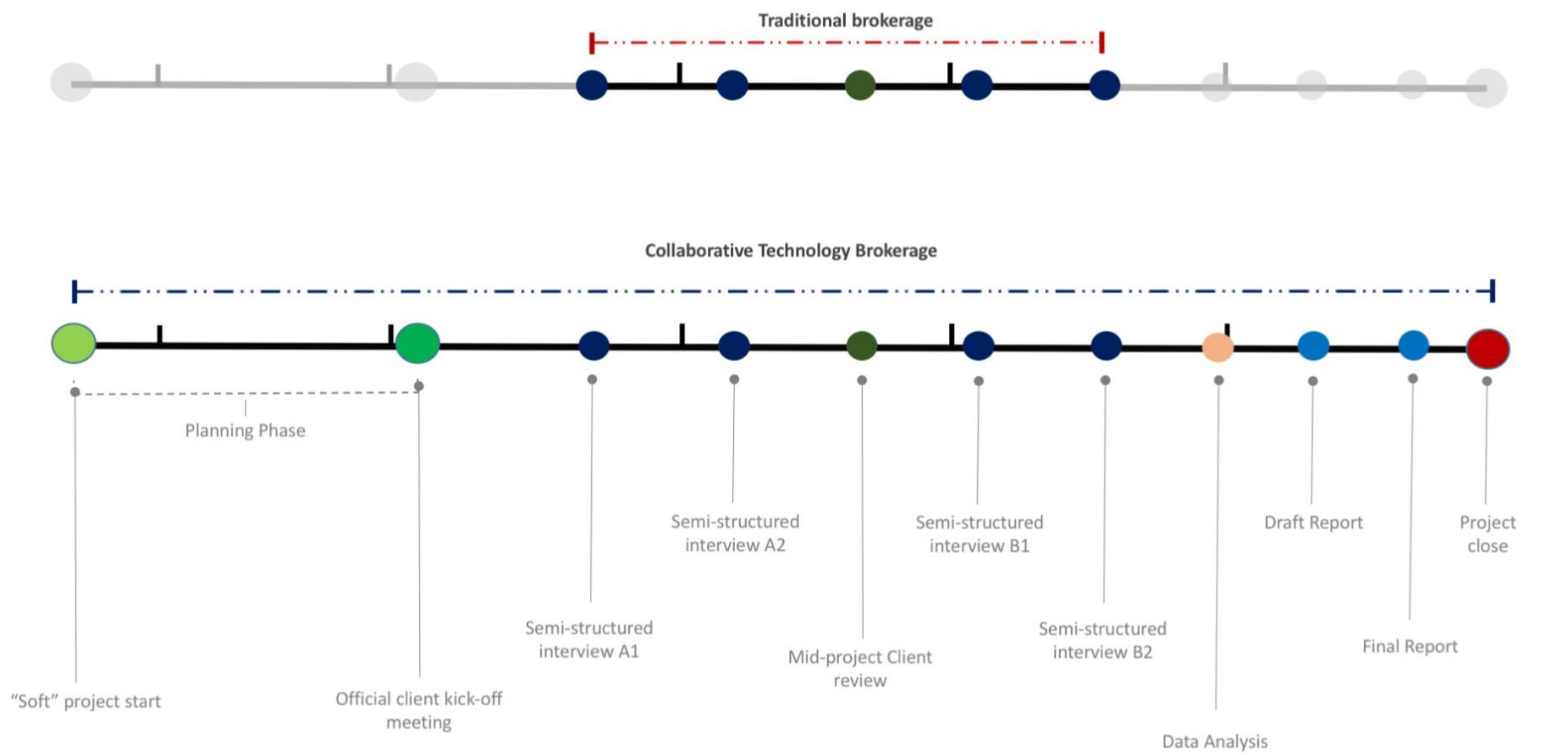


Figure 17: Proposed extended timeline illustrating process of collaborative technology brokerage

a significant level of knowledge relating to the technology system (the PC had extensive experience developing similar technologies) and the theory of collaborative working, they had very little pre-existing knowledge of the internal and external system. Specifically, the development of the brokers knowledge seems to occur across three distinct "areas" or "systems"; the technology system, the internal system and the external system (see figure 18). The technology system refers to the knowledge relating to the technology being developed. The internal system relates to the contextual knowledge of the collaboration itself; its structure and its governance. The external system refers to the environment in which the technology is to be integrated and eventually used.

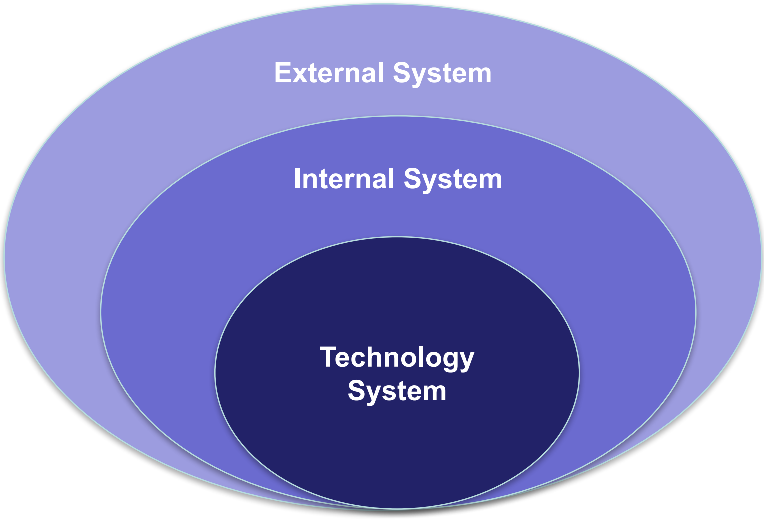


Figure 18 – Nested system of knowledge systems

Technical Competency:

The need for a broker to demonstrate technical competency is something identified in the literature (Hargadon 2002; Hargadon & Sutton 1997) and also in the pre-planning phase of the research. Specifically, the need for a broker to possess technical competency in order to build trust and confidence was evident throughout. The PC, as an experienced principal consultant, with 40 years in the field led most of the discussions and immediately commanded the respect of those interviewed. The ease with which he could converse with the use of acronyms was particularly powerful and aided the flow of conversation through the development of trust with interviewees.

The author believes it was this technical competency demonstrated by the PC, which enabled the brokers to more effectively appraise the current collaborative set up, through the teasing out of intricate information they otherwise may not have provided. A further note of interest here is the role technical competency plays with relation to power. Specifically, the PC's experience and competency often seemed to place him in what appeared to be a powerful position. The interviewees seemed often aware of his technical capability and genuinely intrigued by his experience and knowledge.

Interestingly, scholars such as Hargadon and Sutton (1997) state that technical competency should be possessed by the broker and employed as a source of power for personal gain. Similarly, Spiro et al in their identification of three processes of brokerage suggest that power can be obtained by the broker through the manipulation of actors it is seeking to connect (Spiro et al. 2013). Whether the PC was always cognisant of his power position is not known, but what is clear is that if he was aware, he certainly didn't exploit it. Consequently, the author believes that in the context of brokering collaborative technology developments, power is not something which should be sought through technical competency, for the purpose of personal gain. Instead, it should be used to make more informed and pertinent lines of enquiry, in order to appropriately assess and support the collaborative approach.

A further use for technical competency throughout the brokerage process was during the collation and analysis of information, to inform the report. Whilst throughout the project the work had relied heavily on the technical competency of the PC, the assessment was concerned with analysing the data gathered to understand how the collaborative approach was operating and make suggestions as to how it may be improved. At this stage, it was the technical competency of the researcher which was required, to combine the multiple perspectives and views collected relating to the collaborative approach and prepare them in a way as to enable an effective evaluation of key themes to inform the key findings.

Knowledge Transfer, Communication, Independence and Power Equality:

As illustrated earlier, the extant literature pertaining to brokerage centres significantly on the role of brokers spanning gaps to support communication and aid knowledge transfer (Burgess & Currie 2013; Currie & White 2012b; Burt 1992; Hargadon 2002). Throughout this project, both the PC and researcher were responsible for enacting such a process, transferring knowledge between several actors across both organisations. However, interestingly, the literature suggests that a broker traditionally demonstrates value by spanning a gap between two unconnected, or unaffiliated actors (Burt 2005). Whilst this undoubtedly occurred throughout the project, the PC and researcher found themselves in a position whereby they were transferring new knowledge between two supposedly *connected* actors.

The author believes this illustrates a further feature of the broker; to unearth nuanced pieces of information and transfer such knowledge between two actors, even when a tie is present. Such value seems to stem from the belief that, as an independent entity, actors may divulge information to a broker that they may not ordinarily choose to share between colleagues, despite their relevance or impact upon the project. Certainly, throughout the interviews conducted by the PC and researcher, interviewees would often caveat responses with phrases such as "this goes no further", or "I wouldn't say this to by manager but…". Whilst some of these often led to personal opinions and conjecture offered by the interviewees, many points offered valuable insight into the structural workings of the collaboration.

A particular instance in which this occurred happened when an interviewee was discussing the cultural conditions, which they believed were impairing their ability to perform. Subsequent to detailing their thoughts and concerns, they ended with the following statement "…now obviously I would never say any of this to my superiors as it would be seen as counter-productive to my professional development and promotion opportunities". Such a statement highlights the importance and indeed value a broker brings by retaining a level of objectivity and independence, which should be considered a key tenet of technology brokerage.

Specifically, through maintaining a role of independence, it enables the broker to better elicit the more protected thoughts and motivations of actors, which they would not usually “give up”. Such a role however has distinct ethical considerations and relates closely to the final tenet of brokerage which has been identified throughout this research; power equality.

The concept of maintaining power equality and not seeking to personally profit or gain from it is a major tenet of technology brokerage. If this is not maintained then the ability for a broker to elicit important pieces of information and thus provide value is significantly challenged. Further, the maintenance of power equality can be achieved by a broker in another capacity, as it was in this project. Specifically, the PC and researcher spoke with some actors in the collaboration, who traditionally would not be able to contribute to the assessment due to their relative junior grade. By conversing with this actor and attributing equal value to their perspectives as was to other interviewees, the broker effectively mitigated power imbalances in the collaboration, ultimately presenting views from more junior members of organisation B directly to senior members in organisation A, a traditionally hierarchal company, via the final report.

6.6 Framework Development

The principles identified in section 6.7.2 have been collated and developed into a framework for technology brokerage, an overview of which is illustrated in figure 19. The framework is intended to support consultants acting in a brokerage role to support collaborative technology developments, identifying the required skills they should possess and key actions they should undertake. A more detailed overview of the key themes are presented below.

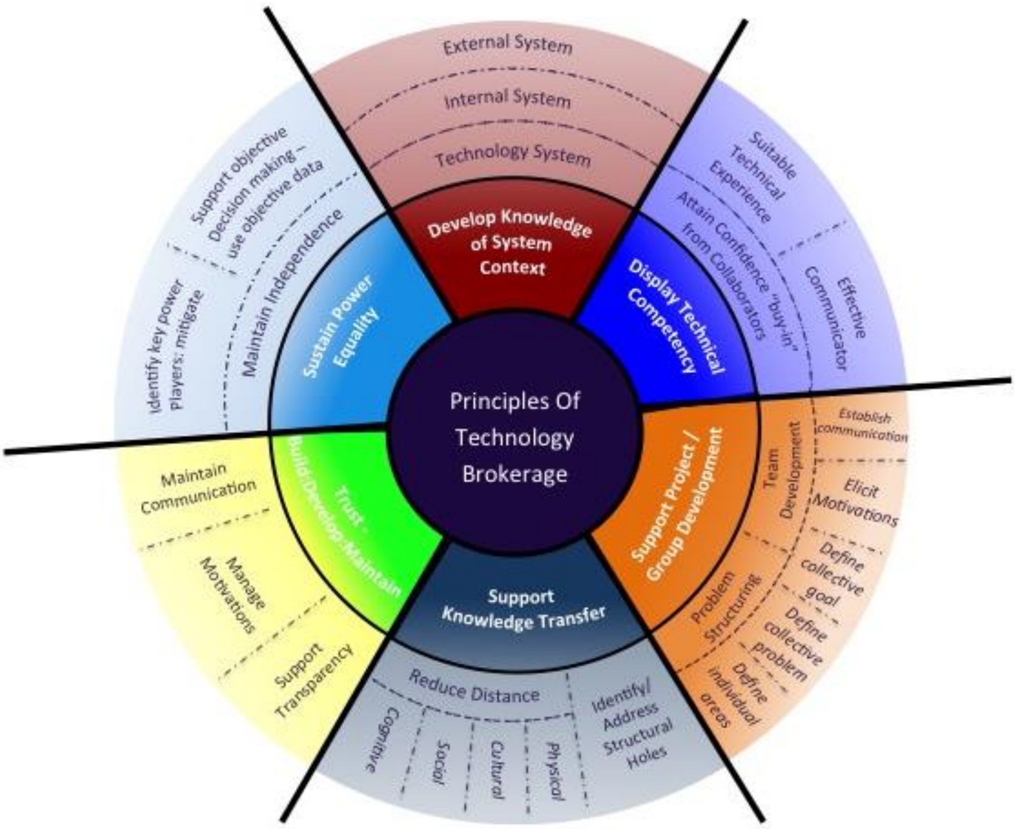


Figure 19: Framework illustrating principles for Technology Brokerage

6.6.1 Develop Knowledge of System Context

This theme refers to the brokers need to contextualise their explicit knowledge by expanding their understanding of the three key systems pertaining to the collaborative situation. Specifically, the broker should define the boundaries of the three system and subsequently expand their knowledge to bridge the gaps.

6.6.2 Display Technical Competency

This theme relates to the need for the broker to demonstrate a level of technical competency, relative to the technical programme they are seeking to assist. Specifically, this technical competency should be used to generate buy-in form stakeholders and support the broker attain a level of respect within the network in order for them to more effectively to deliver value. It should not be used as a source of power for personal gain.

6.6.3 Support Project / Group Development

This theme relates to the requirement of the broker to be capable at identifying team dynamics through the elicitation of individual motivations and objectives. Specifically, it seeks to demonstrate that a broker must have “soft” skills relating to governance and group development as well as the technical skills required.

6.6.4 Support Knowledge Transfer

This theme relates to the need for the broker to be effective at transferring knowledge between both connected and unconnected actors. Specifically, it centres around the concept of reducing distance and seeks to recommend that a broker should be able to identify opportunities to reduce distance across four key areas; physical, social, cultural and cognitive.

6.6.5 Building Development and Maintenance of trust

This theme refers to the important role a broker must play in terms of enhancing the level of trust between actors in the network. It also refers to the broker’s role as an impartial, objective and hence trustworthy entity, which will support them deliver value across the collaboration more effectively.

6.6.6 Sustain Power Equality

This theme relates to the need for the broker to effectively manage the power imbalances within the group. Specifically, the broker should seek to support actors identified as possessing minimal power, mitigating the gaps in power and ensuring all views and perspectives are considered as necessary.

Chapter Seven

UK Rail Sector Action Case

This chapter is based on work conducted by Frazer Nash Consultancy for a client in the Rail sector. Aspects of this research have therefore been included in a client report as well as presented at the Annual British Academy of Management Conference, 2016, Newcastle.

7.1 Introduction

So far, this research has sought to explore and define the key principles relating to collaborative technology development. It has used the CTD framework as a tool to intervene in two action case scenarios; the first to design and establish a collaboration to support the development of UUVs and the second to assess the effectiveness of an already functioning collaboration in the UK Defence sector. In both cases, an identified limitation has related to the applicability of the framework. Specifically, the framework has been difficult to apply in a consultancy setting and has relied heavily on the skills and experience of those who have applied it.

To address this limitation, this chapter seeks to combine the learning from the CTD framework with the brokerage principles identified in the Technology Brokerage framework in chapter six and create a process to support the development of a novel technology, in the early stages of development. Specifically, where as chapters five and six involved the application of the CTD framework to support a project, this chapter is aiming to base the entire commercial offering on a developed process, informed by the CTD and TB principles.

Through the utilisation of an action case approach, the primary aim of the research is to better understand how the principles of collaborative technology development and technology brokerage may be formalised to support a more effective industry intervention. Specifically, this chapter seeks to address the following questions

- How can the principles of technology brokerage and collaborative technology development be formalised to support organisations in a useful way?
- How may the principles be applied via a commercial offering?

The research in this chapter has been conducted on a consultancy project. The client for whom the work was conducted was a steel manufacturer operating in the telecommunications sector. The purpose of the project however was to assist the client in the development of a composite technology concept, which was to be introduced into the UK Rail sector. As the client had no prior experience either in the development of composite products or supplying technology to the UK Rail sector, the aim of the project was to provide the client with an understanding of potential development paths, identify internal skill shortages and potential collaborators, as well as to better understand the market appetite for the product. Ultimately, the research was to provide the client with the necessary information needed to make an informed decision on the future investment of the product.

7.2 Objectives

The primary objective of this research was to support the client make an informed investment decision, as to whether or not they should continue to develop a novel technology concept for introduction into the UK Rail sector. Specifically, the research consisted of the following core objectives;

1. Identify the potential market size over a five-year period for the proposed technology
2. Identify competitors and current incumbents
3. Identify the market appetite for the proposed technology
4. Identify the acceptance process of the proposed technology customer and subsequently indicate potential development paths and timeframes
5. Identify skill gaps within the organisation
6. Identify potential collaborators to support continued development
7. Identify funding opportunities

7.3 Approach

The research in this chapter adopts an action case approach, as outlined by Braa and Vidgen (Braa & Vidgen 1999). The format of the research follows the four phases of the action research loop as defined by MacIsaac; Plan, Act, Observe, Reflect. However, due to time constraints, only one application of the action research loop is conducted.

As indicated in the introduction, the primary focus of the research is to develop a process to support the collaborative development of a technology, based on the principles of the CTD framework and TB framework. Specifically, the process is to be used to support an investment decision, providing the necessary quantitative and qualitative information to enable the client to make an informed decision as to whether continued development would be worthwhile. To effectively evaluate the value of the developed process, it will be applied alongside a traditional market assessment, which would be the usual approach for such a project.

To appropriately address the research questions of this study, the plan phase will consist of two phases. The first phase will introduce the process, which is informed from the two frameworks created in previous chapters. The second phase of the plan will highlight how the research intends to apply the process throughout the course of the project. In order to accurately test and validate the developed process, it will be applied as part of the "act" section, where comments on the approach and key findings will be detailed. The observation phase will detail the response of the client and the acceptance of the work. The reflect phase will appraise the success of the application and identify limitations.

7.4 Plan

The plan is split into two parts. Part one introduces the process, which will be applied to support the collaborative development of the technology. Part two highlights the intervention approach the researcher will follow when applying the process.

7.4.1 Process Development

The proposed process outlined here has been developed based on the principles identified in the CTD and TB frameworks. Consisting of six phases, the process for collaborative technology brokerage (CTB) details the key themes which must be addressed in order for a broker to effectively support the collaborative development of a technology, in the early concept stages. An overview of the process is visible in figure 20. Each phase is described in detail in the remainder of this section.

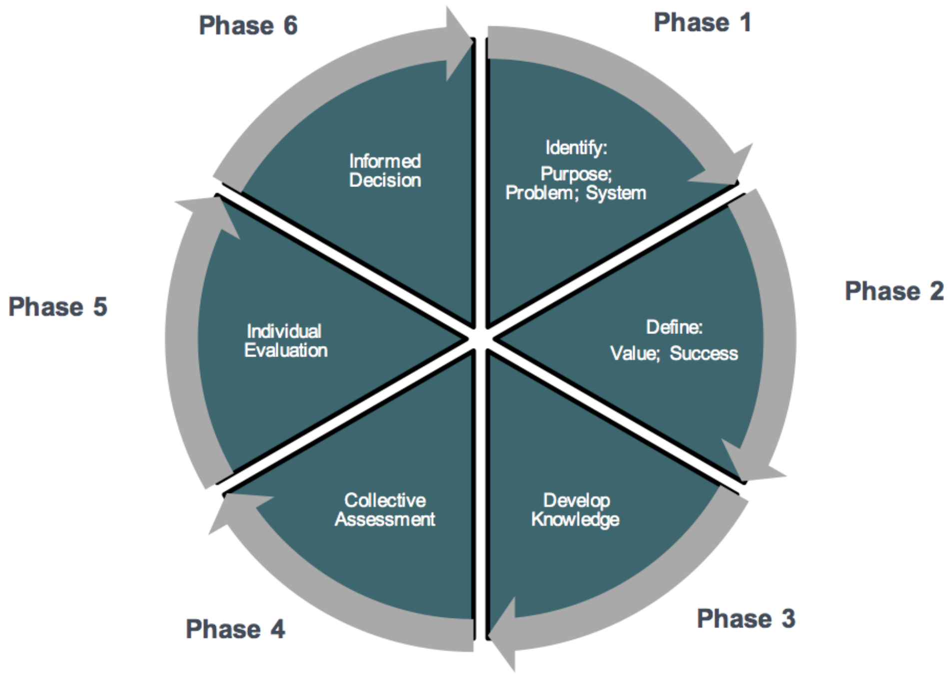


Figure 20: Overview of CTB process

7.4.1.1 Phase One - Identification

The identification phase is intended to provide the broker with the core contextual knowledge pertaining to the collaborative project, which can be used to structure the approach to subsequent phases. The identification phase consists of three key themes, identified below;

- *Identify Purpose* - The initial stage of the process is to define the purpose of the project to be undertaken. As identified in the CTD framework, this stage provides the basic justification as to why a collaborative brokerage approach is being sought and provides a common platform to move forward. The purpose may vary depending on the context of the development and the stance/number of key primary collaborators.

As has been identified in this research, reasons for developing technology collectively range from strategic decisions of network advancement, to simply reducing the financial burden. At this early stage, a clear purpose should be identified and defined.

- *Identify Problem* - Understanding the problem is imperative to progressing with the collaborative development. Based on the context of the collaborative approach, consideration here should be given to the various perspectives of the key collaborators. Understanding that the problem, or at least the priority of problems to be confronted here, may differ depending on the stance and personal motivation of each collaborator.

  Nevertheless, at this stage, priority should be given to defining the overarching collective problem. More detailed exploration of individual priorities for individual stakeholders can be developed at a later stage.

- *Identify Boundaries of Key Systems* – This stage builds on the lessons highlighted in chapter 6 and incorporated into the TB framework. It is designed to support the broker characterise each of the three "systems" by identifying the boundaries of each. By understanding the boundaries of each of the systems, or the "as-is" landscape, it will provide the broker with the contextual basis from which to develop the subsequent phases of the process and define the "gap in knowledge" which needs to be spanned. Specifically, the broker should seek to identify the following;

a. **Technology System**: Relates to the identification of the technology being developed. Consideration here should be given to understanding the proposed function of the technology and the current maturity of the concept.

b. **Internal System:** Relates to the current composition of the collaboration including the structure, governance and partners. Specifically, the broker should seek to identify the current capability of the collaboration, roles of key partners (technical/financial), power distribution and motivations. By identifying each of these, the broker will be better positioned to understand what skills they will need to support the development of the collaboration and help identify what value they may bring.

c. **External System:** The external system encompasses everything not identified as part of either of the first two systems, but which has the capacity to impact the successful development of the technology. This will usually include factors such as market context, competitors, potential collaborators, customers and regulatory bodies. Once the external system has been identified, the intention is for the broker to span the gap between the internal and external system, internalising external factors, through the expansion of the internal system's circle of influence.

7.4.1.2 Phase Two – Definition

The definition phase provides the broker with the key metrics by which to measure performance for the collaborative project. The phase consists of two key themes;

- *Define Value* – Defining the value of the approach is a vital stage to justify the selection of the brokerage approach. Building on the work conducted in chapter 6, a broker typically delivers value across three key areas, which correlate to the three systems defined in phase one;

a. **Technical Competency:** relates to the technical ability of the broker and their ability / requirement to enhance the technology system of the collaboration.

b. **Collaboration Development:** Refers to the value delivered to the internal system. Broker may provide value in terms of supporting the existing collaboration deal with issues such as power diffusion, mediation, trust and communication enhancement, review of structure and governance processes, capability assessment etc…

c. **Network Position:** Relates to the value delivered to the external system, based on the ability of the broker to significantly enhance the network or market position of the collaboration. Typically, this is achieved through spanning gaps to actors not currently present in the internal system, transferring knowledge internally and generally enhancing the capability of the internal system by providing otherwise non-existing links to the external system.

It should be noted that brokerage can provide value in a single area or all three. The importance of this stage is ensuring that value is being gained in at least one. Without this, there is no justification to pursue the brokerage approach.

- *Define Success* – As identified in the CTD framework, defining success criteria is important to validate the performance of the broker and understand the ultimate output of the process. Consequently, whilst being careful not to be too prescriptive, the criteria for success should be agreed with all key members. Success should also be defined against the key value areas identified.

7.4.1.3 Phase Three – Develop Knowledge of Key Systems

Phase three involves the broker expanding their knowledge base of the three key systems. Based on the findings of phases one and two, the broker should understand the key limitations of each system, based on their identified boundaries and where knowledge is to be acquired base on value areas identified.

Specifically, the broker should seek to understand what partners are currently present within the system and which partners are yet to be identified and connected to. Using their position, they should then seek to bridge the identified gaps and expand their knowledge pertaining to each system. Key activities here include;

- Expanding internal system definition to include key collaborators
- Defining group goals
- Eliciting individual motivations and knowledge
- Establishing communication pathways between actors
- Expanding knowledge of the external system

This is an important phase of the process, where the broker collates the missing system information to construct a multi-world view of the problem space.

7.4.1.4 Phase Four – Collective Review

In this phase, the broker should collate the knowledge developed in the previous phases, together with the key actors identified. The purpose of this phase is to collectively assess the current problem, to ensure the correct one has been identified and structured in an appropriate way, utilising the multiple perspectives of the actors identified and synthesised by the broker. Traditional approaches to support this phase include workshops.

7.4.1.5 Phase Five – Individual Evaluation

Based on the output of phase four and the broker's own technical competency, the broker should conduct an individual evaluation on the outputs generated from the collective review. Specifically, if solutions were identified in phase four, the broker should seek to rank them based on their potential and effectiveness. Similarly, if a different aspect of the collaborative project was discussed, the broker should seek to analyse based on the objectives of the project identified in phase one.

7.4.1.6 Phase Six – Informed Decision

Broker synthesises phase five outputs into an appropriate medium, such as a report or presentation, which can be communicated to key decision makers

7.4.2 Preparing to Apply the Process

An overview of the approach to apply the process is outlined in figure 21.

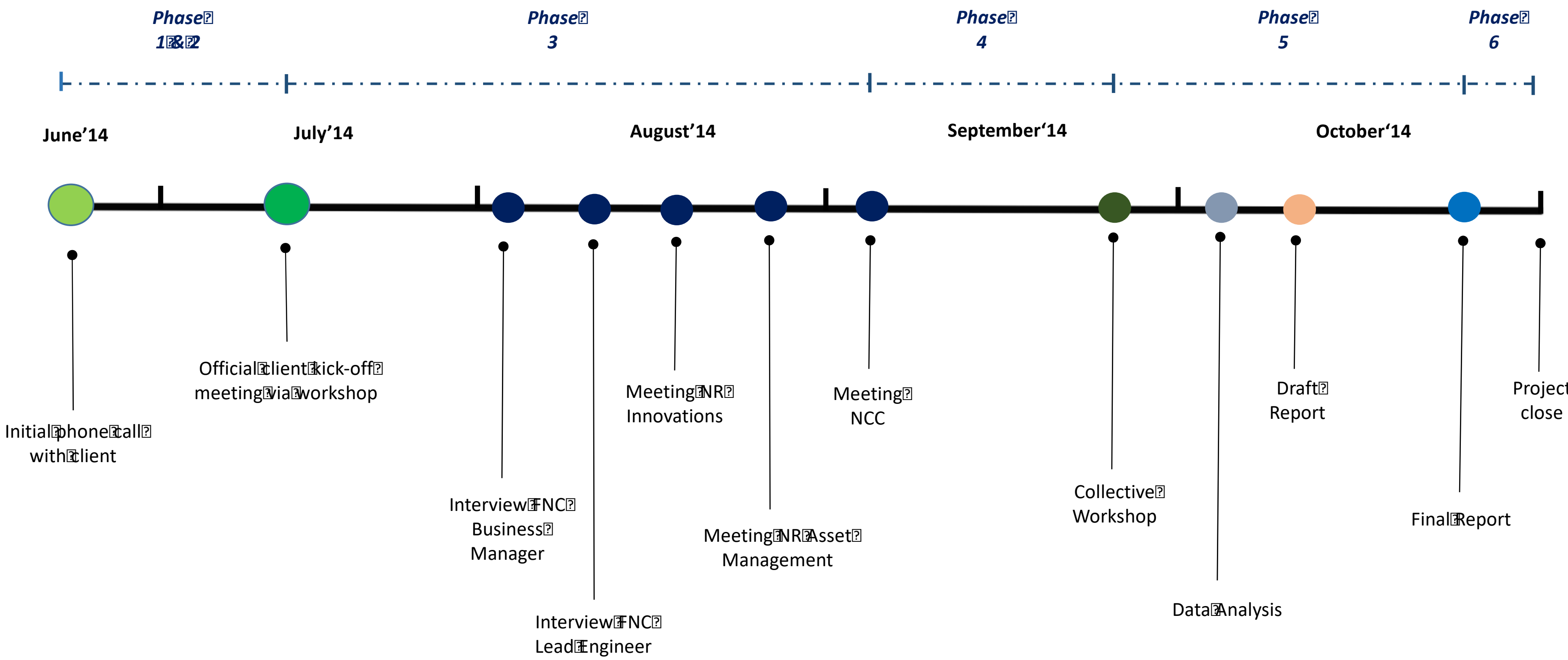


Figure 21: Overview of application approach for CTB process

7.5 Act

This section describes the application of the process, providing details relating to the approach and key findings for each phase.

7.5.1 Phase One – Identification

The identification phase was conducted in an introductory phone call and subsequent three-hour meeting between the researcher, two FNC colleagues and the client. The key outputs pertaining to the three themes are highlighted below;

- *Identify Purpose*
  - The primary purpose of the project was to support the client better understand the development potential of a novel technology concept they had developed. It was identified that the client was currently developing the technology individually, despite having no experience of composite design or manufacture and it wished to introduce it into the UK Rail sector – a sector they had no experience servicing.
  - Ultimately, the client wanted an independent assessment of the markets and of the technology concept in question. Having recently developed a technology for another industry at a cost of £4m, which was ultimately unsuccessful, they were keen to engage with the brokerage approach in order to minimise the risk of the same mistake being repeated.

- *Identify Problem*
  - The overarching problem faced by the client was that they did not possess enough experience or knowledge to make an informed decision as to the likely risks associated with the continued development of their proposed technology concept
  - Specifically, the client faced the following issues
    - The currently maturity of the proposed concept was TRL1 and due to the client's lack of experience with composite design and manufacture, they were unsure of the best development paths

- Having not worked in the UK Rail sector before, they were unaware of routes to market or the process they needed to follow in order to comply with new technology procurement procedures and thus could not identify a likely timeframe for development
- They had no contacts to the rail sector, potential customers or composite designers/manufacturers
- The proposed development costs were based on inaccurate data
- The client had no concept of market size or customer appetite for the proposed technology
- Similarly, they were not aware of competitor products currently on the market
- They had a poor track record of developing technologies successfully, particularly in new market areas

- *Identify Boundaries of Key Systems*
  - Technology System:
    - The current technology concept was of a maturity of TRL1 at most. At the kick off meeting, the only evidence of the concept presented was a single annotated drawing.
    - The client had identified several USP's of the technology, however, these were not validated by any external stakeholders
  - Internal System:
    - The internal system currently comprised of one organisation only – the client
    - Whilst they were interested in partnering with people, they had no experience of collaborating
    - The client did not demonstrate any experience or capability in the development of composite designs or manufacture, despite suggesting these were both capabilities they would like to develop

        - There was a clear hierarchy within the clients organisation, with all development decisions resting with the CEO. The proposed technology had been developed by the chief engineer, who seemed to have little decisive influence over the future investment decision of the product
        - Whilst the client possessed little in terms of technical capability, they were willing to fund the development of the technology, should the market size be of adequate persuasion
    - External System:
        - Given the limited capability of the client and thus the internal system, the external system is viewed as being of significant size
        - The external system would include potential technical, regulatory and funding partners
        - At the initial session, Network Rail and the National Composites Centre were two potential collaborators identified
        - Two competitor products and companies were also identified by the FNC business manager
        - Network Rail was also identified as the end customer and the issue of their funding rounds was raised.

7.5.2 Phase Two – Definition

The definition phase was conducted in an introductory phone call and subsequent three-hour meeting between the researcher, two FNC colleagues and the client. The key outputs pertaining to the two themes are highlighted below;

- *Define Value*
    - The identification of the system boundaries highlighted that the client needed significant support in terms of technical competency and expanding their network into the external system. As a result, these were the two areas FNC identified they could provide value.
    - Technical competency value:
        - FNC possessed significant experience of composite design and working with composite manufacturing processes

- Had experience of successfully developing technologies, including experts in technology roadmappiing
- F`NC had a working knowledge of other products, similar to the composite product proposed by the client. Therefore, would use this knowledge to understand the perceived value of client technology

- Network position value;
  - FNC had experience of working with Network Rail and was aware of their procurement process
  - Also had existing links into organisation, which could be used to "elevate" client's proposed technology to a position where it could be reviewed on the basis of it's value and unique selling points
  - Had existing contacts with composite manufacturers
  - Had contacts and influence over a non-for-profit government organisation, which had been established to invest in promising future technologies, which could positively impact the rail sector

- The main value areas provided by FNC to the client then involved enhancing the technical capability of the client through the technical competency of the broker's firm and advancing the client's network position, utilising the broker's own market position as a vehicle.

- *Define Success*
  - Project success was defined with the client as achieving three main outcomes
    - A market analysis identifying potential size over the next 5 years (addressable and accessible market)
    - An understanding of the customer appetite for the product
    - An outlined technology development path, identifying key tasks needed to be complete to develop a prototype

7.5.3 Phase Three - Develop Knowledge of Identified Systems

The development of the broker's knowledge across the three systems was structured based on the identified boundaries of each system and hence the current limitation of each. The broker approached each system independently and an overview of the approaches and key findings for each are detailed below;

- *Technology System:*
  - Approach
    - The broker undertook a desk study as well as interviewing several FNC colleagues to better understand the key competitors to the proposed technology and how to best develop the design of the composite concept to the prototype stage
  - Key Findings
    - Two competitor products were identified
    - Although neither were fabricated from composite material, one of the competitors demonstrated the same benefits as proposed by the client's technology
    - It was identified that the chosen composite material was not currently approved for the proposed use of the technology in the UK Rail sector
    - The acceptance process of the customer, Network Rail, consisted of four main stages
      1. **Application stage:** product must demonstrate it meets NR need
      2. **Assessment stage:** product evaluated against specific assessment criteria
      3. **Operational trial stage:** Trialled at NR facility. Typical length of trial is 18 months
      4. **Acceptance stage:** product acceptance certificate (PAD) is issued
    - The total time for the NR acceptance process was estimated at two years

    - For a new technology to be considered for the process, it had to be demonstrable in a prototype capacity
    - Interestingly, the prototype did not have to take a physical form, but should be capable of demonstrating functional capabilities

- *Internal System:*
    - It was decided that the internal system was already well enough defined for the broker to provide value. It had been identified that the capability of the client was minimal in terms of designing and manufacturing composite technologies, although there was an intent to develop such services.

- *External System:*
    - Approach
        - The broker undertook a desk study as well as interviewing two representatives from Network Rail. The first NR employee an innovations manager and was interviewed to understand the customer appetite. The second NR employee was head of Asset Management and was interviewed to understand the potential demand for the proposed technology over the subsequent five-year period.
        - The broker also interviewed two employees from the National Composites centre (NCC). The NCC were representing the composite manufacturing considerations.
    - Key Findings
        - It was identified that over the forthcoming 5-year period, two markets existed
            - The new electrification market: NR were electrifying 1,700 miles of track over a 5-year period. It was estimated that this market had a total value of £33m
            - The renewals market: Involved replacing the identified technology with new products. Estimated value was £500,000

- Despite the market size estimated at £33.5m, the study also identified that not all of this market was accessible. In fact, given the position of incumbent technologies and a 2-year development phase for the client's technology, the actual accessible market was appraised as £13m
- NR did not believe that the identified benefits of the client's technology were of significant improvement to the incumbent technology and thus their appetite for it was low
- However, they were intrigued by the concept of a composite design
- NR also advised that there was a fund available to support the development of novel technologies. However, in order to access this, the proposed technology needed to demonstrate functionality

7.5.4 Phase Four – Collective Assessment

The collective assessment phase was conducted by the broker in the form of a workshop. The purpose of this phase was to collate all of the knowledge gathered by the broker so far and discuss it in a structured way with key actors, who would form the basis of the collaboration moving forward. The approach was informed on the basis of the knowledge the broker had acquired throughout the process of phase three. Specifically, whilst the primary objective of the work was to advise on the best development path to generate a physical prototype, the data the broker had gathered up until this point suggested that this would not be the most constructive way to progress.

As a result, the broker developed an approach, which sought to understand alternative development paths, which would best compliment the efficient development of the technology based on the views of all collaborators. The approach involved the development of a presentation, which synthesised the learning of the broker to date. This was delivered to all attendees at the beginning of the session to enable a common understanding and reduce any cognitive or social distance. Attendees were then ascribed roles (depicted in table 9), to ensure each of the four partners identified in the CTD framework were represented at the workshop. Finally, an interactive process was run in which several development options for prototype generation were discussed. The key findings of the workshop are presented below.

Company	Person	Role
FNC	Author	Broker
FNC	Consultant	Mediator
FNC (Representing Network Rail)	Business Manager	Regulatory / Funding Partner
FNC	Engineering Lead	Technical Partner (Design)
Client	Managing Director	Core / Technical / Funding Partner
Client	Chief Engineer	Core / Technical Partner
Client	Accounts Director	Core Partner
Client	Director	Core Partner
Client	Role Unknown	Core Partner
National Composited Centre	NCC Person 1	Technical Partner (Manufacturing)
National Composited Centre	NCC Person 2	Technical Partner (Manufacturing)

Table 9: Workshop attendees characterised by role and company

- Key Findings
  - The workshop re-defined the key requirements of what the prototype should seek to satisfy. The majority of collaborators present believed the emphasis at prototype stage should be on demonstrating functionality, in some capacity, rather than demonstrating physical dimensions.
  - The approach led to the identification of three development options
    - Option A – represented the original concept, which was to develop the design into a physical prototype, but which did not demonstrate any functional capability to be tested
    - Option B – develop a physical prototype with functionality capability
    - Option C – develop a digital prototype, capable of demonstrating functionality through simulation

- Development timeframes were identified for each option
- A discussion ensued around which option represented the least risk development, whilst delivering maximum value and return on envisaged investment
- Despite option C seeming to represent the least risk option, the client remained wedded to Option A. It was at this point of the workshop that the discussion began to stall. The conversation instead began to be dominated by the MD of the client's organisation who insisted on pursuing option A, whilst remaining dismissive of any other discussion regarding alternative options. They did not see a value of developing a prototype which demonstrated functionality at this stage and would not entertain the idea of a digital prototype. Despite the best efforts of the broker and mediator, the meeting drew to a close 30 minutes ahead of schedule.

7.5.5 Phase Five – Individual Evaluation

The individual evaluation involved the broker analysing the output from the workshop, together with the data collected throughout the project. Utilising information from NR and prioritising the assessment to minimise the risk of development, the analysis assessed the three options. The analysis confirmed that option C posed the least risk and therefore the preferred development option, subsequently corroborated by the FNC BM.

7.5.6 Phase Six – Informed Decision

To support the informed decision, a report was generated by the broker. The report detailed the following;

- Quantitative market assessment, detailing;
  - Addressable market over five-year period
  - Accessible market over five-year period
- Qualitative market assessment detailing;
  - Network Rail acceptance process
  - NR perception of technology benefits
  - NR appetite to procure and support development

- Assessment of barriers and drivers to market detailing;
    - Three potential development paths for maturation of concept
    - Identified capability of client, linking with suggested partners focussing on four key roles of collaborative technology development
    - Identified competitors and incumbent technologies
    - Identified funding sources and potential funding partners
    - Exploitation model detailing commercialisation process
- Conclusions

The conclusions of the report ranked the three development options in terms of risk. The least risk option was perceived to be the development of a digital prototype, which demonstrated functionality through simulation. It was appraised that this would best satisfy the requirements of all collaborators and provide the best opportunity for the client to secure further support in terms of technical, financial and regulatory, for continued development of the concept. It also represented the most cost effective option. The highest risk option was the development of a physical prototype, which demonstrated no functionality.

7.6 Observe

The outcome of the process was a report, which detailed the key information requested by the client at the outset of the project. It also provided additional information, in the form of two alternative development paths for the technology concept. As detailed in section 7.5.6, the three options were ranked based on their perceived risk and likelihood to progress to the next phase of development.

Despite option C being ranked as the most favourable option, the client's opinion remained unchanged from the workshop and opted for option A – the original development option. The process had assessed this to be the highest risk approach and significantly more expensive than option C.

Several months after the project had concluded, the client had invested a further £60,000 into the development of a composite prototype, which demonstrated no functionality. The prototype was presented to NR in the attempt to access funding for the continued development of the technology. Unfortunately, the technology was turned down for funding on the basis that NR could not invest in a technology, which did not demonstrate proof of concept.

7.7 Reflect

The CTB process was developed with the explicit intention to understand how the principles of the CTD and TB framework could be combined and applied in a practical setting. In this chapter, they were sought to support an investment decision of a client, minimising the risk of the development of a composite technology concept. Based on the outputs of the approach, the author considers the CTB process to be largely a success.

Specifically, the application of the CTB process in this instance was conducted alongside the application of a traditional market assessment. The output of the market assessment suggested that the market for the technology was of significant size, valued between £13m and £33m. However, that approach did not seek to evaluate any other considerations involved in the development of the prototype such as client capability, customer appetite, customer acceptance process, competitors and incumbent technologies, potential partners or exploitation models. As a result, the output of the market assessment represented only a fraction of the information required to make an appropriately informed decision, when compared to the CTB process.

A particular feature of the CTB process, which proved valuable was the characterisation of the various systems. Commencing in phase one, the broker utilised the three-system terminology to quickly identify the capabilities and thus limitations of the technology and internal systems. This in turn allowed for the external system to be identified, focussing on aspects such as partners which would benefit the internal system and began to frame the scope of the problem. This early system identification and definition stage also supported the broker better identify the areas in which the approach would deliver value. Specifically, in phase two, the limitations of the systems enabled the broker to identify that value would be delivered in terms of identifying and connecting the client to partners who could enhance their understanding of development issues, as well as providing added technical competency to the development of the technology.

The value of the system characterisation continued throughout phase three. Here, it enabled the broker to better understand exactly where knowledge was to be acquired and in what context it needed to be understood. Specifically, it became clear that further understanding of the technology and external systems were required in order to progress with development. This enabled the broker to focus their attention on the various aspects of these systems.

The importance of the three-system characterisation through the first half of the process provides further validation to the observation in chapter six that a broker must first expand and contextualise their knowledge if indeed they are to impart value. The framing of the various systems was conducted with the very intention to identify the "boundaries" of knowledge which existed and subsequently seek to "span those gaps". Further, through engaging with actors outside of the internal system, viewed as potential partners, primarily in an isolated environment away from the client, the broker was able to develop relationships and tease out more pertinent issues, which would prove valuable to the development of the technology. Specifically, this approach led the broker to identify that the current development path of the technology was perhaps not the most constructive in terms of maximising the opportunity for success.

As the process moved into the fourth phase, the project moved from knowledge expansion to knowledge convergence and analysis. The workshop approach proved effective, commencing with a presentation to minimise the social and cognitive distance between all actors present. The workshop then progressed to cross-examine the defined benefits of the technology and the pursuit of the identified development path to generate a physical prototype. By conducting this process with the collective skills of all actors present, the purported benefits of option A were brought into question. As a result, two alternative development options were able to be generated; something not possible through the traditional market assessment.

The value of the collective workshop undoubtedly benefited from the classification of actors into various roles. However, upon reflection, this is also where the broker failed to account for the complete characteristics of identified roles. Specifically, the broker did not account for the power dispersal between the actors present and the ultimate influence each could impart upon the final decision. As illustrated in section 7.5.4, the MD of the client organisation was not overly fond of the alternative development options identified. As the workshop progressed they became more dismissive when discussing them and visually agitated when identifying the risks with option A. The author believes this occurred for several possible reasons.

One of the roles ascribed for the purpose of the workshop was a FNC business manager representing NR in a regulatory and customer capacity. This was coupled with a Lead Engineer, also from FNC, occupying a technical partner role, brought in to provide technical expertise on the design of composite products. As the workshop developed, it became apparent that the client MD and Chief Engineer were weary of the suggestions and contributions posited by the FNC representatives. Specifically, it was the engineering lead who initially suggested the development of a digital prototype and the FNC business manager supported it. As the idea gained traction, it was apparent that the client did not possess the capability to develop a digital prototype, but FNC did. Quite quickly, the motivations of FNC representatives, including the broker's were called into question. In hindsight, the client clearly felt that FNC were attempting to manipulate the situation to gain further work. This was not the case, but the author can see how it may have been perceived that way. As a result, the broker's perceived role as an impartial and subjective entity no longer existed and the workshop drew to a close.

This observation is important in terms of it's impact on the future development and employment of the CTB process. Specifically, it illustrates that despite the process employed and the accuracy of the results yielded, the role of the process appears to be limited based on the power of the broker to influence final decisions. For instance, the process applied here was an attempt at a unbiased collective approach, which sought to understand the least risk

However, the author does not believe the fact the client chose a different option renders the process a failure. In fact, as that option was eventually presented to NR and turned down for funding based on the prototype not demonstrating functionality, the author believes it actually further validates the process, as this was something explicitly identified and communicated as part of the report.

Further, whilst the author can understand the reservation of the client relating to the digital prototype option, it does not explain their disdain for option B, which was generated prior to option C and had the majority support amongst actors. Instead, the author believes that the client, despite their previous inclination, did not see a value, nor want to, par take in a collaborative approach to develop the prototype. Instead, they were more interested in the quantifiable market assessment, which detailed the potential market size.

A further point of reflection highlights the potential for the CTB process to be used to collectively define *problems* as well as solutions. Specifically, the collective workshop actually represented collaborative problem structuring. Through engaging with collaborators around their perspective of the perceived problem, rather than solution, a more in depth, richer understanding of the problem context could be generated. This allowed for a more rigorous appraisal of the initial design concept proposed. Understanding how collaborations may form to define problems rather than generate solutions is an area distinctly lacking in research.

Section Three:
Research Findings

This sections consists of the following chapters;

- Chapter Eight: Discussion
- Chapter Nine: Conclusions

Chapter Eight
Discussion

8.1 Introduction

Section two of this thesis has sought to better understand how industry approaches to collaborative technology development may be enhanced. It has adopted a multi-methodological approach, drawing on case study and action case methodologies to explore a diverse range of cases and infer key academic lessons, which may support organisations work together more effectively when developing technology.

This section seeks to discuss the research conducted and identify the implications from an academic perspective. Split into three parts, this section first discusses the three main outputs generated as part of this research. The discussion then moves to synthesise the research through a grounded review of the cases. The purpose of the review seeks to address the third research question, providing a network perspective of collaborative technology development, in an attempt to better understand how failure may be inferred based on the distribution of actors when measured against three key themes. Finally, the limitations of the research are identified and areas for further research suggested.

8.2 Review of Key Research Outputs

Throughout this research, three main outputs have been developed. This section discusses the outputs generated, identifying the implications for literature, the limitations of the research and suggesting how they may inform future avenues for further research.

8.2.1 Output One: Collaborative Technology Development Framework

The CTD framework developed as part of this doctorate sought to address a core line of enquiry of this research; to understand the principles one should consider, when designing collaborative approaches to support technology development. Building on extant literature identified in chapter two, the framework initially took shape based on the learnings of two cases in chapter four. Subsequently, the framework was tested through an action case approach, with clients in the Marine and UK Defence sector (Chapters five and six). The output learning from these cases generated an iterated and validated framework, and demonstrated its value in the contexts of both designing and assessing pre-formed technology development collaborations.

The framework identifies nine key principles, which should be considered when designing a collaborative technology development. Whilst four of these principles were identified as part of the literature review in Chapter 2, five have been informed from the industry studies and trials. Further, of the principles pre-identified within the current body of knowledge, some have been revised based on the experiences of this research.

Partner selection is one such principle, which was enhanced as a result of this research. Specifically, two key sub themes were identified as important when considering which partner's to select; the approach to identifying partners and the categorisation of partners across four main roles. The first aspect of this, the partner selection approach, is an area widely covered in the literature. However, a significant amount of this research emphasises the benefit of a particular approach to performing this. This research highlighted that in industry, quite often no formal approach is followed. Instead, the focus is more pertinently placed on how a potential partner perceives the collaborative endeavour, with preference ascribed to partners who buy into the proposed value of the collaborative approach.

The second aspect related to the characterisation of partners based on their role and contribution. Specifically, four roles were identified as integral to collaborative technology developments; core role, technical role, regulatory role and financial role. To date, extant research has only focussed on how a potential partner may enhance a technology development based on their technical skills. There is scant research that seeks to understand how categorising a potential partner in one of the other three roles delivers value. Of particular note here is the absence of any research which emphasises the importance of a regulatory partner in the development of a new technology. As is evidenced in the cases throughout chapters four and five, the inclusion of such a partner may prove integral to the ultimate success of that technology. It also emphasises the need to address the wider aspects of technology development in a collaborative context, outside the technical considerations, to maximise the opportunity for successful technology integration.

The fourth identified role, a financial partner, is inextricably linked to another of the framework's identified principles; Financial Mechanism. The cases in chapter four illustrated the impact of the funding mechanism in each of the collaborations. In fact, in both situations, the funding mechanism seemed to be a core driver in the pursuit of a collaborative model. Of particular relevance here is the source and structure of the funding and how this interrelates with other partners across the collaboration.

Interestingly, extant literature does not seem to consider the funding of a collaborative development as important to it's development. Indeed some scholars have even suggested the opposite; that finance has minimal to no impact on the formation of a collaboration (Hagedoorn and Schakenraad, 1993). However, the author believes this research illustrates otherwise and that understanding the source and structure of funding as well as characterising partners based on their financial contributions is an important principle of collaborative design when developing technology.

A further principle identified in the CTD framework is the importance of the context, in which the collaboration is occurring. Identified as part of the first trial of the framework in Chapter five, contextual consideration proved an important step in the design and development of the collaborative approach. This was further confirmed in chapter six, where it was clearly illustrated that the contextual conditions, specifically the culture, in which the collaboration was occurring were negatively impacting the collaborative approach. Interestingly, the author can find minimal evidence of research exploring the impact of context on collaborative endeavours in the context of technology development and whilst scholars such as Vangen (Vangen 2016; Vangen & Huxham 2012) have sort to draw a connection between the complexity of context and achieving collaborative advantage, it has not been explored in relation to technology development.

Although the research exploring collaboration formation is reasonably expansive, the author believes the CTD Framework represents a genuine and novel contribution to knowledge. The identification of principles such as context and funding mechanisms as well as suggesting the characterisation of partners on the basis of the four identified roles distinguish it from other approaches such as BS11000. The application of the framework to design a collaborative approach in Chapter 5 and assess a current collaborative set up in Chapter 6 validate the identified principles and demonstrate the value of the framework in an industry setting.

Further, as well as addressing the first research question posed in Chapter 3, the CTD framework contributes to the literature gaps identified in Chapter 2. Specifically, the author believes that the development of the framework provides a unique collation of principles, capable of informing collaborative design in the context of technology development. Further, the application of the framework in several action case scenarios demonstrates the value in a practical setting and offers insights into the constructive application of collaborative principles within industry.

A clear limitation of the framework is the cases it has been applied to and the process through which it has been applied. Specifically, it has only been trialled with engineering firms in the context of technology development. Understanding the value of the framework in more general collaborative endeavours would be a useful piece of further research. Further, the framework has been applied in each instance by the author and so it is difficult to assess whether it could be applied to similar effect should a user less familiar with the subject of collaboration be the primary applicator.

8.2.2 Output Two: Technology Brokerage Framework

The Technology Brokerage framework was inferred based on extant literature and the research conducted in Chapter 6. It seeks to address another main line of enquiry of this doctorate; how can a broker benefit a collaborative approach and what characteristics should define them. The framework builds on existing theory pertaining to brokerage and provides what the author considers to be the only attempt at summarising the key principles a broker should to possess, in order to positively assist a collaborative technology development, into a singular framework.

The TB framework identifies six key themes, each of which consist of several sub-themes. Three of the themes; Support group development, Build maintain and develop trust and Support knowledge transfer are well documented in the literature (Parjanen et al. 2011; Vangen & Huxham 2003; Huxham 1996; Gray 1985; Taket & White 2000) with the framework seeking to utilise them in the novel context of technology development.

A further theme identified in both the literature and the framework is technical competency. The TB framework identifies that a broker should demonstrate a significant level of technical competency, in order to gain the “buy-in” of stakeholders and attain a position of significant influence for the benefit of the collaborative endeavour. It is this influence, which supports the broker provide value to the collaborative technology development. The importance of technical competency in the role of brokerage is not a new contribution in itself. However, scholars to date, such as Hargadon (1997) suggest that the technical competency and experience of a broker should be used to elevate them to a position of power. Specifically, Hargadon views technical competency as a way to control other actors in a collaborative setting and personally benefit the broker. The inclusion of technical competency in the TB framework has a different purpose. The author does not believe that a broker should ever benefit personally based on their experience or competency. Instead, they should apply this to position themselves advantageously in the collaborative network, which allows them to negate any power imbalances that may exist.

This theme of power also relates closely to the fifth theme identified; Sustaining power equality. Again, the theme of power and it’s relation to brokerage is not a novel contribution. Indeed, as identified in chapter 2, power forms a significant body of discussion in the extant brokerage literature. However, what is important here is the clarification that a broker supporting collaborative technology development should not seek to capitalise personally from power imbalances across the group. Instead, the research suggests that a broker must retain a form of independence and impartiality. This view is supported by scholars such as Dodgson (1993).

The framework continues to define a sixth principle; Develop knowledge of key systems. This theme highlights the need for a broker to contextualise their specific technical knowledge in order to appropriately provide value to the collaborative approach. This concept is something that is not explicitly explored in the extant literature, as identified in chapter two of this thesis. Indeed much of the literature around brokerage seems to focus on the ability of a broker to "span gaps" (Burt 2004; Nooteboom et al. 2007; Granovetter 1983) and transfer knowledge from an external source to a new group of actors (Hargadon & Sutton 1997; Hargadon 1998; Burgess & Currie 2013; Currie & White 2012a). It ignores however the need for a broker to first contextualise their explicit knowledge in the new environment of the technology development in order to effectively deliver this value.

As illustrated in Chapters six and seven, this process of expanding a broker's knowledge around the key technological issues as well as defining internal and external contextual conditions provides the broker with the relevant basis of understanding upon which to act. This research illustrates that without such contextualisation, a broker cannot provide value to a collaborative technology development. Such an observation is something which the extant literature does not identify. Further, it also provides an indication of how the principles of brokerage, and indeed collaboration, transpire in a practical setting. Specifically, it identifies the role a broker must play in expanding their knowledge base, utilising their technical competency and impartial role to elicit protected information pertinent to the collaborative approach, mitigate power balances, develop trust and relationships and transfer knowledge between unconnected and *connected* actors in order to successfully apply the CTD framework.

Understanding how brokers, or indeed consultants, support collaborations in a practical setting is a gap in the literature identified in chapter 2 and forms the basis of the second research question. Whilst the TB framework does not advocate a specific process per se to address this gap, the author believes that through the unification of six principles pertinent to technology brokerage, it provides a better understanding of what skills someone requires in order to positively impact and support collaborative technology developments. Consequently, it enhances the literature around this area and begins to address the questions identified in the second research question of this thesis.

A key limitation of the TB framework is that it has been inferred on the basis of a literature review and single case study. Whilst there are crossovers in principles between the CTD framework and the study of brokerage to support collaborative technology development, the author must concede that the principles are not inferred on the basis of a significant data set. However, the author does believe this limitation is mitigated somewhat when reviewing the approach taken in chapter 7. The process developed and applied in that context (as discussed in 8.2.3) was based significantly on the principles identified in the TB framework and many of the principles are confirmed throughout that particular study. However, in order to truly understand the accuracy of the framework, it perhaps require further testing.

Nevertheless, the author does believe the framework constitutes a first attempt to unify the principles of brokerage in relation to technology development, addressing a key gap identified in this research. Further, the TB framework serves as a good starting point to further explore the principles. Indeed a further piece of research should be based around that and seek to further validate the framework on similar cases, either retrospectively or in action.

8.2.3 Output Three: Collaborative Technology Brokerage Process

The third output of this research is a process for Collaborative Technology Development. Developed as part of the research in Chapter seven, the approach seeks to address the second research question of the doctorate. It was also an attempt to satisfy the requirements of the author's host organisation Frazer Nash, by combining the principles of the two frameworks into a process which could be delivered to clients commercially.

The CTB process identifies six key phases to support collaborative technology development. The first three phases focus on identifying and defining the "as-is", categorising observations into three distinct systems. This definition of the as is supports the identification of system boundaries and thus, where value can be delivered by the broker and ultimately where they should seek to expand their knowledge base in order to provide that value. The final three phases then focus on the convergence and analysis of this knowledge, utilising the skills of the actors present to form a novel perception of the problem space to minimise the risk of an informed decision.

In Chapter 7, the CTB process is applied to support an investment decision into the development of a novel technology in the UK Rail Sector. Whilst the author recognises the limitations of this application to infer general theory pertaining to all interventions in collaborative situations, it still illustrates some key points of learning, which may support further enquiry into this area.

Specifically, the process demonstrated that there is significant value in conceptualising collaborative technology developments into three systems. This supported the broker identify current limitations and boundaries with the current set up, from which value streams could be inferred and potential partners to "span the gaps" identified. It also served as a useful way to communicate the service to the client to demonstrate how the broker was delivering value.

Further, it also demonstrated the ability of a broker, through their impartial role, to independently capture perspectives of individual actors, and subsequently synthesise these into a holistic understanding of the problem space. Using this as the basis to then present back to the actors in a collective setting enabled new discussions to take place and identify novel issues and ultimately development options for the proposed technology. Building on the observations detailed in Chapter 6, this further emphasises the importance of the role of the broker in not only transferring knowledge, but expanding, collating and analysing knowledge in order to provide value to the collaborative set up. It also demonstrates the necessity of impartiality in order to perform such a task.

An interesting aspect to the application of the CTB process occurred in the fourth phase; the collective workshop. As illustrated in Chapter 7, the project in which the CTB process was to be applied involved working with a client who had verbally stated their desire to collaborate with external partners in order to enhance their technical capability. However, given this earlier intimation, their behaviour in the collective workshop seemed counter intuitive to support this. Specifically, the MD of the client's organisation would not entertain discussion around alternate development paths and was dismissive of anything, which did not relate to the original development option.

Whilst this made the workshop difficult to run throughout the latter stages and ultimately contributed to the client opting not to follow the advice generated through the CTB process, it provided an interesting insight into the governance of actors when applying approaches in a practical context, Specifically, it illustrated the importance to appropriately consider the distribution of power throughout the collaboration in which the approach is being applied. Until this point, whilst the broker had sought to allocate roles to the workshop attendees, these were based on those defined in the CTD framework and did not reference power.

Further, whilst the importance of power had been considered in the TB framework, it had been done so from the perspective that it is the broker's duty to support the less powerful actors and elevate them to a position of equal standing. It had not sought to address actors who demonstrate high power positions. Perhaps rather naively, it had been assumed that the actors in such powerful positions were in such a position as they were advocates of the collaborative approach and their power would not detriment the approach in a negative way. Based on the experiences of applying the CTB process, this was a clear oversight.'

The application of the CTB process also illustrated the fluctuating demands of clients within industry. Often, literature pertaining to theoretical frameworks and principles will characterise actors based on a static assessment and use this to inform an approach. In reality, actors, specifically clients, can be much more “dynamic” and “whimsical” in their thoughts, demands and requirements, evidenced in Chapter 7 through the conflicting stance of the MD; from advocating a collaborative approach verbally, to conducting actions that appear to not support such an approach.

This observation highlights an interesting aspect of collaborative research, which has yet to be addressed. That is, the dynamic and shifting requirements of clients and the relationship of this to actor power and collaborative outcome. In chapter 7, the power of the MD at the outset of the project was responsible for commissioning the work and so, in the view of the broker, this was a positive thing. However, by stage 4, this power seemed to act more as a hindrance as the MD no longer demonstrated an appetite to collaborate. The concept that power can act as a hindrance to the development of collaborative approaches is not something which has not been explicitly explored in the extant literature. Further, understanding how to cater for such shifting demands in high powered actors would constitute a novel and important piece of further research. Similarly, understanding how a broker’s power should relate to the power of other actor’s in the network would also constitute a useful line of enquiry in supporting greater understanding of the balance between broker impartiality and independence and the necessary power required to effectively deliver value.

As intimated at the beginning of this discussion, whilst the author believes the CTB process sheds a new dimension on the application of collaborative principles to support technology development in practice, it is recognised that it has been tested in only a single scenario. Further, the scenario in which it has been tested is relatively niche, given that the focus is on the very earliest stages of technology development and sought to inform an investment decision of a concept. However, the process did highlight a strength of collaborative approaches to developing technology, which has not received much attention in the literature.

Specifically, the process illustrated the potential for collaborative problem structuring to contribute positively to collaborative technology development, rather than collaborative problem solving. For instance, during the workshop phase in chapter seven, aside from identifying possible solution paths, part of the approach focussed on synthesising the knowledge of several actors, to refine and validate the problem space the client was seeking to solve. The researcher considers this a significant area lacking research as currently many approaches seek to use collaborations and collection of disparate entities to **solve** problems. Little research has explored how actors may be best orchestrated to further define problems. This also constitutes an active area of research of the researcher, who is currently commercialising an approach to do just this, in an attempt to enhance the opportunities for innovation in the water sector. However, further research into the value of collaborative problem structuring to support technology development would be a valuable avenue of research.

8.3 Synthesising the Research

The overriding theme of this thesis has been to understand how to minimise the risk of failure when organisations are developing technology collaboratively. To address this issue, the research has produced three main outputs, as indicated in section 8.2, which seek to enhance the ability of organisations to better work together. Each of these approaches were developed and applied based on industry cases of organisations actively collaborating to develop a novel technology. Although each of these cases were diverse in terms of context and the stage of technology development, they provide a common platform through which to try and understand the key themes which may influence the likely failure, or success of a collaborative technology development.

As a result, the author has attempted to synthesise the learning from this doctorate by conducting a grounded review across the cases. Attempting to better understand why some of the cases succeeded and why some failed from a network level perspective in order to address the third research question of this thesis, this section identifies three themes which may influence the outcome of a collaborative technology development. Specifically, this section describes how the interrelation between three key themes identified as a result of the research, can be used to infer the likely chance of collaborative failure, based on an assessment of actor distribution.

Theme One - Collaborative Behaviour of Actors:

The first key theme this research has identified, which is vital to the success of a collaboration is the collaborative behaviour of the actors involved and their willingness to collaborate. Throughout the various cases, the researcher interviewed and worked with many of the people responsible for supporting the development of each technology. During this time, what became apparent was the differences in attitudes and approaches of actors involved and the impact the various behaviours had on the ultimate success of the technology development.

Expanding on this point, the author considers the ASTRAEA case an exemplar in terms of a successful approach to collaborative technology development. From interviewing the lead broker for this project and the depth of data compiled as part of the research, it is clear to the author that all actors involved with ASTRAEA were highly motivated and incentivised to work together. As a result they demonstrated a high level of collaborative behaviour. This is evidenced in chapter 4 when referring to the number of meetings, the sharing of sensitive data between rival firms traditionally notorious for their secrecy and the level of communication maintained throughout the 8-years. It was this high drive of the actors involved to collaborate, which undoubtedly contributed to the ultimate success of the integration of an unmanned air vehicle into manned airspace.

Similarly, the actors involved with the Carbon Trust OWA case were aligned through similar joint motivations and demonstrated high levels of collaborative behaviour. Again, this is demonstrated through the high volume of communication between key actors throughout the project as well as the positive responses and perspectives of all those involved who were spoken to as part of the investigation.

In fact throughout that particular study, the author was not made aware of any actor or individual who had a negative experience with the collaboration.

Contrasting this finding with the experiences of the author when working with actors involved in the Defence Action Case (chapter 6) illustrates the further importance of the need for a high collaborative behaviour to support successful development. In this instance, the author was confronted by several different perspectives of how the collaboration operated. Perhaps more poignantly were the negative attitudes and beliefs held by individuals towards colleagues both within their core organisation and the greater collaborative network. These views seemed to foster a negative feedback system, in which such behaviours became almost ubiquitous throughout the collaboration, with few exceptions. As identified in chapter 6, a large issue which negatively impacted the current operation of the collaboration was the cultural context and poor governance structure designed. Ultimately, both of these factors led to the development and exacerbation of poor collaborative attitudes, which were underpinning the stagnation of that particular collaboration. The impact of such behaviours was a collaborative project significantly behind schedule and over cost, in the region of £m's.

Aspects of the importance of collaborative behaviours are identified and implied in the CTD framework. Most notably, the recommendation that a core part of forming a successful collaboration for the purpose of technology development is the agreement of collaborative objectives and a clear definition of success for all involved. However, the defence action case clearly illustrates that the agreement of collaborative objectives is perhaps not significant enough to guarantee success. Specifically, the implication here is the effect that a poor governance structure and indeed context in which the collaboration occurs has upon the behaviours of the collaboration. Whilst this is implied in the framework, due to the limitations of the research at the time, it has not so far been explicitly linked to the impact this has on the collaborative behaviours of actors involved and hence there has been no causality drawn between behaviours and collaborative success.

This finding is further reinforced in the final Rail Action Case. In this instance, the author was part of the very foundations of collaborative formation. As is illustrated in chapter 7, throughout the project, the client for whom the work was conducted indicated a clear desire to work with partners. Their belief was that this would enhance their understanding of the market and their capability to develop the technology concept. However, when the time came to broker such a meeting, the actions of the actors within the client organisation were very much anti-collaborative. Aside from remaining adamant in the pursuit of a development path, which had been illustrated as high risk and not meeting the requirements of the customer, the client was dismissive of other's view point and unprepared to entertain any discussions which challenged their point of view. Ultimately, it proved the client had little interest in a collaborative approach, which led to the demise of the project.

These findings also provide a new opportunity to understand and measure collaborative behaviour. So far trust and communication has been a large focus of this literature (Gulati 1998; Zaheer et al. 1998; Dodgson 1993). However, the author believes that an understanding of how collaborative a person is can be garnered based on their perception of others and the collaboration itself. Should these opinions err towards the negative, the author believes this may indicate a less willing predilection for that actor to work successfully in a collaboration. What is less well understood here though and would form an interesting subsequent piece of research is whether the lack of a collaborative behaviour may be improved with appropriate cultural and governance changes, or if that person is just pre-disposed to not be effective at collaborating.

Theme Two - Technical capability of actors

The second theme identified as important to the success of collaborative technology developments is the technical capability of actors involved. Technical capability relates to the ability of an actor to positively influence the technical aspects of the technology development. In the ASTRAEA case study, it is clear that a great deal of actors possessed a high technical capability and this understanding of which actors were best placed was enhanced by the structural design of the collaboration compartmentalising the problem space into four distinct technical streams. This is remarkably similar to the approach adopted for the CT OWA case and hence there are a great deal of technically capable actors present in that case too.

Conversely, this was not the case in the defence action case. The research identified that there was a distinct lack of adequately capable people in the appropriate positions. This had resulted from contextual issues such as the collaborative culture and poor governance, which in turn had caused a confusion of roles and responsibilities. Consequently, the people performing the technical activities within that collaboration were not appropriately equipped with the necessary skills.

Similarly, the UK Rail Sector action case also suffered from actors who lacked the technical capacity to develop the technology. Interestingly though, the capability was lacking from an organisational perspective, rather than individual level. Specifically, there existed two employees within the client's organisation who demonstrated reasonable experience and knowledge of composite design. However, their unwillingness to collaborate meant the capability of the organisation was not enhanced and thus, they failed to demonstrate an adequate level of technical capability.

In both the Defence and Rail action cases, the collaborative approaches were not successful at the time of assessment. A significant justification for why this was the case can be attributed to lacking the necessary technical requirements to progress appropriately.

Technical capability as important to the development of collaborative technology developments is identified throughout the literature. Indeed it is also referenced in the CTD and TB frameworks, which advocate the need for collaborative technology developments to comprise of the appropriate technical partners and be assisted by brokers with adequate technical competency respectively. The identification of technical capability of actors as important to the success of a collaborative endeavour then may not appear a revelation. However, what is less understood is how the theme of technical capability relates to the theme of collaborative behaviour and in turn, how this duality may impact the outcome of a collaboration.

Duality of Themes One and Two

It has been identified that the collaborative behaviour and technical capability of actors partaking in a collaborative technology development directly influence the potential for failure / success of that project. Whilst the impact of each of these themes individually is important to consider, the author believes it is understanding the duality between them, which has the capacity to effectively indicate the likelihood of collaborative failure. Specifically, it is proposed that by characterising actors present in a collaboration based on their collaborative behaviour and technical capability, the likelihood of failure of that collaboration may be inferred. To understand this correlation further, a simple 3x3 matrix has been developed, as illustrated in figure 22. The two cases outlined in chapter four and the action cases in chapters six and seven will then be used to inform four different plots.

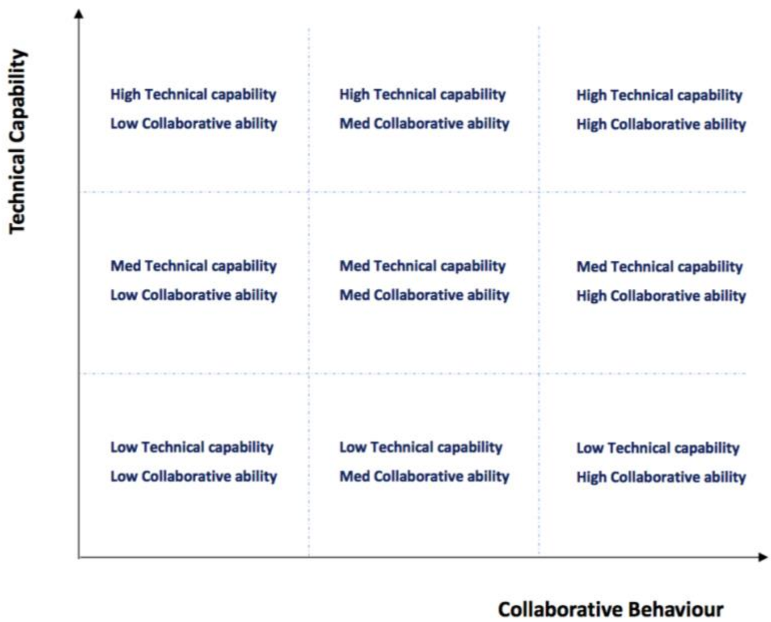


Figure 22: Overview of actor plot characterised by collaborative behaviour and technical capability

As is clear from fig 22 actors will be ranked according to their collaborative behaviour and technical capability. They will be ascribed with a score for each, simplified to “High”, “Medium” and “Low”. Importantly, the technical capability of an actor is assessed based on an actor’s capacity to positively impact upon the technical development of the technology being developed. Collaborative behaviour is assessed based on several factors including an actors perceived willingness to collaborate, what they “gave up” as entities to the researcher during discussions, willingness to discuss challenging issues, ability to surrender power and capacity to discuss varied ideas and development paths. The resulting distributions of actors for each case are evident in figures 23(a) – 23(d).

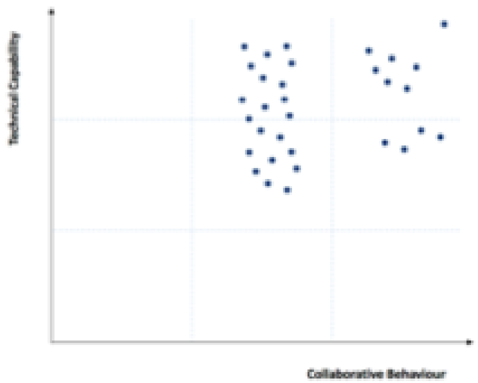


Figure 23(a): Distribution of actors in ASTRAEA

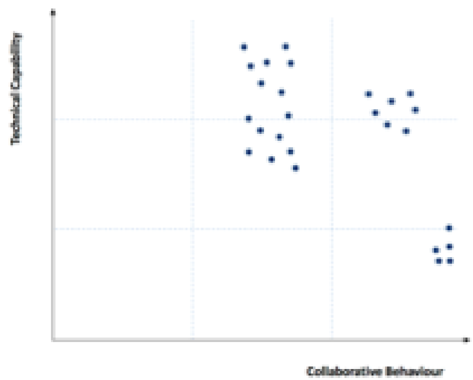


Figure 23(b): Distribution of actors in CT OWA

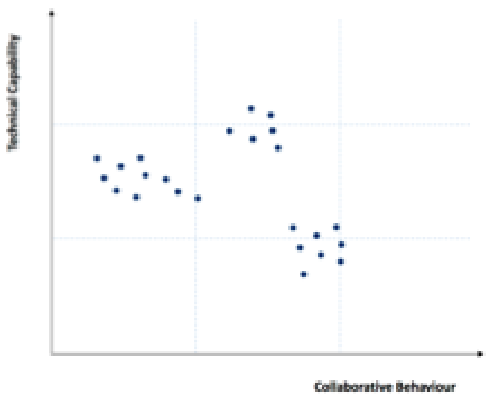


Figure 23(c): Distribution of actors in Defence AC

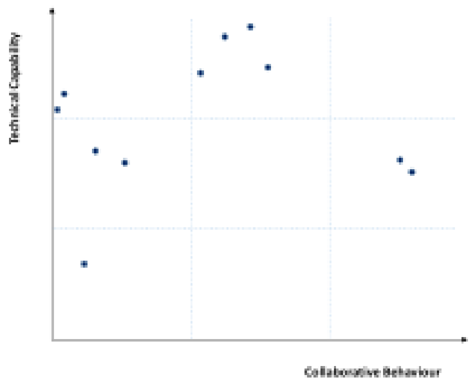


Figure 23(d): Distribution of actors in Rail AC

Observing the general distribution of actors in each case demonstrates a clear correlation between technical capability, collaborative behaviour and the success of the collaborative endeavour. For instance, in the ASTRAEA case, the majority of actors are distributed in the upper right four quadrants of the graph. They all demonstrate a medium-high technical capability as well as a medium-high collaborative behaviour. Similarly, this trend is continued in the CT OWA distribution, albeit with some actors falling into the bottom right quadrant. Interestingly, both of these cases represent successful collaborative technology developments.

Conversely, in the defence client action case, the distribution is more focussed on the centre and left of the graph. Although a few actors demonstrate a high technical capability, none demonstrate high collaborative behaviour. As this is an example of a collaborative technology development not currently achieving success, the distribution further confirms the proposition that a distribution of actors in the top right four quadrants is indicative of success.

The distribution of case four is interesting. Whilst more dispersed than the other three distributions, there are still no actors in the upper right quadrant of the graph. Further, whilst there are actors with medium technical capability who demonstrate a high level of collaborative behaviour, these appear to be offset by the two actors placed in the top left of the graph. Specifically, one of these actors was the MD of the client, whilst the other was the Chief engineer, both of who proved to be particularly disruptive and demonstrated minimal evidence of collaborative behaviour. As illustrated earlier in this thesis, whilst they were significantly invested in the development of the technology, their disposition and attitude towards other collaborators was poor. They were unwilling to surrender any power or entertain any ideas presented that weren't the original ideas presented by themselves. As they were arguably two of the most powerful actors involved in the collaboration, their disruptive attitude had a contagion effect and ultimately led to the collaboration's demise. However, this also highlights the third key theme, which underpins collaborative success; power.

Theme Three – Actor Power

The third theme identified in this research is power. Specifically, the power of individual actors and their ability to influence the successful development of a collaboration. As has been identified earlier in this discussion, the topic of power forms a substantive element of research relating to both brokerage and collaboration. However, there is no extant research which explores the relationship between power, collaborative behaviour and technical capability and it's impact on the success of a collaboration.

This relationship between capability, collaborative behaviour and power is interesting. Scholars such as Eden (1996) have illustrated the benefits of identifying stakeholders with high interest and high power and their ability to positively influence projects . However, taking the UK Rail Sector action case as an example and ranking the actors involved in that case using Eden's (1996) typology would place the client MD and Chief Engineer towards the top right, i.e. an ideal placement. However, as is clear from figure 23(d), when assessed based on their technical ability and collaborative behaviour, they rank in the top left of that graph, i.e. not an ideal placement.

Consequently, one may surmise that power and interest may not always complement a collaboration. In fact, high power in this scenario has clearly acted as a hindrance. Expanding on this notion and re-plotting the graphs in figures 24(a) – 24(d), this time manipulating the size of the actor plot to represent power, where the larger the plot the greater the power, illustrates this point.

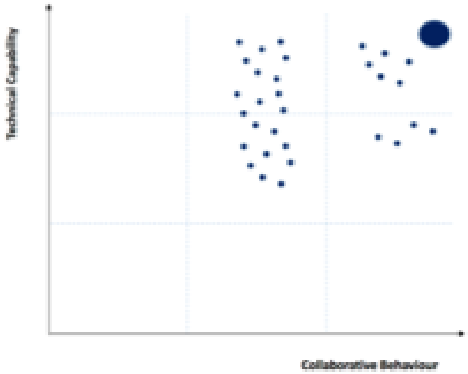


Figure 24(a): Distribution of actors in ASTRAEA

Figure 24(b): Distribution of actors in CT OWA

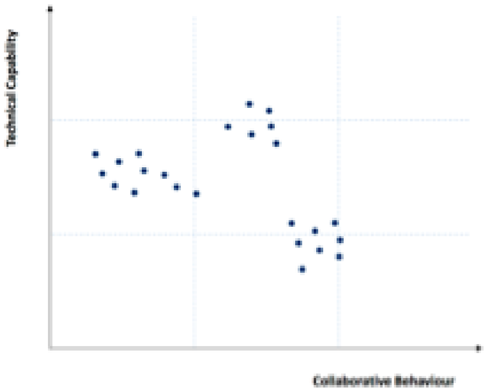


Figure 24(c): Distribution of actors in Defence AC

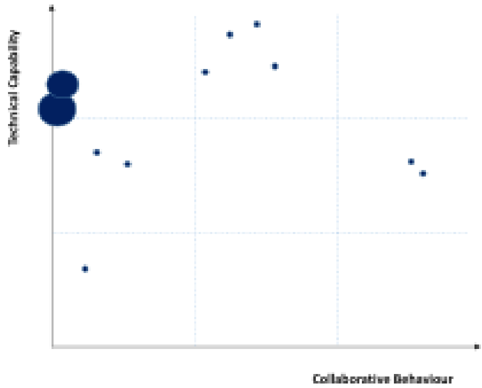


Figure 24(d): Distribution of actors in Rail AC

As can be seen from the revised distributions, power is clearly capable of acting as both a hindrance and a driver, dependant upon which actor possesses it. For instance, in the ASTRAEA and CT OWA cases, the majority of power lay with the brokers. Despite occupying different roles in terms of technical capability, the actors with most power also possessed a high level of collaborative behaviour. Contrasting this with the UK Rail action case and it's clear to see here that the actors with most power did not demonstrate a high level of collaborative behaviour. This observation may also explain why in this case, despite having two actors characterised as having a high collaborative behaviour, they were unable to support the development of the collaboration effectively, as they did not possess the necessary power to mitigate the effect of those actors who were unwilling to collaborate.

This observation leads the author to surmise that an actor's collaborative behaviour is more important to a collaborative technology development than their technical capability, should that actor be in a position of significant power. Should the characterisation be the other way around and the actor demonstrating high power also displays high technical ability but low collaborative behaviour, then the chances of collaborative failure are heightened.

Such observations pertaining to the relationship between the three key themes and their impact upon collaborative outcome are novel and have not been explored in the literature to date. Further, the relationship raises an interesting question around whether collaborations are more likely to succeed should collaborative behaviours be encouraged from a top down perspective.

This assumption gains some traction when viewing the revised plot for the defence action case. As can be observed, no actor has been plotted with a larger power influence than any other. This is based on the authors experience of that case and the identification that actors involved were confused as to their roles and thus no one appeared to be leading. This fostered, in that instance, a general growth of non-collaborative behaviour.

Suggested Actor Distribution and Typology

From observing the distribution of actors in figures 24(a) – 24(d), it seems to confirm that there is in fact a preferred distribution, when actors are characterised based on their collaborative behaviour, technical ability and power, which may minimise the chance of collaborative failure. Figure 25 illustrates this suggested distribution.

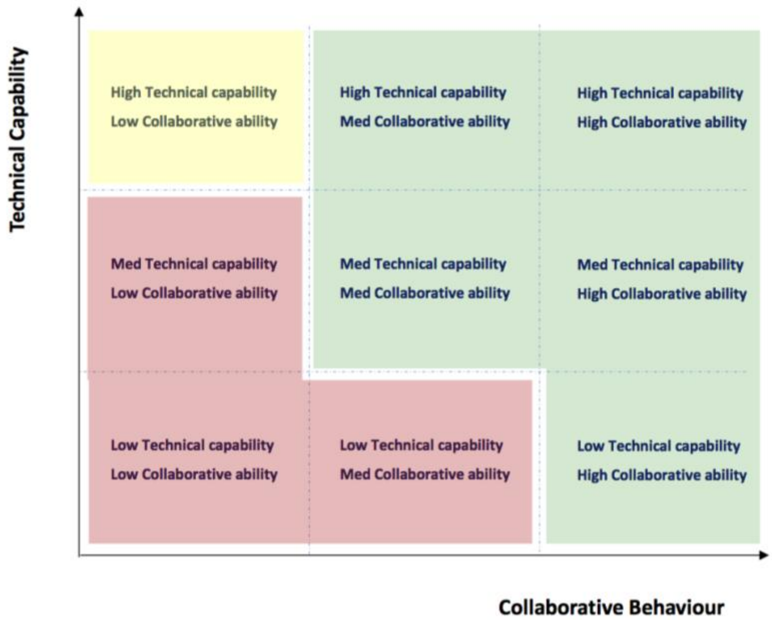


Figure 25: Suggested distribution of actors in a collaborative technology development

Figure 25 highlights a suggested distribution of actors, when characterised against the three key themes, in order to minimise the chance of collaborative failure. The areas of the graph highlighted in green represent where the majority of actors should fall, advocating high collaborative behaviours and high technical capabilities. The areas outlined in red indicate that an actor may not be of significant value to the collaborative endeavour. Further, if a significant number of actors within the collaboration fall into one of these three quadrants, that could indicate a higher chance of collaborative failure. The top left quadrant is highlighted yellow. This is to indicate that an actor falling into this ranking may either positively or negatively impact the collaborative approach depending on their power ranking. Specifically, it is noted that actors placed in this quadrant will demonstrate a high level of technical ability. However, it is proposed that if they are in a position of significant power, their lack of collaborative behaviour has the potential to derail the collaborative approach. Alternatively, should they demonstrate low power it is acknowledged that the technical ability of the actor may be used to the advantage to the collaboration, despite their poor ability to collaborate.

To expand on the suggested distribution and to enable the matrix to be used more constructively when designing collaborative approaches, a suggested typology of actors has also been developed. Outlined in figure 26 the typology is a 3x3 matrix, which can be overlaid onto the distribution graph and depicts the various roles of actors based on their ranking. An explanation of each of the roles is provided below the typology.

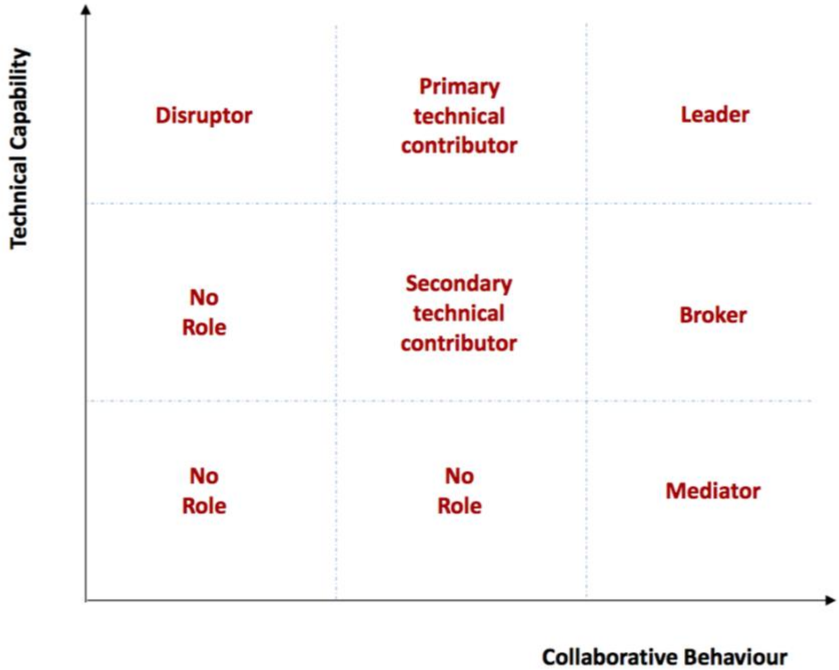


Figure 26: Suggested typology of actors in a collaborative technology development

As can be seen, figure 26 outlines 7 roles;

- **Leader:** An actor identified as a "leader" demonstrates a high technical capability and high collaborative behaviour. They may be characterised by their willingness to support the collaborative endeavour completely, but also by their ability to positively contribute to the technical development of the technology. The presence of a leader will significantly minimise the likelihood of failure of the collaboration.
- **Broker:** A technically competent actor with a high collaborative behaviour. They understand the key concepts and areas of the technology but may be of reduced use when developing certain aspects from a technical perspective. Whilst they are not someone who can typically innovate in this area in terms of technical development, they are highly

collaborative and understand the technical aspect to a significant level in order to achieve stakeholder buy-in.

- **Mediator:** A mediator is an actor who can significantly enhance the collaborative governance of the collaboration, albeit with limited potential to contribute to the technical development. They demonstrate high collaborative behaviour but low technical ability.
- **Primary Technical contributor:** A primary technical contributor has a high capacity to positively enhance the technical development of the technology. Their high technical ability means they are likely to be a source of innovative developments relating to the technical aspect of the project. They also demonstrate a reasonable amount of collaborative behaviour, although should not be relied upon to orchestrate others.
- **Secondary Technical Contributor:** Similar to the primary technical contributor, this role has a significant ability to impact the technical development of the technology. However, given its medium ranking, it should not be expected to lead technically. Technically competent and understand the role of the collaboration, however, they do not have the capability to lead either
- **Disruptor:** The disruptor is a role of high technical capability but minimal demonstrable collaborative behaviour. Actors in such a role have the capacity to significantly enhance the technical development of the technology, however, due to their behaviour, similarly have the capacity to derail the collaboration. Their predilection to derail the collaborative approach is directly related to their power standing within the network. Disruptors whow demonstrate high power should be avoided and not chosen as part of a collaborative approach. Disruptors with low power can be considered for inclusion, but should be treated with caution. They need to be closely governed by an experienced leader, otherwise they could cause the entire endeavour to fail.
- **No Role**: Actors here are judged to be of no value to the collaboration, unless they can improve either their technical capability or collaborative behaviour.

The author believes that by developing a suggested definition of role typology such as this, it enables the compilation of a collaborations to be more accurately assessed and understood, ensuring there is the right balance of skills. Despite this, it should be noted that the suggested distribution and typology of actors should not be considered a panacea approach to guarantee success of a collaborative technology development. However, the author does consider that by viewing collaboration in such a way and considering the distribution of actors, based on the triality between the characteristics of collaborative behaviour, technical competency and power, can indicate a likelihood for collaborative failure.

Further, the author believes that such a network perspective of actor distribution in a collaboration could form a useful decision tool. Specifically, it could be used to illustrate current weaknesses, or "reverse salients" within the network. For instance, if a collaboration is assessed as not having sufficient actors with high collaborative behaviour, this could be identified and addressed. Similarly, if actors with high power are characterised as disruptors, they may be removed from the collaboration, or more powerful actors placed into leader/broker roles to mitigate. Further, it could also be used to identify training requirements, should actors be categorised as "low" in any of the themes.

The distribution and typology also create the basis for further research opportunities. Specifically, further understanding the relationship between the suggested distribution and Eden's (1996) work on power/interest could lead to an interesting avenue of enquiry, informing a more detailed definition of role typology. Further, quantifying the metrics used to assess actors based on the three key themes would be another useful form of enquiry.

Chapter Nine
Conclusions

This thesis has explored the theoretical grounding of collaboration in the context of technology development and sought to understand the practicalities of supporting the development of such approaches in industry. It has produced three key outputs, which seek to support organisations collaborate more effectively for the purpose of developing technology. It has also provided a network level perspective of how the likelihood of collaborative failure may be inferred based on the distribution of actors, when characterised against three themes; technical ability, collaborative behaviour and power.

This chapter summarises the contributions of this thesis by referring to the three research questions identified in chapter three. It also identifies directions for future research.

9.1 Research Question One: What are the key principles to consider when designing collaborative approaches to support technology development?

This research has identified nine key principles one should consider when designing collaborative approaches to technology development. These have been detailed and presented in the CTD framework. Within the nine key principles, 28 sub-themes have also been identified as pertinent to collaborative technology development. The principles have been tested and validated through several action case applications of the CTD framework, where they sort to support an array of organisations develop novel technology collaboratively.

9.2 Research Question Two: How can the principles of collaborative technology development be constructively applied in industry?

This thesis has identified several ways in which the principles of collaborative technology development can be constructively applied in industry. Specifically, the research has explored the role of brokerage as a vehicle to support the application of the CTD framework. In doing so it has identified six key principles of technology brokerage, which broker should demonstrate in order to to support organisations collaborate effectively. These have been consolidated and presented in the TB framework. Further, this thesis has synthesised they key learnings from both the TB and CTD framework in a six stage process for collaborative technology brokerage, which supports organisations minimise the risk of collaboratively developing technology in a constructive way at the concept stage of development.

9.3 Research Question Three: How can the risk of failure of collaborative technology development be minimised from a network level perspective?

Finally, this thesis has synthesised the learning from this research through a grounded review of the cases to identify three key themes which impact the outcomes of collaborative technology development approaches. Specifically, the thesis has identified that by characterising the distribution of actors present in a collaboration based on their technical capability, collaborative behaviour and power, the likelihood of collaborative failure can be indicated. This insight into the triality of these key themes and their impact on collaborative outcomes has been used to develop a suggested distribution of actors and typology of actor roles one should seek when establishing a collaborative approach to technology development.

9.4 Contributions to Industry

Throughout this research, the author has been based in an engineering consultancy, where there was an expectation to conduct research in a commercial environment in order to support the development of a new service offering. During this time, the research has positively contributed to the host organisations in several ways. Notably, the research has;

- Supported the growth of a new service area for FNC
- Supported the delivery of several commercial projects, contributing to the generation of revenue for FNC
- Enabled the author to publish and present several thought leadership pieces, raising the profile of FNC
- Supported the content development of multiple tenders in an attempt to secure paid consultancy work and in at least one instance been solely responsible for securing a project with an associated value of £10k

- Supported the development of a new service area for Atkins Consultancy; Digital Intelligent Brokerage (DIB). DIB has been developed based on the key theoretical tenets identified and developed in this doctorate. At present, it has been successfully applied in the Utilities sector, supporting a client enhance their innovation processes through improved engagement with the supply chain. It is currently being developed for future application with clients in the Transport, Infrastructure and Defence sectors.

9.5 Limitations of Research

Limitations of the research have been highlighted and discussed throughout chapter eight. As a summary, the author considers the following to be the primary limitations of the research conducted;

- The engineering context in which the research has been conducted represents a relatively narrow and isolated field of enquiry in which to completely test and appraise the frameworks and process developed. The author is acutely aware of this limitation and therefore believes conclusions relating to the outputs of the work should support inferences in this area only. To fully appraise the wider application potential of the CTD and TB framework as well as the CTB process, further testing should be sought in non-engineering or technology related sectors.
- Similarly, whilst the action cases selected to develop and test theory were done so through the utilisation of a rigorous assessment criteria outlined in the methodology, the opportunities to assess were constrained by the strategic intent and tendering success of the host company, FNC. As a result, the research was somewhat limited by the availability and timing of appropriate projects presenting themselves.

9.6 Directions for Further Research;

This research has enhanced many aspects of the knowledge base pertaining to collaboration, brokerage and technology development. It has developed a framework of principles to inform the design, development and assessment of collaborative technology developments as well as exploring the most practical methods of application. Focussing on the role of brokerage to support application, the thesis has derived a set of principles which detail the hey tenets a broker should possess in order to effectively support collaborative technology developments. Finally, it has also identified three key themes, which when used to characterise the distribution of actors in a network can indicate the likelihood of collaborative failure.

Despite this, there are several directions in which the research can continue to be enhanced. These are summarised below;

- The CTD framework has so far only been applied by the author in the context of an engineering consultancy supporting the development of technology. A useful avenue of further enquiry would be to ascertain the value of the framework when applied by other actors. Further, understanding the value of the framework outside the context of technology development would also be useful.
- The TB framework stipulates that a key principle of technology brokerage is for a broker to possess and demonstrate technical competency. Whilst the framework highlights the importance in contextualising the explicit knowledge f the broker in order to deliver value, it does not seek to explore the relationship between technical competency and the knowledge held by the broker. Specifically, the framework does not attempt to quantify what level of knowledge a broker may possess in order to effectively deliver value. Further studies to understand this would provide an interesting addendum to the TB framework
- The CTB process illustrated the potential value of orchestrating actors to support collaborative problem **structuring** rather than problem **solving**. Conducting studies to further explore the value of collaborative problem structuring to minimise the risk of technology development in the early stages would be a useful and novel line of enquiry
- The grounded review of cases illustrated the triality between the technical capability, collaborative behaviour and power of an actor and how characterising the distribution of actors against these three themes can indicate the likelihood of collaborative failure. An interesting piece of further research would be to further explore the relationship between the three themes identified here and the subsequent suggested typology of actors with Eden's (1996) power / interest typology. Specifically, understanding how to combine the two approaches to better inform the distribution of actors in a collaboration would be most beneficial

- In relation to the three key themes identified, a further avenue of research which would prove useful is understanding how to better quantify the ranking of an actor against each of the themes. Currently, the ranking system if relatively basic, with only three scale points of disparity. Identifying further metrics by which to assess the actors could lead to a more accurate scoring and more nuanced and informative plotting of actor distribution.

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