International Journal of Operations and Production Management
Available online 21 August 2023
DOI:10.1108/IJOPM-11-2022-0697

Using not-for-profit innovation networks to transition new technologies across the Valley of Death

Abstract

Purpose: This paper seeks answers to the question: What are the relevant factors that allow not-for-profit innovation networks to successfully transition new technologies from proof-of-concept to commercialization?

Design/methodology/approach: This question is examined using the knowledge-based view and network orchestration theory. Data are collected from 35 interviews with managers and engineers working within seven centres that comprise the High Value Manufacturing Catapult (HVMC). These centers constitute a not-for-profit innovation network where suppliers, customers and competitors collaborate to help transition new technologies across the "Valley of Death" (the gap between establishing a proof of concept and commercialization).

Findings: Network orchestration theory suggests that a hub firm facilitates the exchange of knowledge amongst network members (knowledge mobility), to enable these members to profit from innovation (innovation appropriability). The hub firm ensures positive network growth, and also allows for the entry and exit of network members (network stability). Our study of not-for-profit innovation networks suggests the role of a network orchestrator is to help ensure that intellectual property becomes a public resource that enhances the productivity of the domestic economy. We observed how network stability was achieved by the HVMC's seven centers employing a loosely-coupled hybrid network configuration. This configuration however ensured that new technology development teams, comprised of suppliers, customers and competitors, remained tightly-coupled to enable co-development of innovative technologies. Matching internal technical and sectoral expertise with complementary experience from network members allowed knowledge to flow across organizational boundaries and throughout the network. Matrix organizational structures and distributed decision-making authority created opportunities for knowledge integration to occur. Actively moving individuals and teams between centres also helped to diffuse knowledge to network members, while regular meetings between senior management ensured network coordination and removed resource redundancies.

Originality/value: The study contributes to knowledge-based theory by moving beyond existing understanding of knowledge integration in firms, and identified how knowledge is exchanged and aggregated within not-for-profit innovation networks. The findings contribute to network orchestration theory by challenging the notion that network orchestrators should enact and enforce appropriability regimes (patents, licences, copyrights) to allow members to profit from innovations. Instead, we find that not-for-profit innovation networks can overcome the frictions that appropriability regimes often create when exchanging knowledge during new technology development. This is achieved by pre-defining the terms of network membership/partnership and setting out clear pathways for innovation scaling, which embodies newly generated intellectual property as a public resource. The findings inform a framework that is useful for policy makers, academics and managers interested in using not-for-profit networks to transition new technologies across the Valley of Death.

Keywords: new-technology development, innovation networks, knowledge-based view, network orchestration theory

1 Introduction

The scaling of a technological concept to a successfully commercialized product is essential to organizational growth (Dean et al., 2020; Markham et al., 2010; Milewski et al., 2015). The journey, however, is not easy: at least four in five new technologies are likely to never reach the commercialization stage (Dean et al., 2020). The majority of new technology development (NTD) efforts fail in what has commonly been referred to as the 'Valley of Death' (VoD) – the gap between proving a technological concept can work in the laboratory, and the testing and validation of that technology in a relevant environment for onward commercialization (Branscomb and Auerswald, 2003; Markham et al., 2010).

In 2011, the UK government sought to address the VoD problem by funding a new innovation network known as the High Value Manufacturing Catapult (HVMC) (Osborne et al., 2021). The HVMC is a not-for-profit innovation network comprised of seven centres that act as a risk-pooling platform, where material and machine suppliers, customers and competitors share the risks and rewards of co-developing novel technologies (Moradlou et al., 2022). Innovation networks are defined as interconnected entities, including businesses, research organizations, universities and governments, that work together to achieve shared innovation goals (Rampersad et al., 2010). Innovation networks have long been recognized as an important source of new knowledge because a diverse range of network actors bring innovative ideas to the network collaboration (Powell and Grodal, 2006; Powell et al., 1996; Potter and Paulraj, 2020). Orchestrators of for-profit networks offer resources and connections to prospective members to join and extract value from the network to develop and commercialize new products and technologies (Dhanaraj and Parkhe, 2006; Hurmelinna-Laukkanen and Nätti, 2018). In contrast, orchestrators of not-for-profit innovation networks act as intermediates that strive to facilitate collaboration and innovation amongst network partners (Howells, 2006).

Existing studies have sought to understand how innovation networks can overcome a number of challenges associated with crossing the VoD (Son et al., 2020). Prior studies tend to focus on only one stage of the NTD process. Examples include the role of university incubators in ideation and concept development (McAdam et al., 2006; Son et al. 2020; Rothaermel and Thursby, 2005), the hand-over between academia and industry (D'Este and Patel, 2007), or the role of Proof of Concept Centres (POCCs) and university spin-outs in commercialization (Hayter and Link, 2015). However, the pivotal role that not-for-profit innovation networks play in transitioning new technologies across the VoD remains unexplored. Filling this knowledge gap is important since managers are increasingly turning to not-for-profit innovation networks to accelerate their NTD efforts (Ellwood et al., 2020; Reypens et al., 2021). Policy-makers, universities and business managers alike require guidance on how to capture the knowledge and innovation benefits that come from working with not-for-profit networks.

This study seeks to address this gap in knowledge by answering the question: *What are the relevant factors that allow not-for-profit innovation networks to successfully scale new technologies from proof-of-concept to commercialization?* We examine this question using both the knowledge-based view (KBV) (Eisenhardt and Santos, 2000; Grant, 1996a), and network orchestration theory (Dhanaraj and Parkhe, 2006). The KBV suggests that knowledge is the most valuable resource of the firm, and that individuals are the source of that knowledge (Grant, 1996a). Network orchestration theory explains how orchestrators facilitate knowledge mobility amongst members, enforce innovation appropriability and ensure network stability (Dhanaraj and Parkhe, 2006). Through these lenses, we examine how the UK's HVMC network transitions NTD projects across the VoD. Data is collected from 35 semi-structured interviews with individuals working at the seven centres that comprise the HVMC, including senior engineers and supply chain managers, intellectual property (IP) protection managers and chief technology officers.

The findings contribute to knowledge-based theory by explaining how knowledge is exchanged and integrated between individuals working in NTD teams, and how knowledge aggregates to network partners situated within not-for-profit innovation networks. The findings contribute to network orchestration theory by finding that not-for-profit innovation networks can achieve network stability by ensuring that the network orchestrators remain loosely-coupled, while the suppliers, customers and competitors within the network remain tightly-coupled to co-develop innovative technologies. This combination of loose and tight-coupling is achieved using a disseminated matrix structure, and a decentralized decision-making authority, that enables NTD teams to accelerate the early stages of new technology development.

Our findings challenge the assumption that innovation appropriability must be enforced by a network orchestrator through patents, copyrights, and trademarks to ensure members can profit from innovation (Dhanaraj and Parkhe, 2006; Teece, 2000). Our results suggest that knowledge mobility can be enhanced by establishing clear terms for network membership/ partnership upfront, and by removing the barriers that IP protection regimes place on knowledge exchange in typical NTD projects. The findings contribute to the NTD literature by explaining how not-for-profit innovation networks remove friction related to knowledge mobility and, in doing so, support the transition of NTD projects across the VoD. These findings inform a managerial framework for NTD in not-for-profit innovation networks that is generalizable to other networks operating in different countries and contexts.

2 Theoretical Underpinnings

2.1 The Knowledge-Based View

The KBV is a particularly useful lens for examining how knowledge is generated, integrated and aggregated throughout the NTD process. The KBV argues that individuals are the locus of knowledge in firms (Grant, 1996a, Felin and Hesterly, 2007). These individuals accumulate knowledge through on-the-job experience, where learning is brought to the firm from prior employment or is created when carrying out meaningful tasks during their current job (Grant, 1996b, 1996a; Zollo and Winter, 2002). KBV theory suggests that structures and business processes encourage individuals to interact and share knowledge with one another during NTD projects (Grant, 1996a). Organizational structures, including job roles, managerial hierarchies, departments and routines set the parameters for individual interactions within an organization, and facilitate efficient knowledge sharing and integration (Felin et al., 2012). Organizational processes, such as new technology development, bring individuals together from diverse backgrounds, including design, engineering, marketing and manufacturing, into cross-functional teams where they can interact and share new ideas (Clark and Fujimoto, 1992; Pérez-Luño et al., 2018). These interactions aggregate knowledge from individuals to collectives of individuals (or teams). As these teams interact with other teams located in different organizations to co-develop new technologies, knowledge aggregates from collectives of individuals (teams) to networks of collectives (innovation networks).

2.2 Orchestrating Knowledge Exchange in Innovation Networks

Knowledge is the chief currency within innovation networks and is dispersed amongst network partners (Dhanaraj and Parkhe, 2006). The orchestration of innovation networks requires high levels of knowledge mobility, defined as the ease with which knowledge is acquired, shared and deployed within the network (Dhanaraj and Parkhe, 2006, p. 660). According to theory, the role of the network orchestrator is to ensure that rigorous appropriability regimes are in place to allow members to 'profit from innovation' (Teece, 1986). The unauthorised imitation of new technologies and products can be mitigated, and appropriability regimes strengthened, through protective measures including contracts, patents, copyrights and trademarks (Teece, 2000). The governance of IP is pivotal to the success of the innovation network as it determines value appropriation for the network members and positively influences the success of new technology development projects (Leten et al., 2013). The orchestrator must remain aware of the relevant knowledge development activities of network members, within an agreed upon framework, so there is no attempt to copy or steal innovative ideas and technologies (Leten et al. 2013).

Innovation networks can be organised in a variety of ways including tightly-coupled (Hofman et al., 2016; Hofman et al., 2017) or loosely-coupled networks (Dhanaraj and Parkhe, 2006: Orton and Weick, 1990). Tight organizational coupling is evident in interfirm relationships when close teamwork brings unique skills to the NTD project, and an expectation that partners will be working together far into the future (Dyer and Singh, 1998; Hofman et al., 2017). An example of a tight-coupling mechanism is supplier involvement in new product development projects, where the supplier brings innovative ideas to the design and development of a buying firm's new products (Dyer and Singh, 1998; Lawson and Potter, 2014). Loose coupling is defined as a situation in which network actors are responsive to each other, but retain evidence of separateness and identity (Weick, 1976 p.3). An example is given by Kaplan (1982) who explored a loosely-coupled federation of independent state agencies that shared a mandated common funding source (the US Government).

Some studies argue that tight organizational coupling can improve innovation performance because high degrees of reciprocity and closer working relationships facilitate the effective exchange of complex knowledge between partners (Hofman et al., 2017). Others argue that tight-coupling leads to information redundancy and network inertia that can stall the NTD process (Kim et al. 2006). Loosely-coupled networks, on the other hand, are believed to create opportunities to access novel, heterogenous resources and knowledge and offer the potential of recombining these inputs to create new technologies and products (Hofman et al., 2017). However, the risk inherent in loosely-coupled networks involves a lack of network stability due to unstable linkages among members that can result in collaborations ending abruptly, or members leaving to join competing networks (Dhanaraj and Parkhe, 2006).

Studies on innovation networks have sought to categorize orchestrator types, and their roles and responsibilities (Hurmelinna-Laukkanen and Nätti, 2018; Leten et al., 2013). A key distinction is whether the network orchestrator is motivated by financial gain. 'Player orchestrators' seek to realize their individualistic goals through extracting value from the network for financial gain (Hurmelinna-Laukkanen and Nätti, 2018; Leten et al., 2013). As the ultimate aim is profit, these network orchestrators are interested in the commercialization of new technologies and/or the licensing of patents. 'Sponsor-orchestrators' may have individual financial goals, without being a direct competitor in the end market. For example, venture capitalists and business incubators may offer resources and network connections to network members, with an expectation that their investments will later be rewarded (Comacchio et al. 2012).

The final type, facilitator orchestrators' are not motivated by profit but act as intermediating organizations that seek to enable collaboration and innovation in the network (Howells, 2006). Also been termed bridging institutions (Stankiewicz, 1995), or superstructure organizations (Lynn et al. 1996), these network orchestrators help link players within a technological system. These intermediary bodies are typically funded by government research councils and universities and operate between the policy level and the operational level to form an ecology of influences on other actors within the system (Howells, 2006; Van der Meulen and Rip, 1998). Networks led by facilitator orchestrators seek independence from any single commercial actor and tend to focus on the pre-competitive stage of new technology development, prior to commercialization (Hurmelinna-Laukkanen and Nätti, 2018). We explore the important role of facilitator orchestrators in our study, and focus on their role in traversing the "Valley of Death".

2.3 Traversing the Valley of Death using not-for-profit innovation networks

For a NTD project to transition from a concept to commercialization, it needs to pass through a number of technology readiness levels (TRLs). To move from one level to the next, managers answer a series of questions regarding whether the technology meets the appropriate level of testing and validation for the respective stage (Markham et al, 2010). The first three TRLs often take place within a university, or company, research laboratory and refer to the basic principles of the technology being observed (TRL1), the technology concept being formulated (TRL2), and an experimental proof of concept (TRL3) being successfully tested. However, the biggest scaling challenge typically occurs when a company attempts to take the proof-of-concept out of the lab and transition it to a relevant environment for testing and validation (TRLs 4-6), the stage commonly referred to as the "The Valley of Death" (VoD) or "Gap" shown in Figure 1 (Markham *et al.*, 2010). These 'scale-up' stages typically consume significant resources in terms of the volume of raw materials, parts, equipment, and labour needed to demonstrate that the technology can operate at high volumes in manufacturing-ready environments. Once the technology is validated in a production representative environment (TRL 6), it is deemed ready for onward commercialization (TRLs 7-9).

The VoD concept is relevant to a range of industries developing new technologies and products, including entrepreneurial start-ups (Levebvre et al 2020), clinical trials (McAdam et al., 2009), medical equipment (Ellwood et al., 2020), technology education (Barr et al., 2009) and advanced technology sectors such as aerospace (Roscoe et al., 2019; Moradlou et al., 2022). The VoD may not be encountered in instances when the new technology is an iteration of a firm's existing profile and issues related to scaling have already been overcome, or in industries with relatively limited regulatory oversight, such as clothing and apparel, where the new technology may not require extensive testing and validation by regulators.

Some studies that have examined why NTD projects become stuck in the VoD focus on a single firm (Markham, 2002; Markham et al., 2010). These studies suggest the primary barriers are that formal NTD processes are often disconnected from front-end issues such as effectively developing seed ideas (Markham, 2002), a lack of formal and informal NTD roles (Markham et al., 2010), and financing gaps between demand and supply of early-stage capital (Frank et al., 1996; Levebvre et al., 2020). Organizational and product complexity, and market turbulence have also been found to inhibit NTD efforts within firms (Dean et al., 2020).

Other studies suggest that firms, in isolation, will struggle to transition new technologies across the VoD, due the significant financial and human resources commitments involved in scaling new technologies that may never reach commercialization (Auerswald and Branscomb, 2003; Branscomb and Auerswald, 2001). These studies tend to stress the importance of policy makers intervening to support businesses in the scaling process to bridge the funding gap (Roca and O'Sullivan, 2020; Wessner, 2005). Policy interventions may include grants and innovation awards, or targeted industrial strategy aimed at supporting strategic sectors (Wessner, 2005; Ellwood et al., 2020). These policy interventions result in the emergence of multi-stakeholder innovation networks, typically consisting of government funding bodies, universities and firms (Aarikka-Stenroos et al., 2017; Levén et al., 2014).

Multi-stakeholder innovation networks can take the form of University Incubators (McAdam et al., 2006, Perkmann et al., 2012; Rothaermel and Thursby, 2005,), university technology holding companies (Siegel et al., 2004: Son et al., 2020), university spin-offs (Nicolaou and Birley, 2003) and Proof of Concept Centres (POCCs) (Hayter and Link, 2015; McAdam et al., 2009). These multi-stakeholder innovation networks are said to have a higher likelihood of success in overcoming the VoD due to government funding, coupled with academic input, help businesses to mitigate financial risks as facilities and equipment are provided to help scale and validate technological concepts.

2.4 Research Gap

While existing studies explain the role innovation networks play in NTD projects, they tend to focus on one or two stages in the NTD process. For example, McAdam et al., (2006) and Rothaermel and Thursby (2005) examine the ideation activities that occur within university incubators (TRLs 1-3), but skip over the VoD to move directly to commercialization. Perkmann et al., (2013) and Siegel et al., (2004) discuss university-industry knowledge transfer, but concentrate on the role of academic engagement in commercialization. Other studies are also focused on commercialization (TRLs 7-9), using Proof of Concept Centres (POCCs) (Hayter and Link, 2015; McAdam et al., 2009) and university spin-offs (Nicolaou and Birley, 2003), but not at the earlier ideation and proof of concept stages. In the main, these studies examine for-profit innovation networks, where the network orchestrator is ultimately seeking financial gain for the commercialization of new technologies and the licensing of patents.

What is missing is an end-to-end explanation of how not-for-profit innovation networks facilitate the transitioning of NTD projects from a proof-of-concept until the technology is validated for onward commercialization. This study seeks to address this knowledge gap by answering the following question: *What are the relevant factors that allow not-for-profit innovation networks to successfully scale new technologies from proof-of-concept to commercialization?* The role of these innovation networks as facilitator orchestrators is believed to be an important factor in scaling new technologies. The following section provides a justification for the research design used to answer this question.

3 Methodology

3.1 Research Design

To examine the research question of interest, we followed an inductive, theory elaboration approach (Ketokivi and Choi, 2014). We compared empirically gathered data to the key tenets of the KBV and network orchestration theory. When inconsistences between the data and theory emerged, we were able to elaborate on existing theory and arrive at novel theoretical insights (Eisenhardt, 1989; Merton, 1968). A case study research design was adopted, in order to investigate a contemporary phenomenon about which little is known (Yin, 2014). A single case design was selected because it allows for an in-depth examination of the research phenomenon (Yin, 2014). The HVMC network was chosen as our research context as it is a well-established not-for-profit network with a proven track-record of new technology development (HVMC, 2021a). Within the HVMC network structure, different technological trajectories are fostered through targeted support from distinct but interconnected government-funded research centres, universities and businesses. These interconnections provide a rich backdrop to explore how knowledge is exchanged, integrated and aggregated within not-for-profit networks, and how knowledge mobility supports NTD efforts. Moreover, existing studies have made good use of the HVMC case to examine knowledge exchange and NTD in not-for-profit networks (see Moradlou et al., 2022, Osborne et al., 2021). In combination, these factors make the HVMC well-suited to provide answers to the research question of interest. Within the HVMC case context, we treated the knowledge-based interactions between individuals working within NTD teams as the unit of analysis.

3.2 Case Overview

The research team were granted a high degree of access to explore how the HVMC works with partners from the UK government, universities, and industry in order to transition new technologies across the VoD. The HVMCs were established in 2011 by Innovate UK (a government funding body) to provide access to world-class facilities and expertise that would otherwise be out of reach for many UK-based companies (Osborne et al., 2021). The HVMCs are a 'not-for-profit', independent, network of facilities that provide cutting-edge research and development infrastructure including hubs, laboratories, testbeds, factories, and offices where buyers, suppliers, customers and competitors can collaborate on research and development (R&D) projects and bridge the VoD (Moradlou et al., 2022). The HVMC is comprised of seven manufacturing research centres spread across the UK (HVMC, 2021b), each with different competencies and technological capabilities, as shown in Figure 1. A comparison of the seven centers, including the similarities, differences and unique features that contribute to knowledge exchange and knowledge mobility, is provided as an on-line supplement.

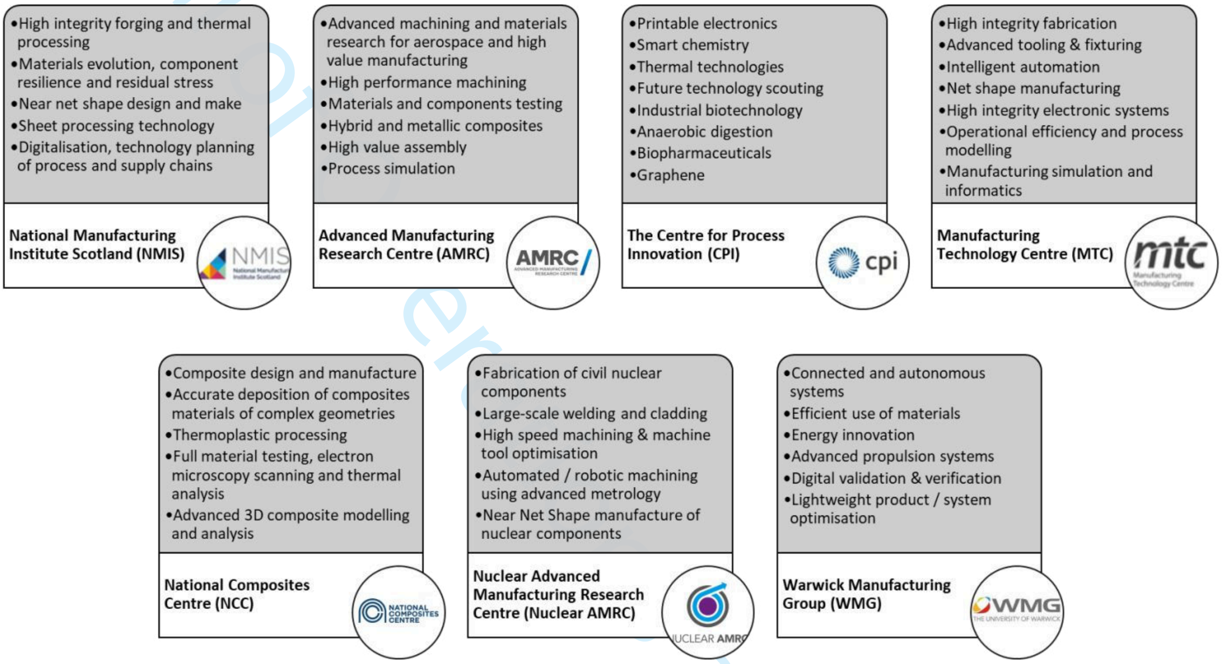

Figure 1, HVMC network of centres and key competencies

Companies can join some of the catapult centres at various tiers. Tier 1 members are normally large original equipment manufacturers (OEMs), or ‘primes’, who benefit from the research outcomes, whereas Tiers 2 and 3 members are generally equipment providers and materials suppliers who might benefit from selling their products to Tier 1 companies. As the purpose of the HVMC is to enable member organizations to transition novel technologies from TRLs 4-6, they occupy a unique position in the UK’s technology development landscape (HVMC, 2021b).

3.3 Data Collection

Empirical evidence was collected using semi-structured interviews with 35 individuals working at the seven centres that comprise the HVMC network. The interviews were conducted across a two-and-a-half-year period (September 2020 to January 2022). The sampling methodology was to interview individuals from a range of departments and seniority levels involved in the NTD process, including Engineers, Technologists, Directors, and Chief Technology Officers (CTOs). All interviewees were selected based on their unique insights into the HVMC network and their understanding of the knowledge exchange processes that occur within its structures. The first interview participants were identified through the academic and industry connections. Further recruitment of interviewees was achieved using a snowball sampling methodology (Parker et al. 2019), where current participants recommended knowledgeable colleagues from their own, or other, department and centres. Potential interviewees were only approached if they were involved in some aspect of the NTD process and could create a diversity of backgrounds and opinions to enhance data richness. The selected interviewees came from a variety of NTD roles, including engineering, technology, supply chain, legal, commercial, and procurement (see Table 1).

Table 1, Overview of Interviewees

No	*Catapult Centre*	*Position*	*Years at Catapult*
1	Centre 1	Research engineer	2
2	Centre 1	Team lead, Technology Transformation	6
3	Centre 1	Head of commercial and legal	2.5
4	Centre 1	Senior research engineer	9
5	Centre 1	Technical specialist, Team lead	8
6	Centre 1	Research engineer	1
7	Centre 1	Technology director	10
8	Centre 1	Senior research engineer	2
9	Centre 1	Senior research engineer	3
10	Centre 1	Supply chain manager	2.5
11	Centre 1	Legal officer	2.5
12	Centre 1	Advanced research engineer	1.5
13	Centre 1	Chief engineer	9
14	Centre 1	Advanced research engineer	2.5
15	Centre 1	Chief engineer	5
16	Centre 1	Principal research engineer	9

17	Centre 2	Research director	12
18	Centre 2	Head of Strategy for Additive Manufacturing	5
19	Centre 2	Deputy head of digital	3
20	Centre 2	Commercial director	18
21	Centre 2	Senior research fellow	14
22	Centre 3	Senior Technology Officer	10
23	Centre 3	Chief Technology Officer (CTO)	6
24	Centre 3	Procurement manager	5.5
25	Centre 4	Program manager	3.5
26	Centre 4	Senior Technology Officer	4
27	Centre 4	Knowledge Transfer Specialist	9
28	Centre 4	Project manager	4
29	Centre 4	Associate Professor	7
30	Centre 4	Chief technology officer (CTO)	3
31	Centre 5	Chief technology officer (CTO)	8
32	Centre 5	Business Development Director	4
33	Centre 6	Chief technology officer (CTO)	10
34	Centre 7	Knowledge Exchange Fellow	7.9
35	HVMC	Chief technology officer (CTO)	17

The interview process began in Centre 1 and then proceeded to individuals working across the seven centres that comprise the HVMC network. Gathering insights from senior executives (Chief Technology Officers, Heads of Strategy) as well as project managers and engineers provided both a top-down and bottom-up perspective of the new technology development process and knowledge exchange activities across the seven centres. After completing 35 interviews, theoretical saturation was reached as no further insights were emerging from the data (Lee, 1999). Due to the Covid-19 pandemic, the interviews were conducted via Microsoft Teams/Zoom and lasted between 45 and 90 minutes, culminating in 2,080 minutes of interview material. All interviews were fully transcribed and then coded using NVivo 11 software.

3.4 Data Analysis

We followed the Gioia methodology (Corley and Gioia, 2011; Gioia et al., 2012) to ensure a systematic examination of the data, including a 1st order analysis using informant-centric terms and codes, and a 2nd order analysis using researcher-centric concepts, themes, and dimensions (Gioia et al., 2012). One member of the research team conducted the 1st order analysis and identified 115 coding categories initially, which were then reduced to 71 based on category similarities. The coder assigned a label and descriptor to each category, where possible retaining the informants' terms. This process was then repeated by a second coder to ensure inter-rater reliability (Armstrong *et al.*, 1997), which produced 63 coding categories. The two coders compared their results and the initial coding was debated and synthesized until a consensus was reached.

During the 2nd order coding, the two researchers discussed the initial coding template and asked whether the emerging themes suggested concepts from the literature that might explain the research phenomenon. At the same time, the two researchers remained open to new and emerging concepts not adequately addressed by the extant literature and knowledge-based theory. Once the team established a workable set of themes and concepts, the emergent 2nd order themes were combined into aggregate dimensions (Gioia et al., 2012). The resulting data structure, shown in Figure 2, provides a visual representation of how the data analysis progressed from raw data to a consolidated set of conceptual themes (for further illustrative quotes please refer to Appendix 1).

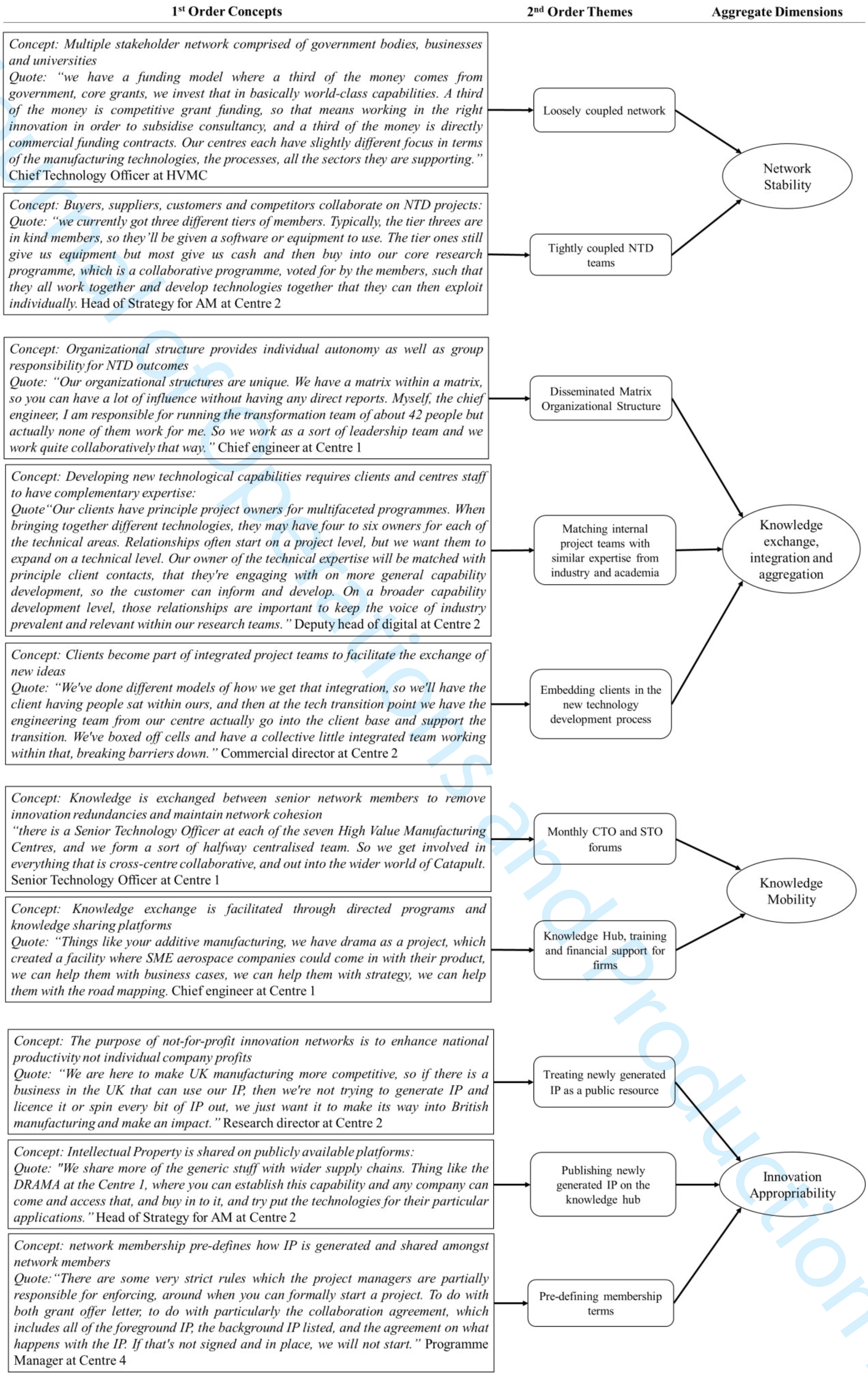

Figure 2, Illustration of data structure

4 Findings

The following section is organized according to the four primary themes (aggregate dimensions) that emerged from the data analysis: 1) network stability; 2) knowledge exchange, integration and aggregation; 3) knowledge mobility, and; 4) innovation appropriability (see Figure 3).

4.1 Network Stability

The HVMC network is one-third funded by Innovate UK, a government-backed research council. Another third of funding comes from collaborative R&D programs where member companies and university partners develop research bids to secure funding from government research councils (EPSRC, ESRC). The remaining third comes from membership fees and/or sponsored projects from industry. Several of the seven centres that make up the HVMC network are partnered with a UK university, such as the National Manufacturing Institute Scotland (NMIS), the University of Strathclyde and the Advanced Manufacturing Research Centre (AMRC), and the University of Sheffield (see Figure 2). Each centre has its own technological focus, such as the Centre for Process Innovation (CPI) that concentrates on thermal technologies and printable electronics, or the Warwick Manufacturing Group (WMG) that focuses on energy storage and management. The area of technological expertise determined which companies and industrial sectors the centre engaged with. For example, WMG's focus on energy storage led to close partnerships with automotive companies pursuing advancements in electric vehicle battery technology. The AMRC's focus on additive manufacturing led to close partnerships with the aerospace industry. Within this broad technology framework, the seven self-governing centres had the independence to select which technologies they pursued. In combination, the centres functioned as a network orchestrator; working as an intermediary between universities, government funding agencies and business.

The centres can be categorized as a loosely-coupled network because of the purposeful lack of hierarchical controls and decision-making autonomy.

Within each centre, another type of innovation network configuration is found. Tier 1 members, which tend to be large OEM's, collaborate with machine, equipment and material suppliers, customers and even competitors, on NTD projects. At Centre 1, for example, a large aerospace OEM works closely with additive manufacturing (AM) machine suppliers and raw material suppliers, to experiment with various AM applications, including electron beam melting, direct laser deposition, selective laser sintering. These suppliers may be competitors, but due to the government-funded model and membership structure, these competitors are encouraged to work together to advance various AM applications. Suppliers, buyers, and competitors work on collaborative NTD projects over extended period of time, with an expectation that these collaborations will extend into the future. Due to the regular and intense nature of collaboration between network members, the network configuration within the centres can categorized as tightly-coupled.

4.2 Knowledge Exchange, Integration and Aggregation

The HVMC was established with a relatively flat organizational hierarchy consisting of three levels: 1) engineer/technologist/project manager; 2) Director or Head; 3) Chief Executive/Chief Technology/Chief Finance Officer. Individuals working in the centres are considered experts in their respective field and given a high degree of autonomy to pursue projects they find interesting, as long as projects are delivered on-time to customer requirements. To facilitate knowledge exchange between individuals, the centres are organized using a matrix structure, comprised of vertically organized sector-specific teams (aerospace, automotive, construction) and horizontally organized technology groups (advanced manufacturing, digital engineering, machine learning, robotics). The Commercial director at Centre 2 explained the organizational structure as follows (see figure 3):

"You have operational capability, core competency, in your vertical columns and then in your horizontal columns what we're looking to do is pull out things like our digital capability, our sustainability strand, our future propulsion, robotic machine, and use those as the linkage between the core competency centres." Commercial director at Centre 2

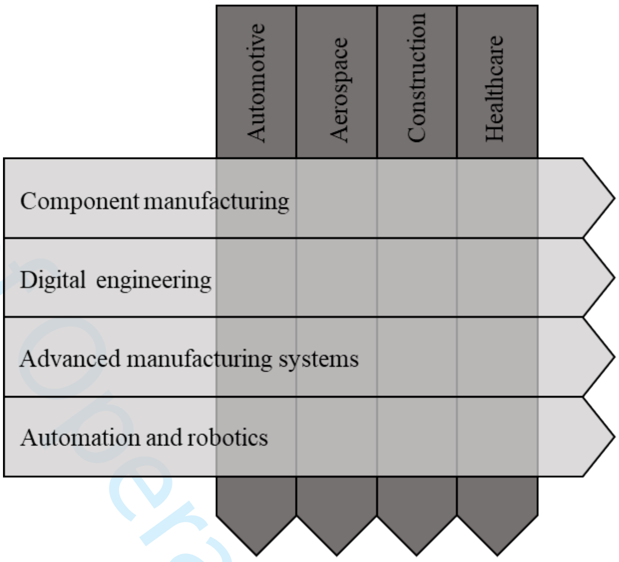

Figure 3, Disseminated matrix structure

Individuals with sector-specific and technology-specific expertise are allocated to an NTD project, consisting of a Chief Engineer, a Technologist, Head of Business Development and a Project Manager. This internal project team is then paired with individuals with similar sector and technological expertise from a member company. The Technical Specialist at Centre 1 explained this engagement as follows:

"We've done secondments in both directions for different projects, so having someone from the customer assigned to the project as a lead is key. It's usually a technical resource that's dedicated to deliver that programme, with the business structured to support that in the background from a business operations standpoint. There's a lot of match pairing and handholding with the client. A good business practice in any domain is to match delivery style in some way. It's the collaborative arrangement that we're aiming for from the outset, so there's nothing hidden, we are all pushing in the same direction rather than working against each other on how we are trying to deliver the work." Technical specialist, Team lead at Centre 1

This quote highlights that the integrated project teams facilitate knowledge sharing because team members speak the same technical language and collaborate to advance NTD projects. The Commercial Director at Centre 2 explained that the member company is expected to nominate a technology champion to drive the NTD project forward.

"Within our machining group we have digital expertise, within our automation group digital expertise, so we then have a digital champion, if you like, running horizontally through those. That's from a structural perspective." Commercial director at Centre 2

A Chief Technology Officer explained how HVMCs matrix structure supports the distribution of authority across the centres, which in turn facilitates agility in managing the flow of information between a vast number of projects at any given time:

"We are at a scale of maybe 4,000 people and by nature are a distributed network of centres; there's lots of distributed authority, which means we are agile. If we weren't, it would be difficult, I think, as a single organization of 4,000 to be quite as agile and responsive as we are, so it's this balance between agility and making sure that we don't end up with overlap or acting in a way that conflicts with our strategy, and I think we've got that balance really well with the cross-cutting themes and groups that we have." CTO at HVMC

The CTO explained that, by distributing decision-making authority, the technology champion and project team had ownership for the deliverables of the NTD project. The project team was able to quickly make decisions about when to invest in new suppliers, materials and testing equipment, without layers of managerial approval. Technology scale-up was quicker as teams were granted autonomy to invest resources into the greatest technological promises.

Depending on the member's tier, companies were given desk space and access to the centre's knowledge exchange platforms. A Senior Technology Officer at Centre 3 explained how co-location provided member companies the opportunity to work closely with HVMC staff and other member companies:

"If you're in Tier 1, that's our most expensive, highest-level tier. You're given ten desk spaces in the building, access to various boards and control systems. The next level down, you get two desks. And the next level down, you have hot desk access. So, everyone who's a member, in the region of 80 to 100 companies, get to choose which of our four large open-plan offices they'd like to sit in. Some of them who are commercially competitive prefer to sit at opposite ends of the building and others prefer to distribute their staff around, depending on whether they want to sit next to the manufacturing department, the automation department, the design department." Senior Technology Officer at Centre 3

We found that co-location not only led to better access to research facilities, but also enabled direct exposure to information that might not be transmitted through formal communication channels. The Technology Director at Centre 1 explained the significance of informal chats between different members that often lead to the exchange of tacit knowledge.

> *"We have a member's area where a lot of our members will come and work one or two days a week from our building. They are then having coffee in the same cafe as our engineers, they have lunch with our engineers, they have conversations, they have all their project meetings and in their project meetings they are discussing ideas for follow-on projects, so yeah, there's an incredible amount of interaction."* Technology Director at Centre 1

The matrix organizational structure and the NTD process bring individuals together formally and informally to share knowledge. Knowledge aggregates from individual experts to the team level using integrated project teams, with expertise regarding the various aspects of new technology development. Knowledge aggregates from the centres to the wider innovation network by matching these teams to a similar composition of experts in the member companies, with similar technical and sectoral expertise.

4.3 Knowledge Mobility

The centres use a variety of methods to improve the ease at which knowledge is acquired, shared and deployed across the network. The HVMC established the One Step Closer Together process, which facilitates the exchange of staff and ideas between the centres to foster new ways of thinking. The Senior Technology Officer at Centre 3 explained how this process improves the mobility of the workforce and facilitates knowledge exchange by moving individuals around the seven centres:

> *"We have the One Step Closer Together process that is ongoing, which is going to enable free movement of staff between centres so that we can get the expertise to where it geographically needs to be in the country more rapidly."* Senior Technology Officer at Centre 3

This cross-centre collaboration allows to reduce redundancies in the NTD process by minimizing duplication and replication between centres. As part of the process, the CTOs of the seven centres met monthly to map each centre's existing technological capabilities and develop a strategic direction for each technology grouping, including capital expenditure plans.

The purpose of the monthly meetings is to share new technological breakthroughs and ensure the centres are focused on a particular range of technological applications to improve coordination and reduce resource redundancies.

The centres also enhance knowledge mobility by encouraging the sharing of ideas on digital platforms, which are accessible to members and the general public. One example is the Digital Reconfigurable Additive Manufacturing for Aerospace (DRAMA) programme, which provides a free, and publicly accessible, knowledge hub on advancements in additive manufacturing development. The DRAMA programme seeks the active involvement of small and medium-sized enterprises (SMEs) in the NTD process as a way of upskilling the UK workforce. The DRAMA database invites critique, feedback and novel ideas from outside the network, to drive forward knowledge exchange. The Team leader of Technology Transformation at Centre 1, explained the three parts of the DRAMA programme as follows:

> *"It's got three key elements to it. One is developing a knowledge base which is, the research the HVMC are doing with other partners, and trying to establish an online library which we're calling the Knowledge Hub. And that will be a public, free online library where people can go and engage, and access the latest and most relevant AM material."* Team Lead, Technology Transformation at Centre 1

4.4 Innovation Appropriability

The HVMC has developed distinct ways of managing IP during NTD projects, specific to each type of funding stream. To pre-empt IP conflicts from occurring, the HVMC has established defined membership/partnership terms, such that new members must contractually agree to share newly generated IP with other members and the public when working on collaborative NTD projects.

Some of the large Tier 1 clients are inclined towards using the private funding route to ensure IP ownership and to avoid sharing knowledge with competitors. However, the majority of large multi-nationals and SMEs embrace the publicly funded routes. These companies see the benefit of working with suppliers, OEMs, customers and even competitors, to co-develop technologies that underpin their future products. They realize that competitive advantage comes from the opportunity to work with experts at the catapults to scale-up new technology, and to use this technology to create novel products. The Senior Technology Officer explained the arrangement as follows:

> *"This is a government innovation institute, if you want to pay for your own innovation institute, then you can own everything. If you don't want to pay for your own innovation institute, and you want to use this government-subsidized one, you cannot own what is in this person's head. That is not legally allowed."* Senior Technology Officer at Centre 4

As the HVMC is two-thirds government funded, project outputs are considered a public resource. This means the centres are not interested in owning the IP from NTD projects, commercializing new technologies or licensing patents. The centres will publish research findings from core research programmes on the knowledge hub, which negates the ability of members to patent or license the IP. The Head of commercial and legal at Centre 1 expands on this issue:

> *"For our core projects, generally, we don't patent any IP, we use other means of protection, such as publishing. We would treat it as our know-how, more than IP. If it is pre-existing, we own it already, that knowledge, that know-how, and we are developing it for use with one customer, that's specific to them, and they would own the specifics to their product, but not the kind of knowledge generated, so we are quite within our means to go and apply it to a different application for another customer."* Head of Commercial and Legal at Centre 1

By not seeking to profit from IP, the focus of NTD projects becomes knowledge sharing and mobility as opposed to protection. IP is treated as a public good that can be applied by local businesses to enhance their own manufacturing capacity, while boosting the productivity of the UK economy.

5 Discussion and Theoretical Contributions

Organizational coupling has been defined as the relationship between innovation network partners in terms of working closeness and reciprocity, which can vary in strength from loose to tight (Hofman et al., 2017). While tighter organizational coupling can help coordinate the exchange and integration of resources across organizational boundaries, due to network partners working closely together on a regular basis, it can also lead to uniformity of ideas and entrenched ways of working (Hofman et al., 2016). Loose coupling encourages different organizational actors to share their diverse knowledge in new and interesting ways but on a more infrequent basis, creating less opportunities for reciprocity (Hofman et al., 2016). Existing studies tend to view innovation network configurations as either loosely or tightly-coupled, where the network coordinator seeks to ensure the network stability, knowledge exchange and innovation appropriability (Dhanaraj and Parkhe, 2006).

Our findings suggest that the HVMC network is a hybrid configuration, where the seven centres act as the network orchestrator, bringing together the collective knowledge of government funding agencies, universities and businesses. The seven centres have the autonomy to pursue a wide variety of NTD projects, within a loosely defined technological framework. The centres are responsive to each other, and to stakeholder requirements, but retain separateness and identity (Weick, 1976) in terms of their respective technological profiles and sectoral foci. Underpinning this loosely-coupled network configuration, are the individuals and NTD teams that transition technologies across the VoD. Engineers, academics, suppliers, customers and competitors all collaborate in order to scale new technologies. The working closeness, knowledge exchange and reciprocity of ideas that occur during NTD projects suggests tightly-coupled network interactions within the centres. The HVMC's hybrid combination of loosely-coupled and tightly-coupled innovation networks is established in Figure 4.

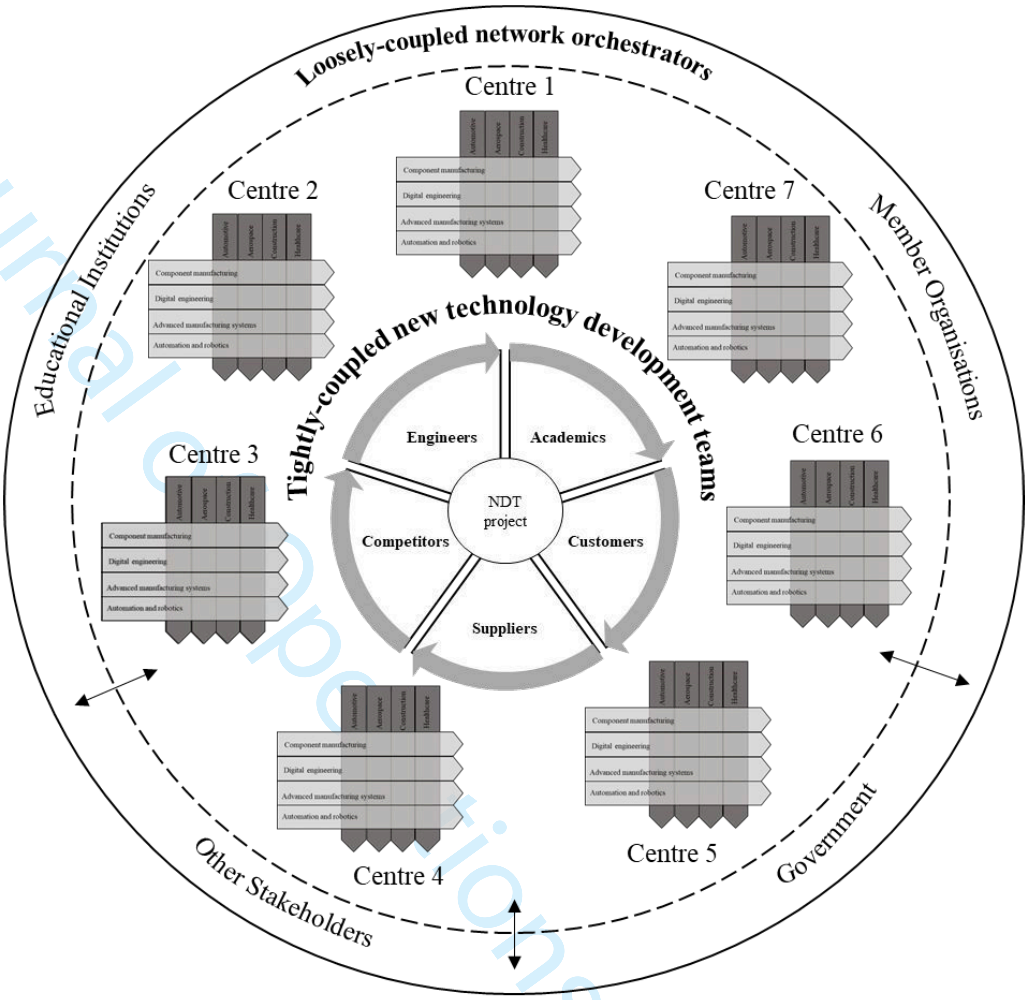

Figure 4, Hybrid combination of a loosely-coupled and tightly-coupled innovation network

From 2011 to 2020, the HVMC transitioned 4,646 NTD projects across the VoD. One example is the UK Energy Storage Laboratory project, hosted by the WMG which created Lithium-ion batteries that reduce grading time from four hours to less than five minutes, with extreme accuracy. By partnering with Nissan, AMETEK and Element Energy, WMG's battery technology team developed a safe, robust and fast grading process, which was subsequently automated using an algorithm developed in the centre (Warwick, 2020). The proven capability of the HVMC network to advance thousands of NTD projects across the VoD suggests a hybrid combination of loosely and tightly-coupled network ties, providing the network stability needed to overcome the VoD. Based on these findings we propose the following:

Proposition 1: A hybrid innovation network configuration, comprised of loosely-coupled network orchestrators and tightly-coupled new technology development teams, creates the network stability needed to transition new technologies across the Valley of Death.

A key assumption of the knowledge based view is that individuals are the locus of knowledge in firms, with interactions between individuals, structures and processes leading to the integration and aggregation of knowledge (Barney and Felin, 2013; Felin et al., 2012). Knowledge is said to aggregate from micro to macro, as individuals interact within teams to solve new technology development challenges (Barney and Felin, 2013). However, a key limitation of the knowledge based view is that it confines our understanding of knowledge aggregation to the boundaries of the firm. Our research augments the knowledge based view by identifying the foundational elements that allows knowledge to be distributed across not-for-profit innovation networks.

Specifically, we found that the HVMC's matrix structure encourages individuals in sector-specific teams and technology groups to interact and integrate their knowledge. Respondents explained how the vertical and horizontal exchange of information within the matrix structure was well suited to the highly complex problem-solving challenges they faced on a day-to-day basis. Technology and sectoral experts from within the centres are then matched with the corresponding skill set from business partners. The distribution of authority across the centres was further complemented by the nomination of a technology champion from the business partner, who was given responsibility to drive forward the NTD project. Respondents explained how technology champions acted as conduits for knowledge sharing by acting as gatekeepers and knowledge facilitators for a particular NTD project. This finding supports earlier work on the importance of champions in facilitating knowledge exchange during NTD projects (Gattiker and Carter, 2010; Markham et al., 2010). Knowledge aggregation between the seven centres is enabled through monthly meetings between the CTOs, which reduce resource redundancies within the network. Knowledge is also aggregated to the network level through the regular secondments and researcher/doctoral placements, where staff move between centres to proactively share knowledge and generate new ways of thinking (see Figure 5).

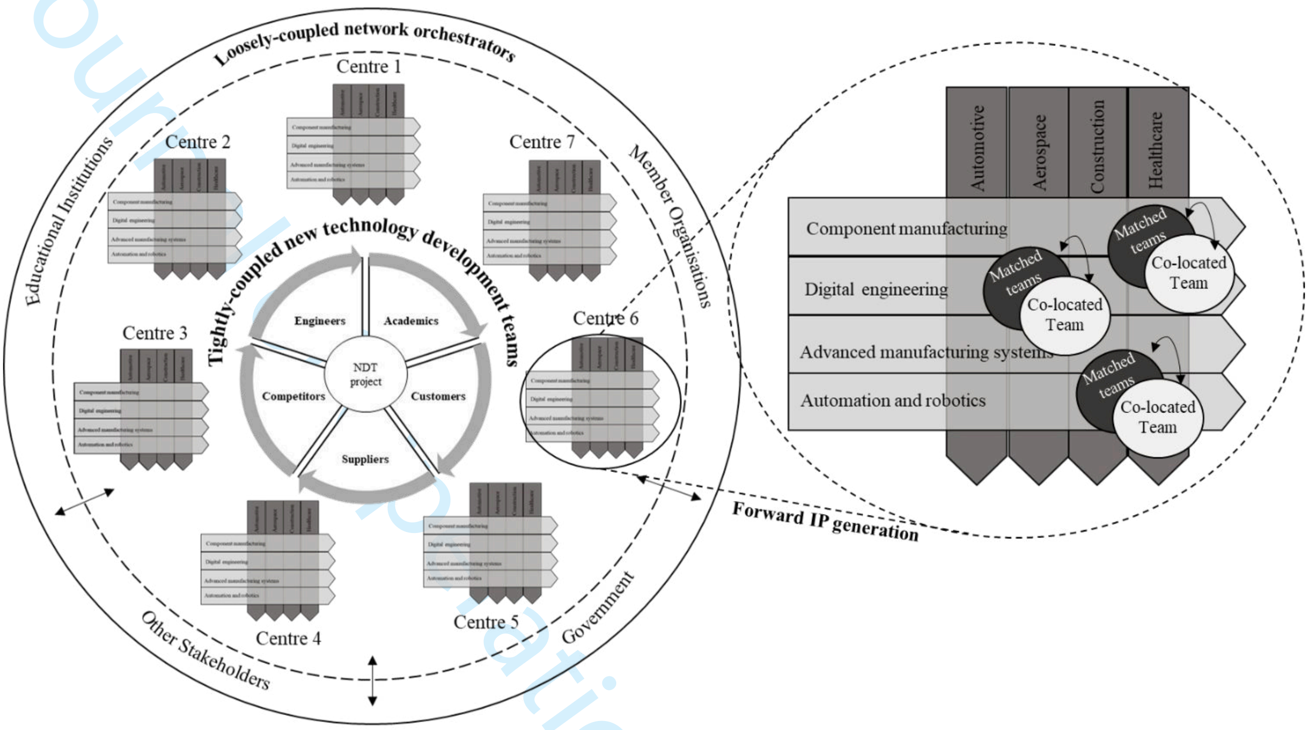

Figure 5, Matching member and staff teams, co-location of integrated project teams and proactively moving staff between centres

These findings lead to our second proposition:

> **Proposition 2**: Knowledge integration and aggregation occurs within not-for-profit innovation networks by combining internal and external sectoral and technological experts in integrated project teams, by distributing decision making authority to NTD teams, and by coordinating technological focus areas between senior managers.

Network Orchestration Theory suggests that the role of the network orchestrator is to improve the ease with which knowledge is acquired, shared, and deployed within the network (Dhanaraj and Parkhe, 2006). The orchestrator must be able to assess the value of relevant knowledge residing at different points in the network, arrange its transfer to other points in the network, and exploit the resources made available through the network relationships. Our findings build on these theoretical tenets by explaining how knowledge mobility is achieved in not-for-profit innovation networks. A key difference between a for-profit innovation network and the HVMC, is that the latter actively publishes and promotes the latest technological breakthroughs on a knowledge hub, available not only to network members, but also to the general public. Training programmes and financial support packages are provided to members to equip companies with the latest knowledge about advanced digital technologies. This supports the argument of Howells (2006) that the orchestrators of not-for-profit networks are not concerned with extracting value from the network, but instead act as knowledge intermediaries between government agencies, universities and businesses during NTD efforts. This leads us to our third proposition:

> **Proposition 3:** The ease with which knowledge is shared, acquired and deployed within not-for-profit innovation networks is enhanced by creating knowledge sharing platforms, and by providing training and support packages that improve the technological capabilities of network members and the general public.

The HVMC model is distinct from Proof of Concept Centres (Hayter and Link, 2015; McAdam et al., 2009) or university spin-outs that seek to 'profit from innovation' (Teece, 1986) through commercialization and the licensing of patents (Nicolaou and Birley, 2003; Perkmann et al., 2013). The HVMC's funding structure shapes and facilitates knowledge mobility because individuals are able to freely share ideas without the frictions that innovation appropriability often imposes on knowledge exchange. The Head of Commercial and Legal at Centre 1 explained that members working on collaborative R&D programmes must sign collaboration agreements in advance, which specify that parties cannot own or profit from forward IP because 'you cannot own what is in someone's head'. The interviewee explained how the HVMC publishes the newly generated IP that emerges from collaborative R&D projects in the public domain.

This finding challenges the assumption of Network Orchestration Theory that the role of the network orchestrator is to ensure that network members capture the profits generated by an innovation by strengthening appropriability regimes using instruments such as patents, copyrights and trademarks (Dhanaraj and Parkhe, 2006; Teece, 2000). Instead, our findings suggest that the orchestrators of not-for-profit innovation networks should establish *pre-*

defined membership rules and distinct paths for new technology development, where the IP outputs of collaborative projects are published and made accessible to any interested party. This approach is not one of creating intentionally weak appropriability regimes (Teece, 1986); instead IP is treated as a public resource that is made accessible for the benefit of the wider community. These findings lead us to propose the following:

Proposition 4: Knowledge mobility is enhanced within not-for-profit innovation networks by removing friction which negatively impacts knowledge sharing through defined membership/partnership rules and paths that stipulate how newly generated intellectual property becomes a public resource that is made freely available.

Drawing together these propositions, we now advance a framework that provides guidance to policy makers, academics and business managers, on how not-for-profit innovation networks can be used to transition new technologies across the VoD (see Figure 6).

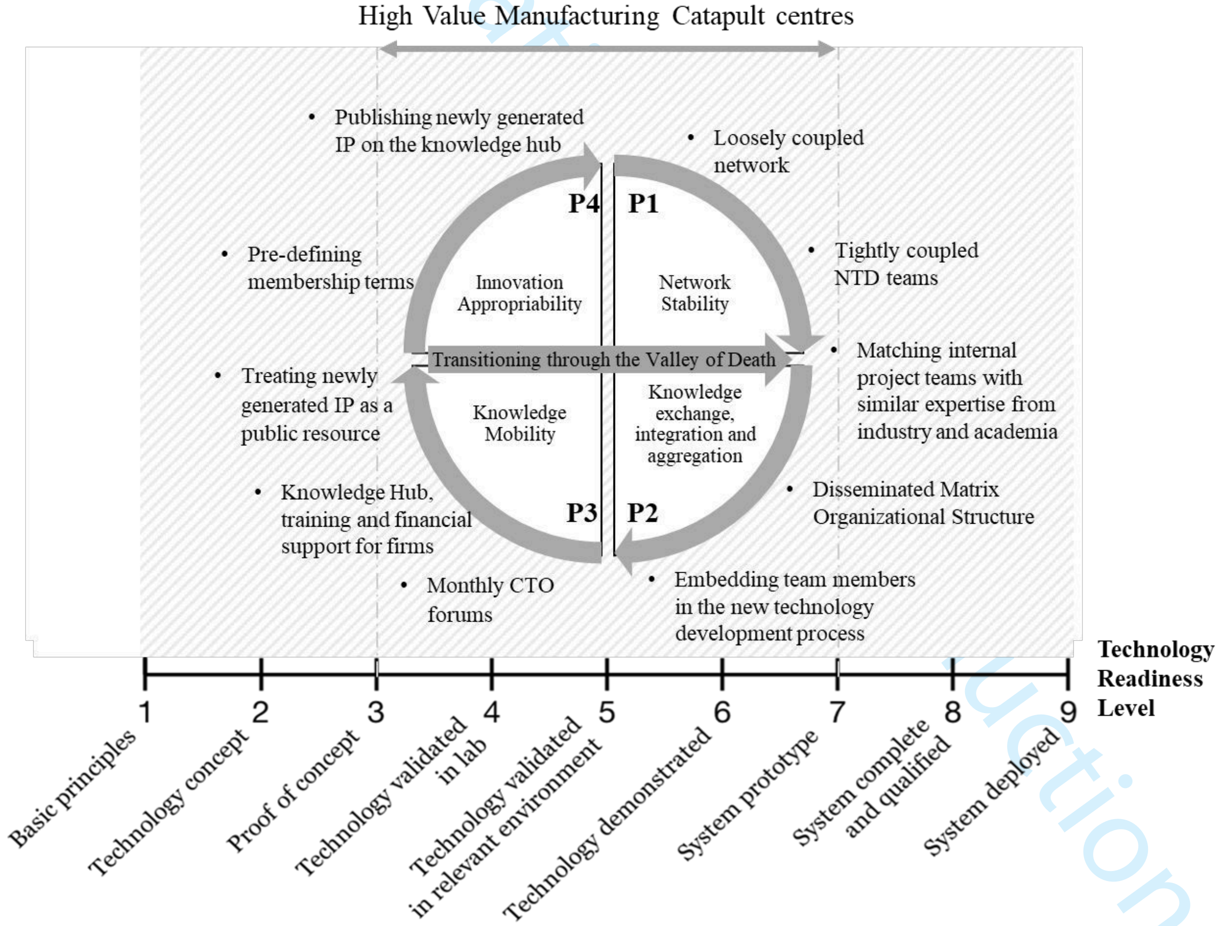

Figure 6, Framework for transitioning new technologies across the VoD in not-for-profit networks

6 Conclusion and Contributions

6.1 Theoretical Contributions

The knowledge based view provides an intriguing argument that individuals are the locus of knowledge in firms, and that this knowledge aggregates from individuals to collectives of individuals (teams) due to their interactions with the processes and structures of the firm (Grant, 1996). However the KBV's understanding of knowledge integration and aggregation is limited to the confines of the firm. Our study contributes to knowledge-based theory by identifying how knowledge integrates and aggregates across not-for-profit innovation networks. Our findings suggest that matching internal technical and sectoral expertise to the complementary experience of network members, allows knowledge to transfer across organizational boundaries and across the wider network. Matrix organizational structures and distributed decision-making authority create the opportunities for knowledge interactions to occur. Actively moving individuals and integrated project teams between innovation centres diffuses knowledge to network members, while regular meetings between senior management ensures network coordination and removes resource redundancies. These findings contribute to the operations management literature by moving beyond an identification of the micro-foundations of NTD capabilities in firms (see Peng et al., 2008; Roscoe et al., 2019), to an in-depth understanding of how knowledge integrates and aggregates across not-for-profit innovation networks.

The findings contribute to network orchestration theory by showing how hybrid network structures, including loosely-coupled network orchestrators and tightly-coupled NTD teams, provide the network stability needed to transition new technologies across the VoD. Our findings challenge the key assumption of network orchestration theory that network orchestrators should enact and enforce appropriability regimes (patents, licences, copyrights) to allow network members to profit from innovation (Dhanaraj and Parkhe, 2006; Teece, 2000).

Instead, we find that not-for-profit innovation networks can overcome the tensions that appropriability regimes create when exchanging knowledge during NTD projects, by pre-defining the terms of network membership/partnership and setting out clear pathways for innovation scaling. By treating newly generated IP as a public resource, the parties co-developing new technologies are no longer encumbered by knowledge exchange frictions, such as the secrecy and lack of trust that often arise when the goal is to patent the latest technological breakthroughs. By acting as a knowledge intermediary, the orchestrator of a not-for-profit innovation network can concentrate on advancing new technologies from the proof-of-concept stage to a point when the technology can be handed back to a commercial partner for onward commercialization.

6.2 Managerial Contributions

Managers are provided with a detailed framework that explains how not-for-profit innovation networks can support the transition of NTD projects across the VoD. The findings will benefit managers facing the difficult prospect of having to invest in new machines, resources, and facilities to scale new technologies, without any guarantee of success. Our framework highlights how not-for-profit innovation networks de-risk the innovation process by pooling risks and resources between its members, saving significant investment accordingly. The framework calls on managers to consider if new technology development can be better facilitated if appropriability regimes are removed, and newly generated knowledge is made freely available to members and the general public. Being open to treating newly generated IP as a public resource, can provide managers the opportunity to work with suppliers, customers and competitors in order to co-develop new technologies, and subsequently use that technology to manufacture distinctly new products. For example, by working with material and machines suppliers to scale various AM applications, the collaborators were able to apply these AM applications to create novel components and subassemblies for their latest product offerings.

In these instances, the value of the IP is not in the technology itself, but in the final product that is created using that technology. We encourage managers to embrace this novel, not-for-profit, new technology development approach to spread risk and overcome the VoD.

6.3 Limitations and Future Research Directions

The findings from this study should be viewed in light of its limitations. We focused on a very specific research context, i.e. crossing the VoD using not-for-profit innovation networks. Due to the specificity of our research question, we were limited in options for data collection and instead sought to take a deep-dive into a single case study of the HVMC. Due to our single case research design, we do not claim that the findings are statistically generalizable to all innovation networks, at all times. Instead, we aimed for analytical generalization (Yin, 2014) by generalizing from the empirical findings to knowledge-based theory. Future studies looking to test the validity of our propositions may wish to extend our data collection efforts to other not-for-profit innovation networks such as University Technology Centres (UTCs), which are focused on early-stage ideation. One example from the United States (U.S.), shows how industrial policy is funding a new National Institute of Standards and Technology (NIST) semiconductor programme to support advanced manufacturing. The programme's funds will also support workforce development, ecosystem clustering, 5G leadership, and advanced assembly and testing. The policy establishes a $5 billion Advanced Packaging National Manufacturing Institute under the Department of Commerce (DOC) to enable U.S. leadership in advanced micro-electronic packaging and, in coordination with the private sector, fosters private-public collaborative R&D programmes to advance novel technologies. Future researchers may wish to examine if our propositions hold true in these different research contexts. It is likely that different not-for-profit innovation networks will use particular network configurations to ensure network stability. At the same time, different platforms for knowledge exchange and mechanisms for knowledge mobility are likely to emerge by testing our propositions in different network contexts.

References

Aarikka-Stenroos, L., Jaakkola, E., Harrison, D., & Mäkitalo-Keinonen, T. (2017). How to manage innovation processes in extensive networks: A longitudinal study. *Industrial Marketing Management*, 67, 88–105.

Armstrong, D., Gosling, A., Weinman, J. and Marteau, T. (1997), "The Place of Inter-Rater Reliability in Qualitative Research: An Empirical Study", *Sociology*, Vol. 31 No. 3, pp. 597–606.

Barr, Steve H., et al. "Bridging the valley of death: Lessons learned from 14 years of commercialization of technology education." *Academy of management learning & education*, 8.3 (2009): 370-388.

Branscomb, L. M., & Auerswald, P. E. (2003). Taking technical risks: How innovators, managers, and investors manage risk in high-tech innovations. MIT Press.

Clark, K. B. and T. Fujimoto (1992). Product Development Performance. Harvard Business School Press Boston, MA.

Comacchio, A., Bonesso, S., & Pizzi, C. (2012). Boundary spanning between industry and university: The role of Technology Transfer Centres. *Journal of Technology Transfer*, 37, 943–966

Corley, K.G., and Gioia, D.A. (2011), "Building theory about theory building: What constitutes a theoretical contribution", *The Academy of Management Review*, 36, 12–32.

Dean, T., Zhang, H., and Xiao, Y. (2020), "The role of complexity in the Valley of Death and radical innovation performance", *Technovation*, 102160.

D'Este, P. and Patel, P. (2007), "University–industry linkages in the UK: What are the factors underlying the variety of interactions with industry?", *Research Policy*, Vol. 36 No. 9, pp. 1295–1313.

Dhanaraj, C., & Parkhe, A. (2006). Orchestrating innovation networks. *Academy of management review*, 31(3), 659-669.

Dyer, J. H., & Singh, H. (1998). The relational view: Cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review*, 23(4), 660-679.

Eisenhardt, K.M. (1989), "Building theories from case study research", *Academy of Management Review*, Vol. 14 No. 4, pp. 532–550.

Eisenhardt, K.M. and Santos, F.M. (2000), "Knowledge-based View: a new theory of strategy", in Pettigrew, A., Thomas, H. and Whittington, R. (Eds.), *Handbook of Strategy and Management*, Sage Publications, Thousand Oaks, California.

Ellwood, P., Williams, C., and Egan, J. (2020), "Crossing the valley of death: Five underlying innovation processes", *Technovation*, 102162.

Felin, T., Foss, N.J., Heimeriks, K.H., and Madsen, T.L. (2012), "Microfoundations of routines and capabilities: Individuals, processes, and structure", *Journal of Management Studies*, 49(8), 1351-1374.

Frank, C., Sink, C., Mynatt, L., Rogers, R., & Rappazzo, A. (1996). Surviving the "valley of death": A comparative analysis. *The Journal of Technology Transfer*, 21, 61-69.

Gattiker, T.F. and Carter, C.R. (2010), "Understanding project champions' ability to gain intra-organizational commitment for environmental projects", *Journal of Operations Management*, Vol. 28 No. 1, pp. 72–85.

Gioia, D.A., Corley, K.G. and Hamilton, A.L. (2012), "Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology", *Organizational Research Methods*, Vol. 16 No. 1, pp. 15–31.

Grant, R.M. (1996a), "Toward a knowledge-based theory of the firm", *Strategic Management Journal*, Vol. 17 No. S2, pp. 109–122.

Grant, R.M. (1996b), "Prospering in Dynamically-Competitive Environments: Organizational Capability as Knowledge Integration", *Organization Science*, Vol. 7 No. 4, pp. 375–387.

Hayter, C.S. and Link, A.N. (2015), "On the economic impact of university proof of concept centers", *Journal of Technology Transfer*, Vol. 40 No. 1, pp. 178–183.

Hofman, E., Halman, J. I., & Van Looy, B. (2016). Do design rules facilitate or complicate architectural innovation in innovation alliance networks? *Research policy*, 45(7), 1436-1448.

Hofman, Erwin ; Halman, Johannes I. M. ; Song, Michael (2017), When to Use Loose or Tight Alliance Networks for Innovation? Empirical Evidence: When to Use Loose or Tight Alliance Networks, *The Journal of product innovation management*, Vol.34 (1), p.81-100

Howells. (2006). Intermediation and the role of intermediaries in innovation. Research Policy, 35(5), 715–728. https://doi.org/10.1016/j.respol.2006.03.00

Hurmelinna-Laukkanen, P., & Nätti, S. (2018). Orchestrator types, roles and capabilities–A framework for innovation networks. *Industrial Marketing Management*, 74, 65-78.

HVMC. (2021a), "HVMC Annual Report", available at: https://hvm.catapult.org.uk/HVMannual-review-2019-2020.pdf (accessed 29 April 2022).

HVMC (2021b), Our Centres. https://hvm.catapult.org.uk/our-centres, (accessed 15 July 2021).

Kaplan, R.E. (1982) Intervention in a loosely organized system: An encounter with non-being. *The Journal of Applied Behavioral Science*, 18 415-432

Ketokivi, M. and Choi, T. (2014), "Renaissance of case research as a scientific method", *Journal of Operations Management*, Vol. 32 No. 5, pp. 232–240.

Kim, T. Y., Oh, H., & Swaminathan, A. (2006). Framing interorganizational network change: A network inertia perspective. Academy of management review, 31(3), 704-720.

Lee, T.W. (1999), *Using Qualitative Methods in Organizational Research*, SAGE Publications.

Leten, B., Vanhaverbeke, W., Roijakkers, N., Clerix, A., & Van Helleputte, J. (2013). IP models to orchestrate innovation ecosystems: IMEC, a public research institute in nano-electronics. *California Management Review*, 55(4), 51–64.

Levén, P., Holmström, J., & Mathiassen, L. (2014). Managing research and innovation networks: Evidence from a government sponsored cross-industry program. *Research Policy*, 43, 156–168

Lumineau, F., & Oliveira, N. (2018). A pluralistic perspective to overcome major blind spots in research on interorganizational relationships. *Academy of Management Annals*, 12(1), 440–465.

Lynn, L. H., Reddy, N. M., & Aram, J. D. (1996). Linking technology and institutions: the innovation community framework. Research policy, 25(1), 91-106.

Markham, S.K., Ward, S.J., Aiman-Smith, L., and Kingon, A.I. (2010), "The valley of death as context for role theory in product innovation", *Journal of Product Innovation Management*, 27(3), 402-417.

McAdam, M., Galbraith, B., McAdam, R. and Humphreys, P. (2006), "Business Processes and Networks in University Incubators: A Review and Research Agendas", *Technology Analysis & Strategic Management*, Routledge, Vol. 18 No. 5, pp. 451–472.

McAdam, R., McAdam, M. and Brown, V. (2009), "Proof of concept processes in UK university technology transfer: an absorptive capacity perspective", *R&D Management*, Vol. 39 No. 2, pp. 192–210.

Merton, R.K. (1968), *Social Theory and Social Structure*, Simon and Schuster.

Milewski, S.K., Fernandes, K.J., and Mount, M.P. (2015), "Exploring technological process innovation from a lifecycle perspective", *International Journal of Operations & Production Management*. Vol. 35 No. 9, pp. 1312-1331

Moradlou, H., Roscoe, S., and Ghadge, A. (2022), “Buyer–supplier collaboration during emerging technology development”, *Production Planning & Control*, 33(2-3), 159-174.
Nicolaou, N. and Birley, S. (2003), “Social Networks in Organizational Emergence: The University Spinout Phenomenon”, *Management Science*, Institute for Operations Research & the Management Sciences, Vol. 49 No. 12, pp. 1702–1725.
Orton, J. D., & Weick, K. E. (1990). Loosely coupled systems: A reconceptualization. *Academy of management review*, 15(2), 203-223.
Osborne, P., Routley, M., and Ilevbare, I. (2021), “A Hierarchical Approach to Technology Roadmapping within an RTO Environment”, *Research-Technology Management*, 64:3, 58-67, 1896243
Parker, C., Scott, S. and Geddes, A., (2019). Snowball sampling. SAGE research methods foundations.
Peng, D. X., Schroeder, R. G., & Shah, R. (2008). Linking routines to operations capabilities: A new perspective. Journal of operations management, 26(6), 730-748.
Pérez-Luño, A., Bojica, A. M., & Golapakrishnan, S. (2018). When more is less: the role of cross-functional integration, knowledge complexity and product innovation in firm performance. *International Journal of Operations & Production Management*. Vol. 39 No. 1, pp. 94-115
Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D’Este, P., Fini, R., *et al.* (2013), “Academic engagement and commercialisation: A review of the literature on university–industry relations”, *Research Policy*, Vol. 42 No. 2, pp. 423–442.
Potter, A., & Paulraj, A. (2020). Building supplier innovation triads: the effects of leadership relationships and alliance partner diversity. International Journal of Operations & Production Management. Vol. 40 No. 2, pp. 144-172
Powell, W.W. and Grodal, S. (2006), “Networks of Innovators”, in Fagerberg, J., Mowery, D.C. and Nelson, R.R. (Eds.), *The Oxford Handbook of Innovation*, OUP Oxford.
Powell, W.W., Koput, K.W., and Smith-Doerr, L. (1996), “Interorganizational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology”, *Administrative Science Quarterly*, Vol. 41 No. 1, pp. 116–145.
Rampersad, G., Quester, P. and Troshani, I. (2010), “Managing innovation networks: Exploratory evidence from ICT, biotechnology and nanotechnology networks”, *Corporate Image and Reputation in B2B Markets*, Vol. 39 No. 5, pp. 793–805.
Roca, J. B., & O'Sullivan, E. (2022). The role of regulators in mitigating uncertainty within the Valley of Death. Technovation, 109, 102157.
Roscoe, S., Cousins, P.D., and Handfield, R. (2019), “The microfoundations of an operational capability in digital manufacturing”, *Journal of Operations Management*, 65(8), 774-793.
Rothaermel, F.T. and Thursby, M. (2005), “Incubator firm failure or graduation? The role of university linkages”, *Research Policy*, Vol. 34 No. 7, pp. 1076–1090.
Siegel, D.S., Waldman, D.A., Atwater, L.E. and Link, A.N. (2004), “Toward a model of the effective transfer of scientific knowledge from academicians to practitioners”, *Research on the Human Connection in Technological Innovation*, Vol. 21 No. 1, pp. 115–142.
Son, H., Chung, Y. and Yoon, S. (2020), “How can university technology holding companies bridge the Valley of Death? Evidence from Korea”, *Technovation*, 109, pp. 102-158.
Stankiewicz, R. (1995). The role of the science and technology infrastructure in the development and diffusion of industrial automation in Sweden. Technological systems and economic performance: The case of factory automation, 165-210.
Teece, D.J. (1986), “Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy”, *Research Policy*, Vol. 15 No. 6, pp. 285–305.
Teece, D. J. (2000). Managing intellectual capital: Organizational, strategic, and policy dimensions. London: Oxford University Press.

Van der Meulen, B., & Rip, A. (1998). Mediation in the Dutch science system. *Research policy*, 27(8), 757-769.
Warwick, (2020). Used Nissan LEAF batteries given "second life" thanks to WMG. Available at: https://warwick.ac.uk/newsandevents/pressreleases/used_nissan_leaf (accessed 25 April 2023).
Weick, K. E. (1976). Educational organizations as loosely coupled systems. *Administrative science quarterly*, 1-19.
Yin, R.K. (2014), *Case Study Research: Design and Methods*, 5th ed., Sage Publications, Thousand Oaks, California.
Zollo, M. and Winter, S.G. (2002), "Deliberate Learning and the Evolution of Dynamic Capabilities", *Organization Science*, Vol. 13 No. 3, pp. 339–351.

Appendix 1

The following table shows the illustrative quotes for second order concepts and aggregate dimensions.

Table 2, Illustrative quotes

Second Order Concept	Illustrative Quote
Loosely coupled network	*"A member of the [Centre 1] is someone who is a formal member and contributes either through in-kind contribution or cash. So, there are a number of those organisations within the project, who aren't formal consortium partners, they're not part of the Innovate UK bid, that we wrote in order to deliver the project, but they're still perceived as collaborators because they've had some level of involvement to support and develop the technologies in the project." Senior Research Engineer at Centre 1*
Tightly coupled NTD teams	*"By working through the [Centre 5], we tend to pull the right people together, we identify people with the same type of problem statements together. Therefore, you're showing cost, risk, knowledge and ideas, and you're able to pull that knowledge together. So we are effectively, I would say the glue that holds a lot of these conversations together if that makes sense." Business Development Director at Centre 5*
Disseminated Matrix Organizational Structure	*"When we start a procurement activity, we would always work on, based on a matrix project team, so we would involve people from our technical team, engineers, as well as potentially if it affects the facilities, have someone from facilities, IT, health and safety, so we would work on that basis." Procurement Manager at Centre 3*
Matching internal project teams with similar expertise from industry and academia	*"Once the project is finalised by the business development team, we then allocated technical team with the right skills who will be taking the project forward to work closely with the member company" Knowledge Exchange Fellow at Centre 7*
Embedding clients in the new technology development process	*"we're there to help companies effectively navigate through the valley of death scenarios. So companies that have a have an idea, they have a product on paper. Maybe they want to commercialize it. They don't know how to do the upscaling or scale out part of that. So we're there to help them move faster than they would be without us." Business Development Director at Centre 5*
Monthly CTO and STO forums	*"one of the remits that the CTO team has is to be de-conflicting any of that capability, build, investments, making sure we're not duplicating capability, making sure we're drawing on the knowledge that's already been generated." CTO at Centre 4*
Knowledge Hub, training and financial support for firms	*"The second element is a training programme with the Advance Manufacturing Training Centre. And that's going to contain a number of short courses, primarily five-day courses, where people can access more in-depth information*

	and classroom-environment training with leading experts. And that will have information from design, to manufacture, to health and safety." Team Lead, Technology Transformation at Centre 1
Treating newly generated IP as a public resource	*"So I don't want it to be limited by IP. I'd like it to be as mass open access as possible. So dissemination in a CR&D project is really helpful because by default, by making it public domain information, nobody else can patent it to stop you from doing it." CTO at Centre 5*
Publishing newly generated IP on the knowledge hub	*"we are here to make UK manufacturing more competitive, so if there is a business in the UK that can use our IP, and help business generally to become more competitive then we'll just give it, we're not trying to generate IP and licence it or spin every bit of IP out, we just want it to make its way into British manufacturing and make an impact." Research Director at Centre 2*
Pre-defining membership/partnership terms	*"We do have a membership structure, what we call the tier 1s, which is essence are usually big customers or OEMs, major tier 1s in aerospace or other industries. All of those have a yearly contribution that is 200k. Half of that, actually or... slightly less than that goes into this core programme. And then the other half they spend in whatever they want basically. And whatever research they want. So, the membership is not kind of like a club membership, the membership is fully spent into R&D." CTO at Centre 3*
Aggregate Dimension	**Illustrative Quote**
Network Stability	*"members help us with our technology roadmaps so we'll work with the members to check that it's going to deliver what they need, because there's no point in us putting things on our roadmap that there's going to be no industrial demand, so they help us by validating what's in our roadmap" Chief Engineer at Centre 1*
Knowledge exchange, integration and aggregation	*"The third element is the support packages. Within the support packages, there is one-to-one collaboration, right from the very beginning, where we offer support from [additive manufacturing] AM journey assessment to starting to get their feet and feel for where they're going to enter, all the way right to production." Team lead, Technology Transformation at Centre 1*
Knowledge Mobility	*"there's more that we could do to try and share more of the generic stuff wider to lower down the supply chains. And that's where I guess things like the DRAMA benefits there, where you can establish this capability where any company can come and access that, and buy in to it, and try put the technologies for their particular applications." Head of Strategy for AM at Centre 2*
Innovation Appropriability	*"For our industrial-funded projects, like a direct one-on-one contract with a company, they'll own all of the foreground IP that's generated through that project. For collaborative R&D projects we tend to do collaboration agreements as part of standard Innovate UK funded models. For our core research programmes, we free license the IP to anyone who wants it." Chief Engineer at Centre 1*

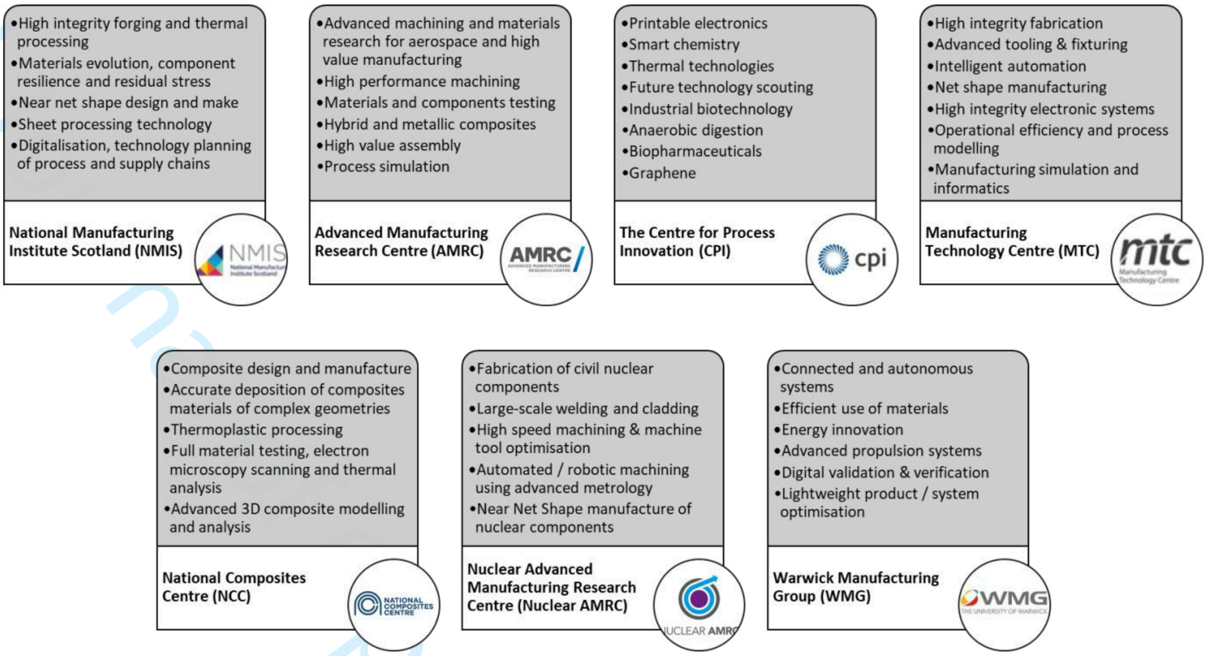

Figure 1, HVMC network of centres and key competencies

Table 1, Overview of Interviewees

No	*Catapult Centre*	*Position*	*Years at Catapult*
1	Centre 1	Research engineer	2
2	Centre 1	Team lead, Technology Transformation	6
3	Centre 1	Head of commercial and legal	2.5
4	Centre 1	Senior research engineer	9
5	Centre 1	Technical specialist, Team lead	8
6	Centre 1	Research engineer	1
7	Centre 1	Technology director	10
8	Centre 1	Senior research engineer	2
9	Centre 1	Senior research engineer	3
10	Centre 1	Supply chain manager	2.5
11	Centre 1	Legal officer	2.5
12	Centre 1	Advanced research engineer	1.5
13	Centre 1	Chief engineer	9
14	Centre 1	Advanced research engineer	2.5
15	Centre 1	Chief engineer	5
16	Centre 1	Principal research engineer	9
17	Centre 2	Research director	12
18	Centre 2	Head of Strategy for Additive Manufacturing	5
19	Centre 2	Deputy head of digital	3
20	Centre 2	Commercial director	18
21	Centre 2	Senior research fellow	14
22	Centre 3	Senior Technology Officer	10
23	Centre 3	Chief Technology Officer (CTO)	6
24	Centre 3	Procurement manager	5.5
25	Centre 4	Program manager	3.5
26	Centre 4	Senior Technology Officer	4
27	Centre 4	Knowledge Transfer Specialist	9
28	Centre 4	Project manager	4
29	Centre 4	Associate Professor	7
30	Centre 4	Chief technology officer (CTO)	3
31	Centre 5	Chief technology officer (CTO)	8
32	Centre 5	Business Development Director	4
33	Centre 6	Chief technology officer (CTO)	10
34	Centre 7	Knowledge Exchange Fellow	7.9
35	HVMC	Chief technology officer (CTO)	17

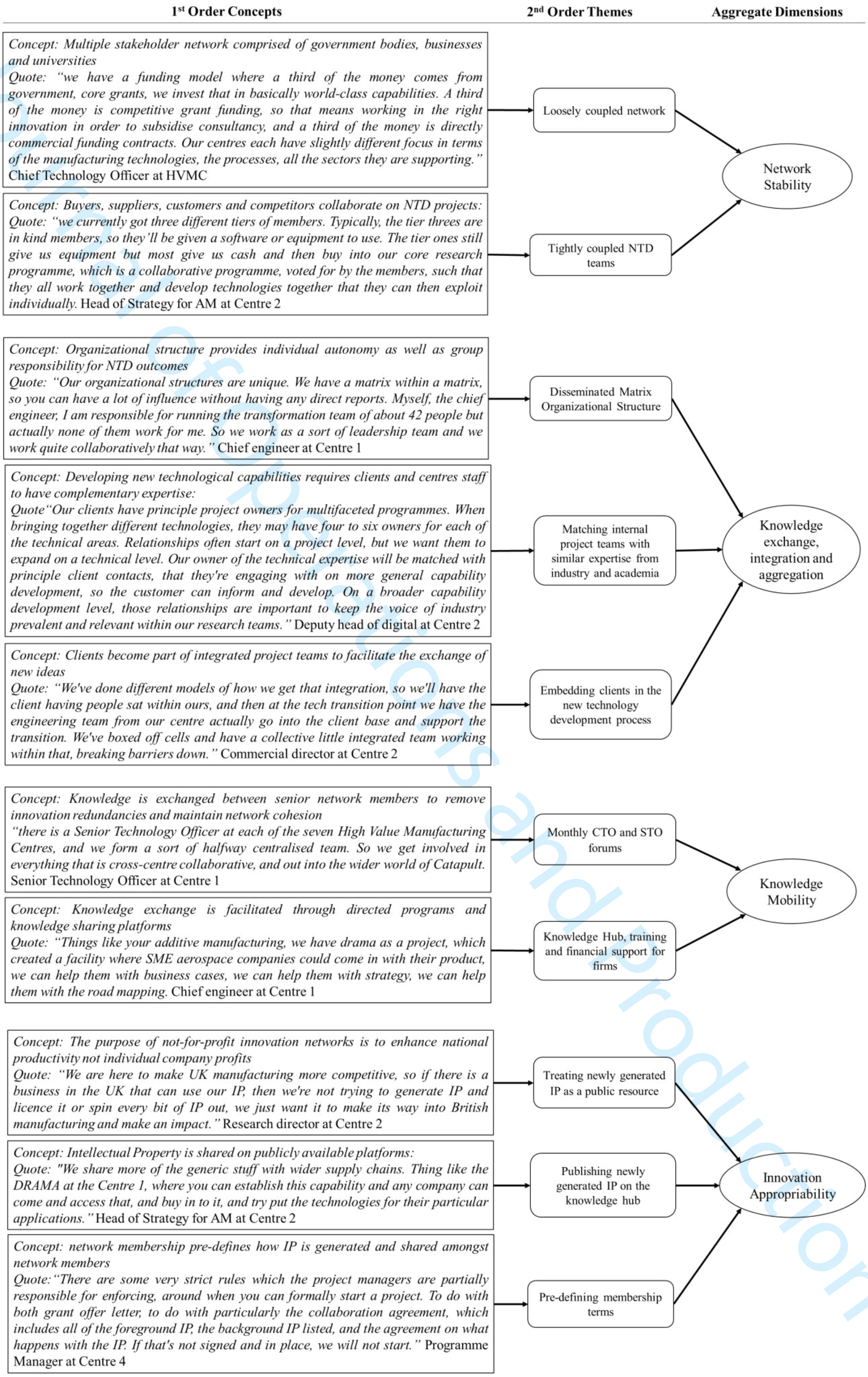

Figure 2, Illustration of data structure

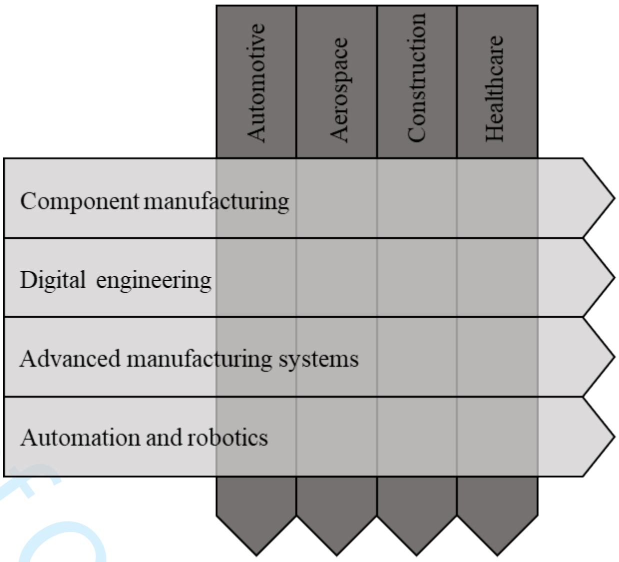

Figure 3, Disseminated matrix structure.

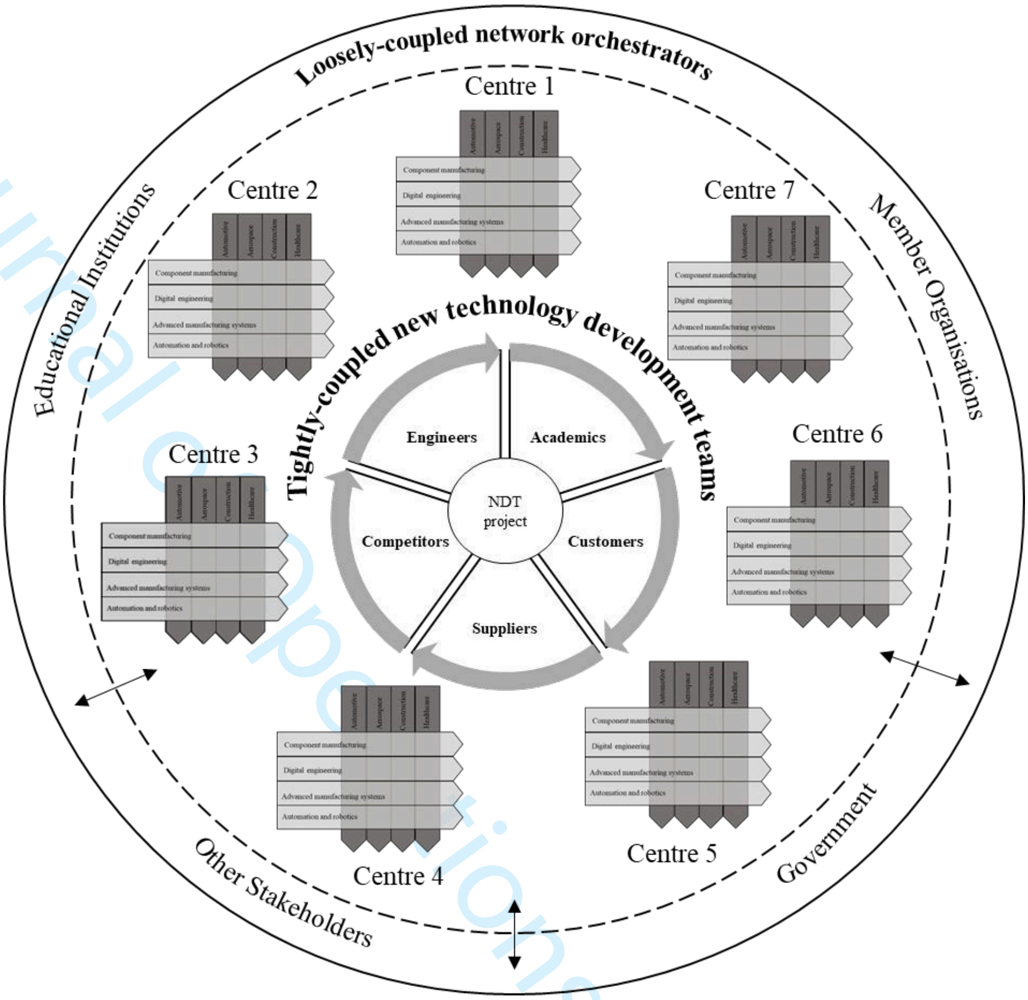

Figure 4, Hybrid combination of a loosely-coupled and tightly-coupled innovation network

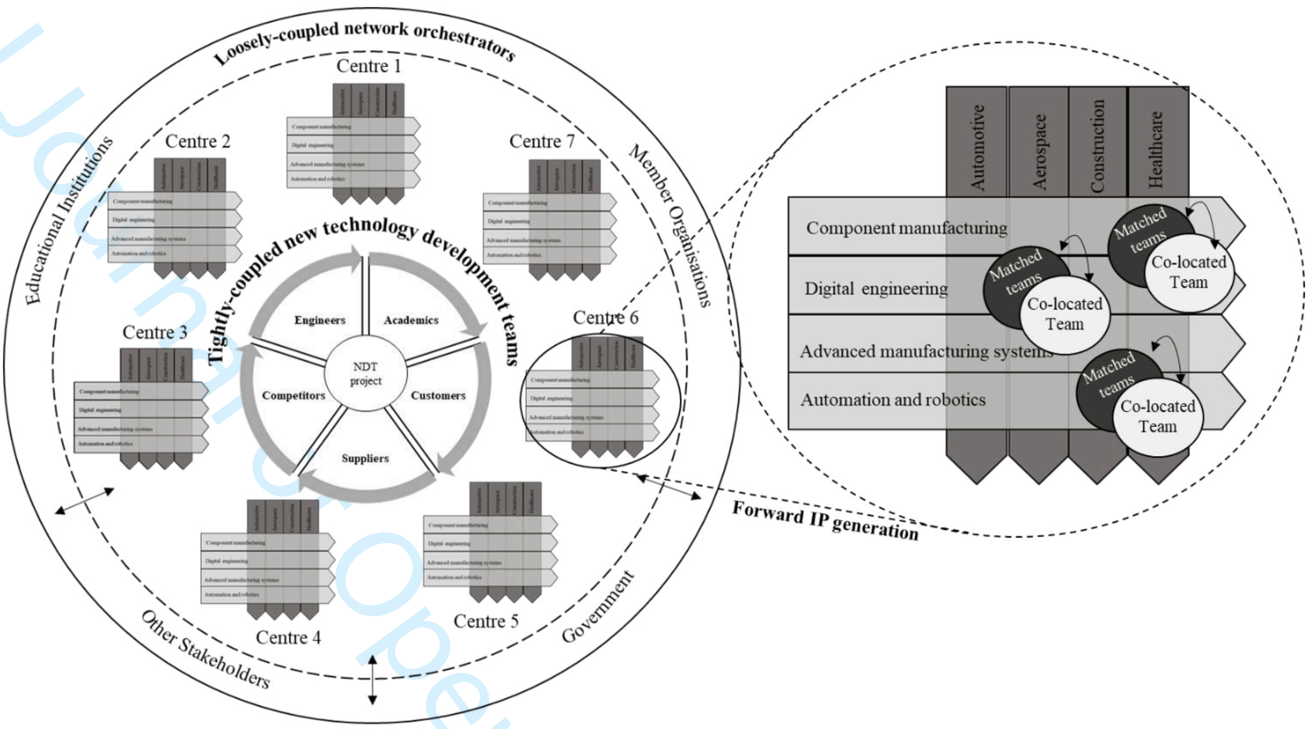

Figure 5, Matching member and staff teams, co-location of integrated project teams and proactively moving staff between centres

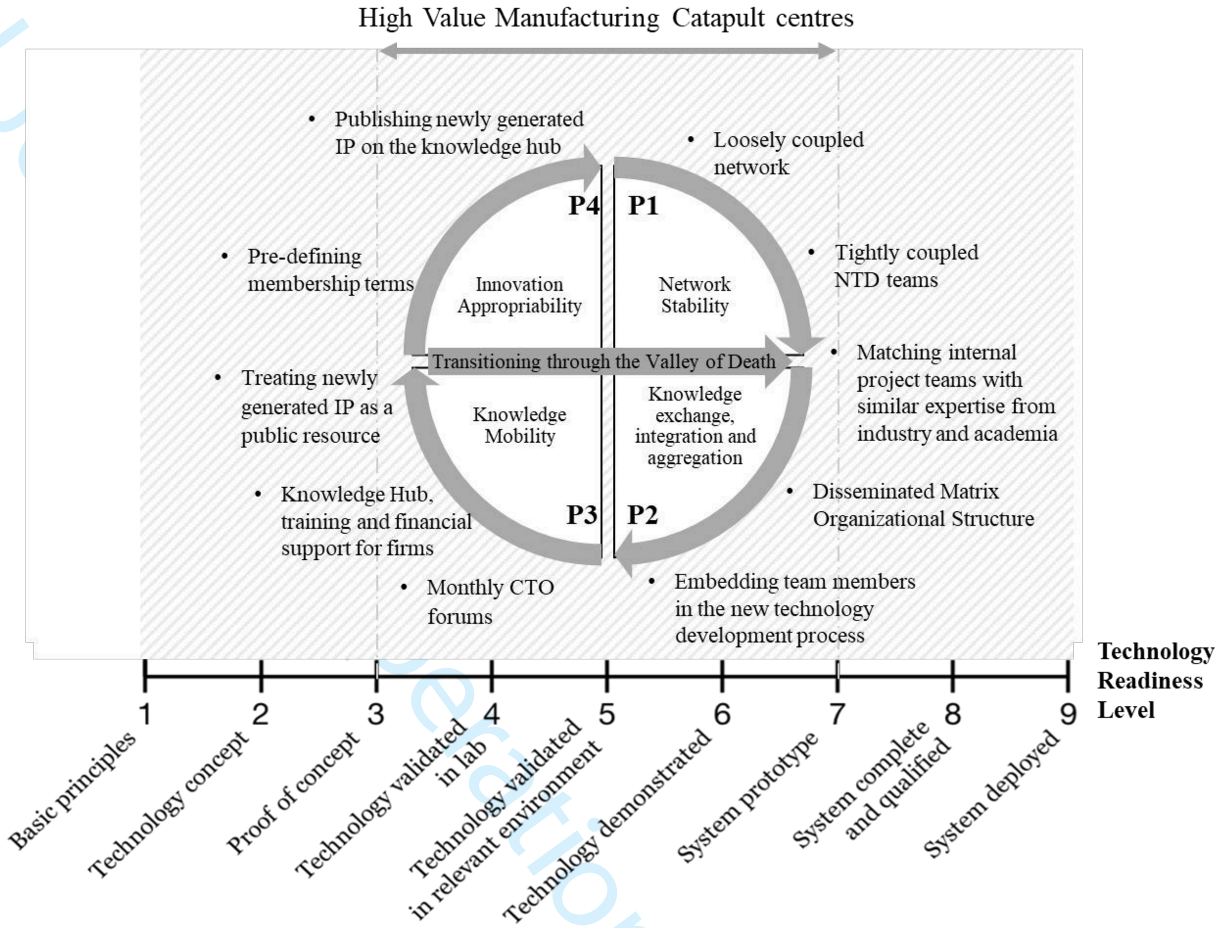

Figure 6, Framework for transitioning new technologies across the VoD in not-for-profit networks

Table 2, Illustrative quotes

Second Order Concept	Illustrative Quote
Loosely coupled network	*"A member of the [Centre 1] is someone who is a formal member and contributes either through in-kind contribution or cash. So, there are a number of those organisations within the project, who aren't formal consortium partners, they're not part of the Innovate UK bid, that we wrote in order to deliver the project, but they're still perceived as collaborators because they've had some level of involvement to support and develop the technologies in the project." Senior Research Engineer at Centre 1*
Tightly coupled NTD teams	*"By working through the [Centre 5], we tend to pull the right people together, we identify people with the same type of problem statements together. Therefore, you're showing cost, risk, knowledge and ideas, and you're able to pull that knowledge together. So we are effectively, I would say the glue that holds a lot of these conversations together if that makes sense." Business Development Director at Centre 5*
Disseminated Matrix Organizational Structure	*"When we start a procurement activity, we would always work on, based on a matrix project team, so we would involve people from our technical team, engineers, as well as potentially if it affects the facilities, have someone from facilities, IT, health and safety, so we would work on that basis." Procurement Manager at Centre 3*
Matching internal project teams with similar expertise from industry and academia	*"Once the project is finalised by the business development team, we then allocated technical team with the right skills who will be taking the project forward to work closely with the member company" Knowledge Exchange Fellow at Centre 7*
Embedding clients in the new technology development process	*"we're there to help companies effectively navigate through the valley of death scenarios. So companies that have a have an idea, they have a product on paper. Maybe they want to commercialize it. They don't know how to do the upscaling or scale out part of that. So we're there to help them move faster than they would be without us." Business Development Director at Centre 5*
Monthly CTO and STO forums	*"one of the remits that the CTO team has is to be de-conflicting any of that capability, build, investments, making sure we're not duplicating capability, making sure we're drawing on the knowledge that's already been generated." CTO at Centre 4*
Knowledge Hub, training and financial support for firms	*"The second element is a training programme with the Advance Manufacturing Training Centre. And that's going to contain a number of short courses, primarily five-day courses, where people can access more in-depth information and classroom-environment training with leading experts. And that will have information from design, to manufacture, to health and safety." Team Lead, Technology Transformation at Centre 1*
Treating newly generated IP as a public resource	*"So I don't want it to be limited by IP. I'd like it to be as mass open access as possible. So dissemination in a CR&D project is really helpful because by default, by making it public domain information, nobody else can patent it to stop you from doing it." CTO at Centre 5*
Publishing newly generated IP on the knowledge hub	*"we are here to make UK manufacturing more competitive, so if there is a business in the UK that can use our IP, and help business generally to become more competitive then we'll just give it, we're not trying to generate IP and licence it or spin every bit of IP out, we just want it to make its way into British manufacturing and make an impact." Research Director at Centre 2*
Pre-defining membership/partnership terms	*"We do have a membership structure, what we call the tier 1s, which is essence are usually big customers or OEMs, major tier 1s in aerospace or other industries. All of those have a yearly contribution that is 200k. Half of that, actually or... slightly less than that goes into this core programme. And then the other half they spend in whatever they want basically. And whatever research they want. So, the membership is not kind of like a club membership, the membership is fully spent into R&D." CTO at Centre 3*
Aggregate Dimension	**Illustrative Quote**

Network Stability	*"members help us with our technology roadmaps so we'll work with the members to check that it's going to deliver what they need, because there's no point in us putting things on our roadmap that there's going to be no industrial demand, so they help us by validating what's in our roadmap" Chief Engineer at Centre 1*
Knowledge exchange, integration and aggregation	*"The third element is the support packages. Within the support packages, there is one-to-one collaboration, right from the very beginning, where we offer support from [additive manufacturing] AM journey assessment to starting to get their feet and feel for where they're going to enter, all the way right to production." Team lead, Technology Transformation at Centre 1*
Knowledge Mobility	*"there's more that we could do to try and share more of the generic stuff wider to lower down the supply chains. And that's where I guess things like the DRAMA benefits there, where you can establish this capability where any company can come and access that, and buy in to it, and try put the technologies for their particular applications." Head of Strategy for AM at Centre 2*
Innovation Appropriability	*"For our industrial-funded projects, like a direct one-on-one contract with a company, they'll own all of the foreground IP that's generated through that project. For collaborative R&D projects we tend to do collaboration agreements as part of standard Innovate UK funded models. For our core research programmes, we free license the IP to anyone who wants it." Chief Engineer at Centre 1*