

# Understanding stages of supply network emergence in technology commercialisation

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## Abstract

This research explores different 'modes' of supply network emergence that may exist in the process of technology commercialisation, and examines how key actors and enterprises design and re-configure their emerging and existing networks. A generic 'stages' model to better understand supply network evolution - in the context of emerging technologies - is developed, based on existing commercialisation case studies, and underpinned by industrial emergence and network theory. The aims of the model are two-fold, namely, to extend theoretical understanding of 'stages' and 'emergence' from a traditional technology and product perspective towards that of supply networks, and to inform existing network analysis approaches (applicable for 'mature' industries) so as to better 'fit' nascent and emerging contexts. Indeed, it is argued that supply networks never quite reach a stage of 'maturity', as organisations continuously look to 're-configure' elements of their legacy networks, leveraging existing capabilities where possible, in response to changes in strategic priorities and the emergence of new market opportunities and threats.

At the practice level, the 'stages' model informs how best to manage critical network resources - supporting the design of alternative business models, and associated supply network strategies, for transforming new technologies into marketable products.

**Keywords:** Supply networks; stages; nascent; emergent; technology commercialisation

**Biographical notes:** Tomás Seosamh Harrington is a Senior Research Associate whose research interests have included product-service network design, configuring nascent networks for emerging technologies and the mapping and analysis of value creation and capture in complex industrial systems and sub-systems. His current research focus examines how technology 'interventions' are enabling the potential for significant step changes across the pharmaceutical/healthcare value chain - from early stage 'system discovery' and clinical trials, through to novel delivery models and the 'end-user'. Specifically, exploring industry transformation through continuous manufacturing and digital factory concepts), and extending the resulting benefits to patients and healthcare providers, through the design of digital supply chains, in a series of commercial and clinical trial contexts. In addition to his research activities, he has been significantly involved in a series of consultancy projects with leading multinational companies, and in the development of management tools for industry. Before joining the IfM's Centre for International Manufacturing in 2009, he worked in industry in a series of senior product design and engineering roles with Intel. He holds Bachelors and PhD degrees in Chemistry and an MBA (with distinction) for which he received a Chartered Management Institute award in 2008.

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## 1. Introduction

The focus of this research paper is to better understand what role supply networks may play in the successful commercialisation of emerging technologies. Previous academic studies on the strategic roles of supply networks have largely focused on large, well-established, market driven organisations. By definition, these *mature* networks seek to be highly responsive to well-known requirements of their customers (Jaworski et al., 2000; Sebastio and Golicic, 2008; Srαι and Gregory, 2008; Harrington and Srαι, 2012). However, having a better understanding of supply network ‘emergence’, ‘evolution’, ‘transition’ and ‘reconfiguration’ is growing increasingly more critical - due to the dynamic nature of the next generation of industrial enterprises (Harrington et al. 2015).

One critical challenge in the commercialisation of a new technology is that there is no defined pathway to follow. Lack of certainty, in terms of product definition and end-user requirements, forces new, emerging actors and enterprises to experiment with supply network strategies through a process described as ‘effectuation’ (Sarasvathy, 2001). This process can be very time-consuming; increasing time-to-market, making it difficult to exploit ‘first-mover’ competitive advantage and reducing opportunities to grow market share.

In better understanding the role supply networks may play in shaping such industrial emergence, the evolution, development and maturity of an industrial system must also be considered e.g. the environment in which one seeks to transform a novel technology successfully into a marketable product. A key consideration here is predicting at which phase of the ‘maturity curve’ a new product may fit and strategically tailoring to this as required (Simchi-Levi and Fine, 2010). In emerging industries, it is often unclear which product and process architecture will become the ‘standard’, which compounds the high degree of market uncertainty that already exists (Jaworski et al., 2000; Hills and Sarin, 2003; Simchi-Levi and Fine, 2010).

Many authors in the academic literature suggest that in order to successfully grow a firm to a ‘mature’ state, various dimensions of the supply network - incorporating resources, partners, suppliers, customers - must all be coordinated (Leibold et al., 2002; Voelpel et al., 2004; Srαι and Gregory, 2008; Harrington et al., 2012; Harrington and Srαι, 2012). Hence, as well as product and process architecture (and associated business model) considerations, designing the supply network to ‘fit’ with the relevant maturity stage is critical (Fisher, 1997; Christopher and Towill, 2002; Lee, 2002; Srαι and Gregory, 2008; Simchi-Levi and Fine 2010; Harrington and Srαι, 2012).

Historically, a popular approach - in the academic literature - has been to consider the industrial ‘emergence’ process to be composed of several distinct phases or ‘stages’ - albeit from a variety of different perspectives (e.g. Levitt, 1965; Utterback and Abernathy, 1975; Churchill and Lewis, 1983; Calori, 1985; Kazanjian, 1988; Kazanjian and Drazin, 1989; Kazanjian and Drazin, 1990; Tushman and Rosenkopf, 1992; Moore, 1993; Cooper, 1993; Cooper, 1994; Mankins, 1995; Dodgson, 2000; Rogers, 2003; Ortt and Schoormans, 2004; Suárez, 2004; Hansen and Birkinshaw, 2007; Adomavicius *et al.* 2007; Phaal *et al.* 2009; Tao *et al.* 2010; Den Hartigh *et al.* 2010). These various ‘phases’, ‘stages’ and ‘descriptors’ - from the many different perspectives listed above - are discussed in more detail in the next section in order to inform model development. In summary, common to most interpretations is the concept of ‘process maturity’ associated with a product or service. Approaches tend to capture an initial R&D phase, next the demonstration of a viable technology and then production in large scale. However, it is argued these ‘stages’ for emerging industries are largely conceptual and descriptive, providing limited content and substance on what the *supply network* features of evolution may be. This can make identification and classification very

subjective and does not provide insights on the operational actions that firms need to consider, or those alternative 'options' that may deliver additional supply network benefits. To this effect, this research paper presents a 'stages' model - to better understand 'emergence' in the context of supply networks.

The remainder of the paper is structured as follows: in summary, section 2 reviews the literature on emerging industrial systems and perspectives on 'stages of emergence, and provides a synopsis of key supply network configuration concepts and dimensions. Section 3 describes the approach to developing a conceptual 'stages' model for supply network emergence, by integrating key insights from the literature. The methodology section next summarises the research strategy and process/methods of data collection and analysis. As part of the data analysis technique employed, section 5 presents case narratives, with section 6 summarising cross-case analysis and contribution to theory. Finally, section 7 presents the conclusions and limitations of the study, in addition to directions for future research.

## **2. Literature Review**

This section reviews the academic literature and summarises those dimensions of analysis that may be particularly relevant to developing a 'stages' model for supply network emergence. This section is organised in terms of several sub-themes that have emerged from the literature on emerging technologies and industries, and is structured around the following research themes, namely;

- Emerging industrial systems
  - Environmental features and network dynamics
  - Resources and capabilities
  - Alternative business models and strategies
- Supply networks - configuration concepts and dimensions of analysis
- Perspectives on 'stages' of emergence
  - Organisational
  - Innovation
  - Business eco-systems
  - Life-cycles and readiness

Key insights, from sections 2.1-2.3 of this review, are then integrated to inform the development of a 'stages' model to better understand 'emergence' - from a supply network perspective in section 3..

### **2.1. Emerging industrial systems**

Any representation of an industrial system should include the context, resources, activities, processes, actors, and interdependencies that support the creation and delivery of products and services (RAE, 2012). Industrial systems continue to emerge - often enabled by new, innovative manufacturing processes and driven by individual actors, new enterprises, and coalitions of more established firms. Sarasvathy and Dew (2005) consider the commercialisation of a new technology or 'new market creation' as a process involving the coming together of a 'new network of stakeholders'. Hence, a key consideration in analysing emerging industrial systems is the role this new network of key institutional, industrial and supply network actors may play in the development of viable products

and services (Srai, 2010; Srai et al., 2014). Institutional actors (e.g. government, agencies, universities, innovation hubs, centres of excellence, strategy groups, consultancies) play a central role in the successful development of an industry through influencing the structure, enabling high connectivity between the various industrial system actors, and by providing incentives, subsidies, and publicly-funded research and development projects (Aldrich and Fiol, 1994; Edquist and Johnson, 1997; Jacobsson and Johnson, 2000; Harrington et al., 2016a).

The following sub-sections consider institutional, industrial and supply network actors, in terms of environmental features, network dynamics, resources, capabilities, alternative business models and strategies - in the context of an emerging industrial system.

### *2.1.1. Environmental features and network dynamics*

In their study of emergent and mature industries, Nair and Boulton (2008) report that features of 'alternative' environments are seen to develop, with varying levels of dynamism and complexity. In addition, these alternative and highly dynamic environments require organisations to proactively adapt their operations strategy to ensure a fit between competitive priorities and the development of supporting structures (*ibid*). Traditional approaches to the study of industrial systems have often been developed on the assumption of 'stable' environments, which may not adequately provide theoretical or practical guidance on how to effectively capture new and emerging market opportunities (Zhang et al., 2007; NAE, 2008; Zhang and Gregory, 2011; Harrington and Srai, 2012). Hence, a better understanding of how emerging actors and enterprises may demonstrate 'value' to the rest of the ecosystem will provide insights for network dynamics and effective supply network design (Kirkwood et al, 2009).

Hence, examining and integrating those environmental features, which are influenced by dynamic factors (both internal and external) encompassing market, product, production system, technology, policy, people and culture - from a supply network perspective - is key (Harrington and Srai, 2012). Factors derived from the emerging industry literature also need to be considered here, and includes product and industry life cycles, levels of scientific progress, market and technology innovation, internal efficiencies, rate of imitation by competitors and customer segmentation patterns (Nair and Boulton, 2008; Simchi-Levi and Fine, 2010; Harrington and Srai, 2012).

### *2.1.2. Resources and capabilities*

In the context of commercialising technologies, managing resources and capabilities is seen as a critical component through which value may be captured. New actors and enterprises, whilst often recognising the importance of managing internal capabilities (e.g. technologies, processes, information as well as resources), often fail to coordinate the external resource capabilities (e.g. their multi-organisational network of collaborators, suppliers, partners and customers) and core activities they may require (e.g. the scouting of critical component suppliers and targeting of downstream markets and partners). In addition, critical resource and capability requirements (in areas such as operations, finance and strategic marketing) are often overlooked or viewed as being secondary to those required for initial technology development and demonstration (Kirkwood et al., 2009).

Furthermore, previous studies have shown that many enterprises commonly focus on too narrow a segment of the value chain, to an extent that the requirements of the ultimate end-user (as opposed to the immediate customer for the product or technology) are not well recognised (Kirkwood et al, 2009). Hence, knowing the key stakeholders within an emerging industrial system and conversely *to be known* is critical in order to foster effective cooperation across the entire value chain

where necessary (Anderson and Tushman, 1990; Hill, 1997; Shapiro and Varian, 1999). In opening up opportunities for the commercialisation of novel technologies, actors may now often partner, in one shape or form for a single commercial opportunity. Large OEMs often look to integrate or partner with university spin-offs or provide joint venture resources to increase their capabilities to (emerging) industry standards. Critically, such practices are likely to increase competitiveness and profitability because key internal activities and business processes may be better managed (Lambert and Cooper, 2000). Hence, new actors and enterprises should look to fully exploit the industrial system in terms of the 'final' end-product and build all necessary competitive resources and capabilities – both internal or external through targeted recruitment, engaging with outside experts, building closer ties with university research centres, and forming strategic alliances that may extend beyond enterprise boundaries in order to integrate key suppliers (Ragatz et al., 1997; Jaworski et al., 2000; Power et al., 2001; Zahra and Nielsen, 2002; Hills and Sarin 2003).

The evolution of complementary products may also have a strong influence on the development of critical resources, assets and capabilities (Helfat, 1997). Complementary product readiness levels can deliver key insights into resolving technological uncertainties (Utterback and Abernathy, 1975; Anderson and Tushman, 1990; Cusumano et al., 1992). Furthermore, managing both applications and complementary products for an emerging technology will have a strong influence on product features as well as those resources made available for its development (Adner and Levinthal, 2002; Adomavicius et al., 2007).

Hence, in the context of this research, it is argued that resources and capabilities may best be approached from three different perspectives: structuring a 'resource portfolio' through (i) defining network roles and responsibilities, (ii) re-grouping resources to build capabilities and (iii) leveraging existing capabilities and products to exploit market opportunities (Lepak et al., 2007; Harrington and Srai, 2012; Harrington and Srai, 2015).

### 2.1.3. *Alternative business models and strategies*

In the development of a new product or service, enterprises look for effective strategies rather than efficient ones because 'survival' is more critical than optimising 'outcomes' at this early juncture (Churchill and Lewis, 1983; Calori, 1985; Fligstein, 2001). Furthermore, how an enterprise chooses to structure its supply network for a product is critical and should align with the firm's overall strategic direction (Sebastiao and Golobic, 2008). Ability to establish a 'dominant design' as an industry standard through licensing, strategically partnering, appropriate positioning strategies, and diversifying when applicable is seen as key here. However, there are benefits, costs, and risks associated with each of these options plus there are additional factors (maturity of competitor capabilities, uniqueness of a product), which may also influence the particular strategy that an enterprise may pursue (Hill, 1997; Utterback and Suárez, 1993).

Two approaches, *effectuation* and *market driving*, to establishing an effective supply network around a disruptive technology, have been reported in the literature (Jaworski et al., 2000; Kumar et al., 2000; Hills and Sarin, 2003; Sarasvathy and Dew, 2005; Santos and Eisenhardt, 2009; Holloway and Sebastiao, 2010).

The first approach describes how emerging firms go through stages of *effectuation*. Given the unpredictable nature of the external environment, an enterprise may pursue the progressive adaptation of a business plan - in stages - in order to match the changing market through a process of trial and error (Thomke 2001; Christensen 2003). This may, ultimately, lead to the emergence of a dominant supply chain strategy even before an enterprise enters a mature stage of development (Sarasvathy and Dew, 2005).

As opposed to matching to changing markets and progressively shaping a network, the second approach focuses on efforts to dominate the shaping of the market rules and norms via a

*market driving* strategy (Jaworski et al., 2000). *Market driving*, or ‘demarcating’ may be possible if an enterprise is successful in commercialising a disruptive technology or brings about a unique marketing strategy (Kumar et al., 2000). An example of which includes large OEMs who often look to foster early collaboration with smaller emerging enterprises in order to exploit their new skills and capabilities (Kamath and Liker, 1997). By pursuing a *market driving* strategy, an enterprise may proactively influence the competitive landscape and industry standards, as opposed to be reactive in response to competitor strategies (Jaworski, et al., 2000; Kumar et al. 2002; Hills and Sarin, 2003; Santos and Eisenhardt, 2009).

## **2.2. Supply networks**

Sebastio and Golicic (2008) present the case that the successful emergence of a new market, based on a radical technological intervention, depends largely on the parallel development of a *new* supply network to support commercialisation activities. Harrington and Srai (2012) have previously summarised the key academic literature on supply network configuration concepts from established domains, hence, this section will only provide a synopsis of key points. The study focused specifically on configuration as a ‘state’, firm archetypes and network context within the broader domain of the configuration literature and considered mature industry network configuration ‘options’ (Harrington and Srai 2012). Follow up studies, in this area, are looking to develop a methodology for best capturing configuration profiles or ‘transitions’ associated with technology emergence and disruptive business models.

In addition to the emergence of new networks and enterprises, this research also considers well established organisations looking to capture value and further diversify product portfolios through new technology adoption e.g. new innovative manufacturing processes (such as ‘continuous’ manufacturing) and the emergence of CMOs, are contributing to the need to reconfigure the pharmaceutical landscape (Srai *et al.*, 2015a,b). To this effect, mature organisations often need to radically ‘re-configure’ their legacy supply networks, leveraging existing capabilities where possible, to support the emergence of a new technology, new operations model or a new business model (Adner and Levinthal, 2002; Adner and Kapoor, 2010). In summary, mature networks (Harrington and Srai, 2012) utilise *network structure* to capture *dispersion* in terms of geographical footprint, the dispersion of network units (e.g. shape, levels of vertical and horizontal integration), and *interdependence* (e.g. levels of partnerships, ownership, flexibility). In the context of emerging industries, the way in which the network is structured may have an impact on which actors capture the most ‘value’ (Lepak *et al.*, 2007). It has been reported that emerging actors and enterprises seek close partnerships and build their networks around the most influential partners - within an industrial system - who may already have market credibility with a strong and reliable set of customers (Dyer and Singh, 1998; Sarasvathy, 2001; Hills and Sarin, 2003; Sebastio and Golicic, 2008; Harrington and Srai, 2015). Despite understandable concerns over the sharing of IP, resulting in some relationships becoming more prescriptive (Kirkwood et al., 2009), long-term partnerships are proving more popular (as opposed, to say, vertical integration or outsource strategies) within an emerging industry context as they provide better efficiency and flexibility (Blois, 1996; Kay, 1997; Casson, 1998; Womack et al., 1990; Smitka, 1991; Nishiguchi, 1994; Shiba 1997). These partnerships or quasi-partnerships are often characterised by inter-firm relationships that arise from joint investment in capital assets, shared know-how and effective governance mechanisms (Williamson, 1985; Dyer and Singh, 1998; Gulati, 1995a; Gulati, 1995b).

Overall, understanding a target configuration and structure and, in some cases, ‘reconfiguring’ the appropriate legacy supply network elements is a critical part of this process (Srai and Gregory 2008; Harrington and Srai 2012). An inability to change organisation structure, practices and supply

network configuration, in line with the evolution of a technology within the industry, can be a major source of failure (Utterback and Suárez, 1993).

### **2.3. Perspectives on 'stages' of emergence**

Previous studies have approached stages of 'emergence' or 'maturity' from a variety of different perspectives – examples of which are summarised in table 1.

While research has focused largely on defining industry development, it is often difficult to generalise 'stages' of development as every industry may possess different growth profiles and characteristics; hence, there is often no common ground on which individual case studies can be compared (Greiner, 1972; Churchill and Lewis, 1983; Kazanjian, 1988; Kazanjian and Drazin, 1989; Brown and Eisenhardt, 1995; Churchill, 1997).

Secondly, research in this area has traditionally been product or technology-focused i.e. common features include product focus, technology feasibility, process/industrial improvement, with stage-gate type processes dominating. Although there are some approaches which may relate to 'network' in terms of e.g. organisation and business structure (Kazanjian, 1988; Kazanjian and Drazin, 1989; Kazanjian and Drazin, 1990; Tushman and Rosenkopf, 1992; Den Hartigh et al., 2010), few have considered the role of the supply network and the evolutionary phases through which they must pass as an industry 'transitions' from a state of emergence to a state of maturity.

As discussed briefly in the introduction - in terms of patterns and common development stages - all models examined as part of this study overlap to some extent. A common element is the concept of 'phases' of emergence and maturity descriptors associated with the commercialisation of technologies. The different perspectives presented in the following sub-sections (2.3.1-2.3.4) and organised by sub-theme (*organisation, innovation, life-cycles and readiness, and business ecosystems and networks*), are then used to inform 'stages' and 'emergence' emergence, from a supply network perspective.

#### **2.3.1 Organisation**

Utterback and Abernathy's empirical study (1975) looked to link the nature of an innovation and 'stage' of a firm's development (in terms of product, process, strategy and drivers) based on data available from a previous study of successful technological innovations across five different industries. The firms were assigned to a specific stage e.g. stage I characteristics included having an *uncoordinated process, a product performance-maximizing strategy* and innovations that were *market need stimulated*. Stage II comprised of having a more *segmental process, a sales-maximizing strategy*, with most innovations *stimulated by technological opportunities*. Finally, stage III attributes included a *systemic process, a cost-minimizing strategy*, with most innovations *stimulated by production related factors*.

Churchill and Lewis (1983) have proposed a five-stage model for firm development (e.g. *Existence; Survival; Success; Take-off; Resource maturity*) in relation to small to medium-sized businesses. Each stage may be characterised by size, diversity and complexity and described by five management factors (managerial style, organisational structure, extent of formal systems, major strategic goals, and owner involvement). Churchill and Lewis (1983) argue that knowing which development stage one is in can help prepare and inform firms looking to grow. In summary, the first stage – *existence* - largely involves the 'customer', through a focus on ensuring order fulfillment and product delivery. A *survival* stage sees firms enter a critical phase of development where they look to attain a viable business proposition. Next – *success* - focuses on 'exploitation' and 'expansion', while the fourth phase – *take-off* - is about sustaining 'growth'. Finally, *resource maturity* is when a firm may

look to take the form of a market leader. Furthermore, the paper reports a series of factors that are prominent in determining a firm's success (or failure) These considerations include goals, resources, financials, systems, operational, managerial and strategic capabilities.

From the perspective of firm strategy, Calori (1985) introduces four generic strategies, with one being identified as the most effective for building market share. Focusing on industrial firms' strategies in two emerging (solar-based) industries, he proposes three 'stages of emergence' (e.g. *Beginning; Middle; End*). In the *beginning* stage, the dominant characteristic is 'technological uncertainty', where primary firm goals are about (in the order of importance) *survival, technological position* and *market share*. The *middle* stage is characterised by 'firms' entries', where *survival* and *market share* take precedence over considerations of *technological position*. At the *end* stage, 'shake-out' is the dominant characteristic, where *profitability* supersedes *technological position* in terms of goals.

In terms of a growth model for technology-based new ventures (TBNVs), four discrete 'stages' are presented (Kazanjian, 1988; Kazanjian and Drazin, 1989; Kazanjian and Drazin, 1990). Here 'stages' are described as the configuration of organisational design variables representing a firm's response to a set of dominant problems it may encounter over time (Kazanjian 1988) The authors go on to report that 'growth' is partially attributable to the fit between a TBNV's 'stage' and aspects of its structure (Kazanjian and Drazin, 1990). The first stage concerns *conception and development* where *structure* and *formality* are described as being largely *non-existent*. All activity at this stage is focused on resolving technical issues, formulating business plans, developing prototype products and looking to secure financial backing. The *commercialisation* stage aims to capture the phase where major focus is on developing the product and/or technology, beyond basic prototyping, towards that of a marketable product. Here, in terms of organisational structure, functional areas begin to emerge but remain largely *embryonic*, given the limited formal nature of relationships. The third stage - *growth* – centres on the production, sales, and distribution of a marketable product or technology, where an organisation typically is in a state of flux. At this stage, a hierarchical structure often tends to emerge, with centralised decision-making decreasing as an organisation moves to this higher stage. Finally, the *stability* stage is concerned with market position and the development of next generation products and technologies in order to maintain growth momentum. By this stage, a stable mode of operating has emerged across the organisation, with formal structures, rules and procedures. Interestingly, it was also observed that while role specialisation in e.g. manufacturing and marketing increases by stage, specialisation (in engineering and technology-based roles and functions) is core and remained high across all four stages of growth.

In their paper on organisational determinants of technological change, Tushman and Rosenkopf (1992) argue that technologies evolve through a combination of events, linking organisational complexity with technology change and uncertainty. Here, multiple competing organisations may shape the standards for an emerging industry. Building on the argument that technological change may be characterised by *variation, selection* and *retention* (Anderson and Tushman, 1990), the authors propose that a cyclical model with four key components, namely, *technological discontinuities* (linked to *variation* - which may be competence enhancing or destroying), eras of *ferment* (which is characterised by substitution, design competition and technical change), *dominant designs* (linked to *selection*) and eras of *incremental change* (which relate to *retention*, elaborate dominant design and technological momentum).

Finally in this sub-section, in the context of competing technologies, Suárez (2004) looked to better understand the process by which a technology may achieve dominance. Through a review of the literature across multiple domains, a series of key *phase-dependent* factors (both firm and environmental) that may affect the emergence of the 'dominant design' are reported. Five key phases are defined as *R&D build up; Technical Feasibility; Market Creation; Decisive Battle; Post-dominance*. The *R&D build-up* phase explores how a technological field emerges. Here the technology, still unproven, is just coming into existence and the phase may be characterised by the formation and



restructuring of new and existing linkages respectively. Actors often involve mature entities, with expertise in a complementary technology, coupled with smaller scale operators, which may just consist of a single laboratory in a university research centre (Srai *et al*, 2014). Next, the *technical feasibility* phase is often characterised by the emergence of a working prototype demonstrator. Here a firm-level factor – *technological superiority* - is seen as critical to the final outcome and the ‘locking in’ of a ‘dominant design’ (Utterback and Abernathy, 1975; Anderson and Tushman, 1990; Utterback and Suárez, 1993). In terms of environmental factors, this phase may also be influenced by the emergence of an active regulator role. Phase III - *Market Creation* – is characterised by the arrival of a viable commercial product in the market. Here, market factors (rather than the technology) begin to dominate. In phase IV, a large customer base has typically been formed. Suárez (2004) goes on to describe how a firm-level factor (e.g. this installed base effect) in this *decisive battle* phase is largely determined by the strength of network effects within the environment. Finally, the *post-dominance* phase sees a clear dominant technology in the market. Here, having a large installed base is critical in protecting against potential new entrants, particularly in cases where the environment may have strong network effects. Characteristics of this phase include “within-standard” competition, the licensing of production rights, production capabilities and process innovation (Utterback and Abernathy, 1975). This final phase often continues until a technology ‘intervention’ triggers the emergence of a new dominance design and further product generations (Srai *et al*, 2014).

### 2.3.2 Innovation

In the area of innovation diffusion theory, Rogers (2003) has characterised five types of ‘adopters’, namely, *innovators*, *early adopters*, *early majority*, *late majority* and *laggards*. It is argued that a population or social network may be broken down into these five types, for any given innovation, with each adopter classification possessing a specified rate of innovation adoption.

In their study on innovation and breakthrough communication technologies, Ortt and Schoormans (2004) introduce the idea of patterns of development linked to phases, which they report as *invention*; *introduction*; *industrial production* (and *large-scale diffusion*). Common to previous authors in this section (e.g. Churchill and Lewis, 1983; Calori 1985; Saurez, 2004), there are numerous implications for firms, based on the various differences between these phases - hence, the need to adopt different strategies in each individual phase. In a later study on diffusion of product innovations, Ortt and Egyedi (2014) report the importance of timing and start, the effect of pre-existing standards and regulations on subsequent development. Results demonstrated that pre-existing standards and regulations significantly shorten the *adaptation* phase (e.g. large-scale industrial production and diffusion) of innovations, an effect not found for the *development* phase (characterised by a first marketable product).

Hansen and Birkinshaw’s (2007) approach to evaluating innovation performance - the innovation value chain – proposes three main phases of innovation (*idea generation*, *conversion*, and *diffusion*). The authors explore new roles within an enterprise (the idea of *external scouts* and *internal evangelists*), which look to perform critical activities during the different phases (activities summarised here as internal intra-unit and inter-unit idea scoping, external scanning of ideas; selection, funding and promoting internally).

Finally here, in a ‘process of innovation’ context, Tao *et al* (2010) introduce the concept of ‘Innovation Readiness Levels’ (IRL) - depicting the development of an innovation over its lifecycle. By providing better monitoring and control between phases, the IRL approach aims to support the implementation of innovation over the lifecycle more effectively. In summary, six phases involving the lifecycle of innovation are proposed (e.g. *Concept*; *Components*; *Completion*; *Chasm*; *Competition*; *Closedown*) with assessment aspects and criteria identified for each phase.

### 2.3.3 Life-cycles and readiness

Levitt (1965) introduced the idea of exploiting the product life-cycle concept and the approach is based on four recognisable 'stages' identified for a series of successful products (e.g. *Market Development; Market Growth; Market Maturity; Market Decline*). The first 'development' stage relates to when a new product is first brought to market. Here, demand (and the technology, at times) has yet to be proven and sales are low. The 'growth' stage then sees an increasing demand as the total market 'expands'. Next, after a period of time, the 'maturity' stage sees demand finally level off until finally (stage 4 – 'decline') a product loses its appeal, which results in a steady drop-off in sales.

From a new product development perspective, Cooper's paper (1994) looked to integrate the results from several historical studies – covering both successful and failed product introductions. Focusing on product readiness (e.g. cycle time reduction) and speed-to-market, the eight key factors derived from the study were product superiority; market orientation; solid up-front homework; product definition; cross-functional team approach; focus and project prioritisation; quality of execution; and a systematic stage-and-gate new product process - summarised here, in terms of stages - as *scoping; build business case; development; testing and validation*. Linked to product readiness is the idea of Technology Readiness Levels (TRLs), which remains a popular way of assessing both the *maturity* of a particular technology and in comparing different types of technologies and concepts (Mankins 1995). In summary, nine levels, from basic principles to actual system 'proven' are reported which broadly cover *'basic' research; focused technology development; technology development and demonstration; system development; system 'launch' and operations*.

In their preliminary framework for mapping industrial emergence (based on roadmapping principles) Phaal et al (2009) again use a series of historical cases (drawing from twenty applications roadmaps) to link science, technology, application and market-dominated phases (summarised as *Precursor; Embryonic; Nurture; Growth; Maturity; Decline/Renewal*) and inform strategy and policy application.

Finally, in this sub-section, Theyel *et al* (2011) introduce the idea of relational 'bridges' and apply the concept to a technology/industry life-cycle framework (Dodgson 2000) as a means of conducting a gap analysis in a study of the solar photovoltaic industry. Stages here consist of *Imagining* (conceiving an idea); *Incubating* (setting up a technology demonstration); *Scaling* (considerations around production and supply chain); *Promoting* (market positioning focus); *Sustaining* (establishing the product offering).

### 2.3.4 Business ecosystems and networks

Moore (1993) argues that an organisation cannot be regarded simply as an actor operating within a single industry, but that it makes up a *business ecosystem* that may transcend multiple sectors. From the business ecosystem viewpoint, a series of enterprises may collectively develop capabilities based on an emerging technology and partner for a single commercial opportunity. This may open up different challenges, within an ecosystem, in terms of *cooperation* and *competition* at different stages of development. It is in this context that Moore (1993) proposes four evolutionary stages e.g. *birth, expansion, leadership, and self-renewal*. During Stage I (*birth*), entities look to focus on defining market requirements, delivery channels and the value proposition of a new offering. At this stage, individual entrepreneurs, new enterprises, and coalitions of more established firms tend to cooperate by working closely with both customers (if defined) and key suppliers, with the view of gaining first-mover advantage. Stage II (*expansion*) is characterised by the development of a viable business concept and having the potential to scale up to large-volume production and distribution. It is during this *expansion* stage that established networks look to eliminate competitive technologies and

competitors. Cooperation and competition at stage III (*leadership*) focuses on the need to set out a future vision that key customers and suppliers can buy into, while retaining bargaining power over key stakeholders respectively. Stage IV (*self-renewal*) may be described as when a mature ecosystem has become sub-optimal – due to changes within the ‘industrial system’, often driven by institutional and/or industrial trends. Here, environmental features may need to be examined i.e. how they are influenced by internal and external factors such as market or resource conditions that may prompt the need for a restructuring (Moore 1993; Harrington and Srari, 2012).

In their study on understanding technology evolution from an ecosystem perspective, Adomavicius *et al* (2007) use case examples involving wireless networking (Wi-Fi) technologies and the digital music industry, to test a new conceptual model that highlights both dynamic and interdependent relationships among multiple technologies. Instead of ‘in isolation’, technology evolution is best viewed as a dynamic ecosystem that needs to include both interrelated and complementary technologies as they collectively interact and impact evolution. *Roles* that technologies may play within an ecosystem are reported (as *components, products and applications, and support and infrastructure*), leading to a classification of interaction types (nine in total, based on variations of the technology roles), which the authors describe as *paths of influence*.

Finally in this section, a key paper informing this supply network emergence research explores the relationship between business networks and technology battles during the technology life cycle. Den Hartigh *et al* (2010) examine patterns of development, the diffusion of high-tech product categories and how business network structure and composition change during the technology life cycle. In terms of *network*, the authors examine network size (number of actors), network diversity (diversity of types and actors within the network) and network structure (*density* or numbers of connections between actors, *structural holes*, type of structure i.e. *core-periphery, amorphous, hubs, chains*) and integrate these dimensions with patterns proposed by Ortt and Schoormans (2004) and Suárez (2004) to formulate a framework for testing. Following a comprehensive review of phases reported in the literature section of their study, Den Hartigh *et al* (2010) propose three, which they describe as *innovation* (covering the invention to a first market introduction phase), *adaptation* (from first phase to large-scale industrial production and diffusion) and *market stabilisation* (covering large-scale production to product end-of-life).

**Table 1** Different perspectives and descriptors of ‘phases’ and ‘emergence’

Perspective	Number of ‘Phases’ - ‘Phases’ Reported	Key Insights	Contributing Literature
Product Lifecycle	(4) - Market Development; Growth; Maturity; Decline	Product readiness and strategies; ‘life extension’ and ‘market stretching’ focus	Levitt (1965)
Process and Product innovation	(3) – Product focus; Technology-stimulated Process Innovation	Links nature of an innovation and stages of a firm’s development	Utterback & Abernathy (1975)
Firm Development	(5) - Existence; Survival; Success; Take-off; Resource maturity	Each stage characterised by size, diversity, and complexity; links a series of factors with firm success or failure	Churchill & Lewis (1983)
Firm Strategy	(3) - Beginning; Middle; End	Links dominant goals and characteristics to different stages of emergence	Calori (‘85)
Growth Model	(4) - Conception and Development; Commercialisation; Growth; Stability	Links growth patterns of technology-based new ventures to configuration and organisational design variables	Kazanjian (1988); Kazanjian & Drazin (1989,1990)
Organisational Complexity	(4) - Variation; Ferment; Selection; Incremental Change	Links organisation complexity to a cycle of technology change	Anderson and Tushman, (1990); Tushman and Rosenkopf (1992)
Business Ecosystems	(4) – Birth; Expansion; Leadership; Self-renewal	Links cooperative and competitive challenges to evolutionary stages	Moore (1993)
Stage-and-Gate Approach	(4) - Scoping; Build business case; Development; Testing and Validation	Product readiness; reducing time-to-market	Cooper (1994)
Technology Readiness Levels (TRLs)	(9) - Nine levels, from basic principles to actual system ‘proven’	Focused on technology development; Assesses maturity of different technologies	Mankins (1995)
Industry evolution	(5) - Imagining; Incubating; Scaling; Promoting; Sustaining	Links gaps (Interest, technology and market transfer, diffusion) with concept of relational bridges	Dodgson (2000); Theyel <i>et al</i> (2011)
Innovation Diffusion	(5) - Innovators; Early Adopters; Early Majority; Late Majority; Laggards	Classifying social system actors in terms of ‘innovativeness’	Rogers (2003)
Technology Life Cycle	(3) - Invention; Introduction; Industrial production (and large-scale diffusion)	Links technology readiness to production volume	Ortt & Schoormans (2004); Ortt & Egyedi (2014)
Competing Technologies	(5) - R&D build up; Technical Feasibility; Market Creation; Decisive battle; Post-dominance	Links key phase-dependent factors (firm and environmental) and the emergence of the ‘dominant design’	Suárez (2004)
Innovation Chain	(3) – Idea Generation; Conversion; Diffusion	Links conversion of ideas into revenue	Hansen & Birkinshaw (2007)
Ecosystem model of technology evolution	(9) - Nine paths of influence	Links component, product and application, support and infrastructure	Adomavicius <i>et al</i> (2007)
Roadmapping	(6) – Precursor; Embryonic; Nurture; Growth; Maturity; Decline/Renewal	Links science, technology, application and market-dominated phases	Phaal <i>et al</i> (2009)
Innovation Readiness Levels (IRLs)	(6) - Concept; Components; Completion; Chasm; Competition; Closedown	Process to manage ‘incremental’ innovation; links technology readiness to market evolution	Tao <i>et al</i> (2010)
Business Network Structure	(3) - Innovation; Adaption; Market Stabilisation	Links TLC to Network Structure	Den Hartigh <i>et al</i> (2010)

### 3. A conceptual stages model for supply network emergence

In contrast to design 'options' previously presented for mature industries (Zhang *et al*, 2007; Srari and Gregory, 2008; Harrington and Srari, 2012), a 'stages' model may provide the basis for a more deterministic and valid classification of current and future state supply network development activities. In order to develop a theoretically grounded 'stages' model - from an emerging network perspective, this section integrates key insights from the literature (summarised in section 2) and extends the concept to a supply network context.

The methodological approach to developing a conceptual stages model for supply network emergence is presented in figure 1. First, the key literature across the various research domains (set out in section 2) was integrated here for the purpose of this research. In summary, this investigative phase examined:

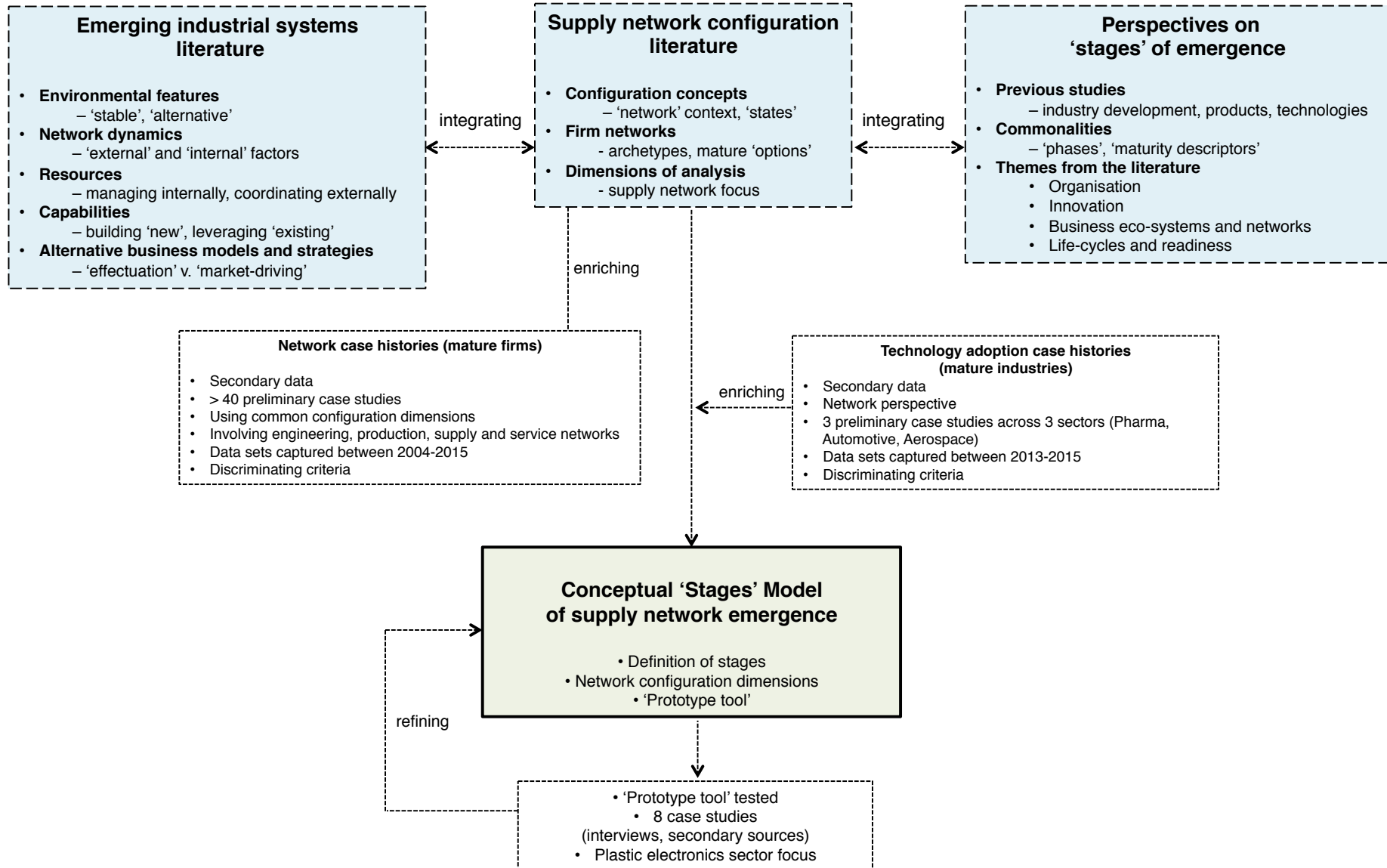
- literature on supply networks (configuration concepts, 'states', 'archetypes') supported by in excess of forty network case studies and secondary data from the literature reflecting a number of diverse network forms (data sets capturing engineering, production, supply and service networks) was first used to explore dimensions of analysis as a basis to better understanding the attributes of supply network 'options' and possible 'stages'.
- literature on emerging industry systems and perspectives on 'stages' of emergence, in addition to a series of technology adoption case studies involving technology disruption across three sectors and taking a supply network perspective (Schneemann, 2013; Hadjadj, 2013; Harrington and Srari, 2015b) further informed the dimensions of analysis and provided useful insights to consider in the characterisation and proposed definition of a series of supply network 'stages'.

A 'prototype tool', based on stages of emergence developed from the literature and supporting supply network configuration dimensions, was then used to test the model using a series of case studies involving firms operating within a 'Plastic Electronics' (PE) industrial ecosystem.

PE is a branch of electronics, principally based on polymers rather than silicon, where electronic circuits may be manufactured at relatively low cost and on a 'roll-to-roll' basis by printing electronic inks and materials directly onto a range of flexible substrates (combining traditional printing techniques with emerging technologies).

Outputs from the case study interviews, in combination with case-specific secondary data, were then used in a feedback loop to refine the prototype tool and finalise the stages model of supply network emergence. From the perspective of emerging supply networks, it is proposed that technological and industrial system emergence be best considered in five *stages* - *Embryonic*; *Fragmented*; *Formation*; *Expansion*; *Stabilisation*. These stages are now briefly summarised in sub-sections 3.1- 3.5, with selected key references to support the proposed definitions.

**Figure 1** Literature synthesis: Investigative phase exploring stages of supply network emergence derived from literature and supported by case histories and secondary data



### **3.1. Stage I – Embryonic**

The first 'chaotic' or 'embryonic' stage proposed aims to capture supply network activity that is *uncoordinated* in terms of *organisational structure, product definition, formal systems and processes, strategy and drivers* (e.g. Utterback and Abernathy, 1975; Churchill and Lewis, 1983; Kazanjian and Drazin, 1990; Cooper, 1994; Sarasvathy, 2001; Nair and Boulton, 2008). Factors prominent in determining success (or failure) such as goals, resources, financials, systems, operational, managerial and strategic capabilities (Calori, 1985; Leibold et al., 2002; Voelpel et al., 2004; Ragatz et al., 1997; Helfat, 1997; Jaworski et al., 2000; Power et al 2001; Zahra and Nielsen, 2002; Adner and Levinthal, 2002; Hills and Sarin 2003; Adomavicius et al., 2007; Lepak et al., 2007) are weak or non-existent. The focus of activities centres on resolving technical issues, formulating value propositions, developing prototypes and securing investment (Utterback and Abernathy, 1975; Anderson and Tushman, 1990; Utterback and Suárez, 1993; Kazanjian and Drazin, 1990). Non-technical resource and capability requirements are often overlooked or viewed as being secondary. Associated supply networks have little or no structure given the lack of or very limited formal nature of relationships (Kazanjian and Drazin, 1990).

### **3.2. Stage II – Fragmented**

This stage aims to capture when the major focus is on developing the product and/or technology, beyond basic prototyping, towards that of a marketable product (Kazanjian and Drazin, 1990; Simchi-Levi and Fine, 2010; Ortt and Egyedi, 2014; The technology, still often unproven, is just coming into existence and the stage may be characterised by the establishment and realignment of new and existing supply network linkages respectively. With supply networks best described as 'fragmented' here, functional areas begin to emerge in terms of organisational structure, with evidence of increasing 'order' within the network that is often characterised by an emerging commercial strategy and potential for partnering arrangements (Kazanjian and Drazin, 1990; Moore, 1993; Sarasvathy and Dew, 2005; Sebastio and Golicic, 2008).

### **3.3. Stage III – Formation**

This middle stage marks the 'formation' of supply networks and the 'emergence' of an 'industry', and may be characterised by 'firm entry', where *survival* and *market share* start to take precedence over considerations of technological position (Churchill and Lewis, 1983; Calori, 1985; Fligstein, 2001). Focus may centre on defining market requirements and delivery channels for a new offering (Moore, 1993; Kamath and Liker, 1997; Jaworski et al., 2000; Kumar et al., 2000; Thomke 2001; Christensen 2003; Sarasvathy and Dew, 2005; Den Hartigh et al., 2010). It broadly covers the transition from viable pilot production of a new technology or delivery platform to a completed value chain with an end-user in the form of an early adopter. At this stage, individual entrepreneurs, new enterprises, and coalitions of more established firms tend to cooperate by working closely with both customers (if defined) and key suppliers, with the view of gaining first-mover advantage. Characteristics of trust building and definition of selection processes are critical, in terms of the supply network here, as enterprises seek close partnerships and look to build their networks around the most influential partners who may already have market credibility with a strong set of customers (Dyer and Singh, 1998; Sarasvathy 2001; Hills and Sarin, 2003; Suárez, 2004; Sebastio and Golicic, 2008; Harrington and Srail, 2015).

### **3.4. Stage IV – Expansion**

Characterised by the development of a viable business concept and having potential for scale-up, it is at this ‘expansion’ stage that multiple customers begin to develop and competitive technologies emerge (Churchill and Lewis, 1983; Moore, 1993; Srai, 2010; Srai et al., 2014). A hierarchical structure often tends to emerge as organisations move to this higher stage, with focus on production, sales, and distribution of a marketable product or technology (Utterback and Abernathy 1975; Kazanjian, 1988; Kazanjian and Drazin, 1989; Kazanjian and Drazin, 1990). The organisation typically is in a state of flux as it looks to eliminate competitive technologies and competitors. In response, supply network elements often undergo rapid and continual change as the associated value chain evolves (Anderson and Tushman, 1990; Hill, 1997; Shapiro and Varian, 1999; Hansen and Birkinshaw, 2007).

### **3.5. Stage V – Stabilisation**

With levels of resource maturity in evidence (Churchill and Lewis, 1983), focal firms may look to take the form of a market leader in this ‘stabilisation’ stage (Den Hartigh et al., 2010). Clusters of network actors start to form, as collaborative models begin to gain traction over competitive technologically differentiated approaches (Kamath and Liker, 1997). Most innovations may now be driven by production-related factors (Utterback and Abernathy 1975). Here, the associated supply network may start to cohere into the form it will take for a mature and viable industrial system (Srai et al., 2014).

## **4. Methodology**

The following sections present an overview of the methodological approach used in his research paper. Section 4.1. briefly clarifies our research philosophy and discusses the choice of research strategy and alternative designs considered. Section 4.2. provides both details on the data collection process and methods, including information regarding the qualitative investigation and case studies development (interviews and timescales) and summarises the data analysis techniques employed to inform the development of the stages model.

### **4.1. Research strategy**

A research strategy aims to provide overall direction to a study including the process by which the research is conducted (Remenyi et al., 2003). Upfront clarification of the research philosophy plays an integral part in this, as it informs the underlying philosophical assumptions that may support final conclusions. In building a logical research design, our research philosophy follows interpretive rather than positivistic logic because of the exploratory nature of the study in question and the objective to develop an understanding of a new and contemporary phenomenon.

The goals of the researcher and the very nature of the research topic also influence the selection of this strategy (Benbasa, 1984). In deriving a conceptual stages model, alternative research designs were first considered based on criteria set out by Yin (2009). The alternative design options (i.e. experiment, survey, archival analysis and case study) leading to a final decision on research strategy were based on (a) the type of research question (b) extent of control over actual behavioural events and (c) the degree of focus on contemporary events (ibid).

The multiple-case study strategy we adopt is in line with Yin’s definition of it being an empirical inquiry that investigates a contemporary phenomenon both in-depth and within its real-life



context. The approach is particularly appropriate here as this study seeks to explore both practice-based (where the insights of key industrial stakeholders are critical) and emerging phenomena when research and theory is at an exploratory or formative stage (Eisenhardt, 1989; Meredith, 1998; Eisenhardt and Graebner, 2007; Yin, 2009).

#### **4.2. Data collection and analysis - process and methods**

In addition to the emergence of new networks and enterprises, this research also considers well-established organisations looking to capture value and further diversify product portfolios through new technology adoption. The PE sector was specifically targeted; it is argued that it is a prime example of an 'emerging industry' - where there is a mix of established actors and new entrants, and is combining traditional printing techniques with novel technologies.

As part of the data collection process, potential case study organisations were first identified from an industrial ecosystem map of the PE sector in which key institutional, industry sector specialists and supply network actors had been captured (Baril *et al*, 2012), using an approach previously reported (Srai 2010; Srai *et al.*, 2014). In order to properly test the conceptual stages model, the following criteria were set out to ensure a balance of (i) new emerging enterprises with innovative manufacturing processes and (ii) more established firms who were looking to leverage existing capabilities, processes and techniques developed in the wider 'electronics' industry. In summation, case studies should;

- represent a diversity of enterprises operating at different (and multiple) points within the value chain
- represent enterprises operating at varying 'stages' of development
- represent supply networks which were either created organically or involved some form of radical transformation of existing networks and
- exhibit alternative evolution paths, hence, providing a broader understanding of the key characteristics of emerging supply network 'stages'.

Using this pre-screening step, and on the basis of general practical considerations involving availability of interviewees and accessibility to sensitive information, eight case studies were selected based on their ability to allow full exploration and test of the conceptual model introduced in section 3. Descriptors of the case study selections are summarised in table 2 and are organised by cluster (i.e. materials developer, component developers and product assemblers) in order to capture potential synergies across networks operating at similar points, and at various stages of development, within the value chain

In order to ensure a coherent and industry-wide representation of the sector, the data collection process involved secondary as well as primary data, and included annual reports of the selected cases, news articles, press releases, market reports for the sector, websites and company presentation material. This integrative use of secondary and primary evidence formed the basis of a data triangulation process, which checked evidence across multiple sources of data in order to increase validity and reliability (Eisenhardt 1989; Yin 2009).

The data collection method involving gathering primary data sources through eight semi-structured interviews conducted with the case companies between March 2010 and January 2011. All interviewees were CEOs, managers or senior engineers who were still active within each case organisation and, hence, knowledgeable about organisational and technology timelines, supply network development history and overall firm strategy. The interviews lasted approximately two hours and consisted of two parts; first, respondents were asked to provide a general overview of their

specific company, product concept, technology development process, supply network structure (including partnerships), their view on overall industry dynamics and opportunities for the sector. Next, interviewees mapped out the development of their supply network, capturing various potential evolution paths (i.e. previous, current, future, alternative scenarios) for selected nodes of their respective networks using the supply network emergence stages model, supported by network configuration dimensions derived from the academic literature. In order to better understand 'transitions', with respect to dimensions and stages as defined by the conceptual model, these evolution paths from current to 'desired' options were discussed in detail. Definitions and descriptors of the 'stages' of supply network emergence model were also discussed and then refined, based on valuable insights from the case study respondents. Finally, repeat access via either informal follow-up meetings or by e-mail correspondence was agreed in order to validate data and seek clarification where required.

**Table 2** Case study descriptors

Case Study	1	2	3	4	5	6	7	8
<b>Company descriptor</b>	Materials Developer	Component Manufacturer	Component Manufacturer	Component Manufacturer	Product Assembler	Product Assembler	Product Assembler	Product Assembler
<b>Company Type</b>	OEM	SME	OEM	OEM	SME	OEM	OEM	OEM
<b>Footprint</b>	Global	Regional (UK)	Regional (Asia)	Global	Regional (UK)	Global	Global	Regional (UK)
<b>Network focus</b>	Upstream	Upstream	Upstream-downstream	Upstream	Downstream	Downstream	Downstream	Downstream
<b>Respondent profile</b>	Chief Innovation Officer	Chief Executive Officer/Senior Engineer	Chief Executive Officer	Head of Division for Sensor Technology	Senior Engineer	Sales and strategic planner	Principle engineer for advanced technologies	Chief Executive Officer

## 5. Case study narratives

The data analysis technique employed as part of this study analysed each cluster (i.e. materials developer, component developer and product assembler), before conducting a cross-case analysis (see section 6) in order to capture stages of supply network emergence for the overall PE sector. Short descriptions and analysis of each of the case companies in each cluster, based on an integration of primary data and secondary sources, are also presented here and focus on aspects of manufacturing capability, supply network configuration and stage of emergence.

### *Case 1. Materials developer*

Case organisation 1 is a global company with production facilities in the US, Asia, and Europe and is a world leader for film products for use in food packaging, photo systems, electrical products and electronics. It has a very well defined business model as plastics (the core business) is already a mature industry, based on commodity materials. The organisation has expanded its product portfolio by supplying films for PE, and is working towards creating plastic substrates as an alternative to glass with cost efficient and high volumes processes. Hence, characteristics of its PE supply network include having a mature network shape with strong supplier connectivity. However, levels of commercial control and customer partnership are significantly less developed. However, the firm is working very closely, through joint development programs with product manufacturers, to be responsive when markets emerge. With its specialism in film production, the case organisation is in an excellent position to aid SMEs develop both materials and manufacturing equipment that is

compatible with their films, and is currently working very closely with clients at early stages of development in order to meet the required product specifications. At the same time, the firm is able to engage with larger players due to its legacy manufacturing capabilities. Production capabilities, with respect to PE films are considered to be in the 'stabilisation' phase of development with capacities exceeding market requirements.

#### *Cases 2-4. Component Manufacturers*

The specialised capability of case organisation 2 lies in ultra-thin and low-cost flexible microcircuits that may be incorporated into mass-market objects and packaging. While this small-to-medium sized enterprise (SME) has a very well developed regional customer base in the UK, it is becoming increasingly affected by global customer pull, with no mature network structure to support this opportunity.

As OEMs, case organisations 3 and 4 have similar supply network profiles to each other. Case organisation 3 is a global player in the research, design and manufacture of electronic components with clients including Apple, Bosch, HP and Nokia. While already well established in the electronics market with a strong supplier network, the industry environment for PE is quite diverse (developing integrated microsystems for medical devices) compared to its core offerings. Case organisation 4 is a high-tech device manufacturer that develops electronic components and batteries, primarily focusing on display, energy, and communication applications. Its network remains regional and its biggest customers include LG and Samsung. In the context of PE, while network structure is weak, both have demonstrated growing interdependent links with the key industrial actors. However, there is a clear difference in the types of relationships they are developing in this space. Case organisation 3 has focused on developing supplier partnerships, with case organisation 4 extensively developing its customers, in order to sustain its development. Both firms are considering a consolidation of their networks through acquiring competitors and suppliers upstream.

#### *Cases 5-8. Product Assemblers*

Two product assembly companies, with regional (UK) footprints, demonstrate many of the early mature characteristics in terms of network structure. Case organisation 5, a developer and manufacturer of lightweight solar modules based on printed plastic, was only established in 2010. Despite its infancy, the firm benefits from its high-speed manufacturing capability and low fabrication costs, and has seen its network dispersion grow from a single location to have a global reach in less than twelve months. In addition to increased dispersion, the strength of its partnerships has also increased and stabilised. Case organisation 8 develops and manufactures flexible plastic displays, based on a licensed transistor technology, and has a strong network structure around individual site centres, customised engineering systems and supplier partnerships which are largely transactional. Engineering resources meet industry requirements and the product features have already been defined. However, commercial and engineering control are still at an early stage of development as the firm is undergoing a transition, from being venture capital-funded to finding a route to market, in commercialising its technology.

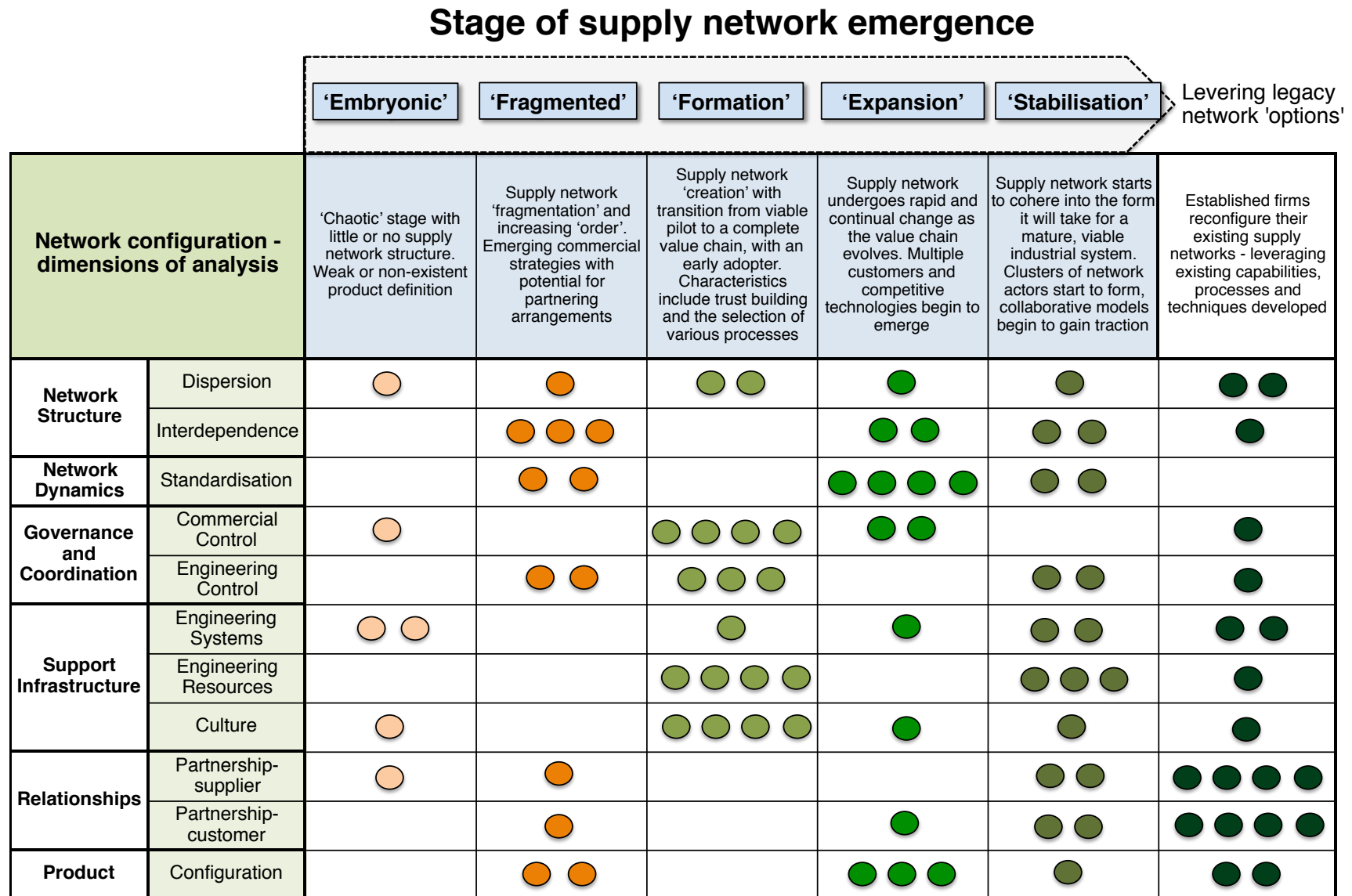
Case organisations 6 and 7 exhibit a very developed network infrastructure due to their leading positions within the wider electronics industry and in the area of LCD displays, in particular. Both companies are leveraging this network infrastructure and industry presence to develop their PE business segments, through engaging in joint ventures and actively cooperating with technology innovators in order to develop their know-how. Both case organisations support their suppliers to ensure they have the resources to develop innovative technologies and in the required quantities.

Furthermore, they are also exploring a vertical integration strategy downstream by acquiring competitors and suppliers of materials for display modules. As well as bringing stability within an emerging sector (where the number of suppliers is very limited) vertical integration of material suppliers may ensure efficient resource management and reduce times-to-market.

## **6. Cross-case analysis and theoretical contribution**

PE is a leading example of a new emerging industry, with novel products being manufactured using a hybrid of traditional printing techniques with emerging technologies. This is also reflected in the composition of the actors within the sector. It is comprised of new entrants driving innovative manufacturing processes, coupled with more established firms looking to diversify their product portfolios. In terms of supply networks, there is often a wide disparity here. Small emerging firms focus their activities on resolving technical issues, developing prototypes and securing investment while 'non-technical' requirements (such as supply network design) are often overlooked. On the other hand, the larger players look to leverage existing capabilities, processes and techniques developed in the wider 'electronics' industry. The case studies selected as part of this study were used to capture the composition of 'current' PE sector supply networks. This involved a diversity of firms at different 'stages' of development and represented supply networks which were either created organically (or are still in the process of) and involved some form of radical transformation of existing networks. For reasons of confidentiality, analysis of individual cases is anonymised, however, an overall snapshot of the PE sector is a valuable contribution. Figure 2 combines the final stages model of supply network emergence in five stages (e.g. *Embryonic; Fragmented; Formation; Expansion; Stabilisation*) with an overview of where the eight PE case study supply networks are positioned (across the x-axis) versus each configuration dimension on the y-axis. Collectively, the sector exhibits alternative evolution paths, hence, providing the study with a broader understanding of the key characteristics of emerging supply network 'stages'.

Figure 2 Stages of supply network emergence in technology commercialisation – PE sector profile



In terms of network structure, two product assemblers demonstrate many mature network characteristics (leveraging existing connections). In terms of *dispersion* (6/8 cases) and *interdependence* (7/8 cases), the majority of cases see their existing supply networks as spanning the five stages (e.g. *Embryonic; Fragmented; Formation; Expansion; Stabilisation*) as would be expected given the diversity of firms at different stages of development. .

On examining network dynamics and *standardisation*, half of the case study networks are in the 'expansion' stage, where focus centres on the production, sales, and distribution of a marketable product or technology. For one case study firm, established in 2010, its network dispersion has grown rapidly from a single location to having global dispersion (enabled by the strength of its network partnerships), advancing to a 'stabilisation' stage in less than a year.

With respect to *governance and coordination* and *support infrastructure*, the majority of respondents identified their networks as being at the 'formation' stage – here, *engineering* and *commercial control, systems* and *resources* may be characterised by the organisations working closely with both customers (in specific cases) and key suppliers, with trust building being vital in terms of supply network development. Interestingly, while one case study firm regarded *engineering resources* to be well advanced and had a well-defined end product, *governance and coordination* (in terms of *engineering* and *commercial control*) remained at the 'formation' stage and had become an area of focus.

With PE predominantly an emerging industry, a good proportion of supply networks are currently positioned within 'formation, 'expansion' and 'stabilisation' stages, with respect to configuration dimensions. However, the OEMs possess mature and well-defined networks, and this is reflected in terms of relationships, with 50% of the case studies leveraging their existing links with high levels of supplier and customer connectivity in evidence. However, this strong supplier connectivity is in contrast with the level of commercial control, which remains significantly less developed. Here, firms are partnering very closely, often through joint development programs with product manufacturers, to be responsive when a market emerges as well as with customers at early stages of development in order to meet all the product specifications. For two of the larger multinational OEMs, who are market leaders in their core sector, the most significant supply network consideration – in a PE context – are supplier partnerships, which are identified being as 'fragmented'. While the strength of their networks lie with established customer partnerships and engineering capabilities, the sourcing of new materials and developing stronger relationships through joint venture agreements or exclusive contracts with smaller technology innovators is a priority.

Finally here, in terms of product, two of the smaller case study firms have developed novel technology to be integrated in innovative products (e.g. such as flexible e-readers and solar cells). This requires the sourcing of new suppliers and new markets to be developed. Hence, supply networks may be best described as 'fragmented' and need to be created around the disruptive technology.

In terms of theoretical contribution, current perspectives on early stage supply network development in new and emerging industries are largely descriptive, and provide limited detail on configuration elements and options. Previous studies on the strategic roles of supply networks have largely focused on large, well-established, market driven organisations, their established products and their extended networks. In contrast, emerging networks often have limited or no structures supporting products with a weak initial focus and definition. The prototype tool developed as part of this study integrates the network configuration approach with a conceptual stages model of supply network emergence, derived from the literature, in order to examine emerging supply network development and evolution using a series of case studies. Outputs inform network theory and extend existing network configuration concepts, recently applied in more mature industries (e.g. Shi and Gregory,

1998; Zhang et al, 2007; Srari and Gregory, 2008; Harrington and Srari, 2012), to better 'fit' emerging contexts. Table 3 highlights the contribution of this study to operations management research in the area of network configuration.

Comparing configuration concepts in mature supply networks (Srari and Gregory, 2008) and emerging contexts (this study), structure in a mature context is focused on tier structure and shape, addressing increasing geographical dispersion and integrating mechanisms. In an emerging context, there are different considerations for the network designer which may include the set-up of new partnering arrangements within emerging clusters of activity at a new location, while leveraging critical elements of pre-existing supply networks that may be well established and relevant to an emerging context.

With respect to network dynamics, a mature network configuration focuses on the flow of materials and information between and within key unit operations, replenishment modes, and (well understood) supply-demand dynamics. In an emerging supply network context, it is more about leveraging existing and establishing new capabilities, with emerging firms often functioning using an 'old and new' hybrid model of customised and established processes. Before industry-standard processes have been developed, firms often have to first demonstrate their 'value' to the overall network. Knowing the key stakeholders within an emerging industrial system and conversely *to be known* is critical in order to foster effective cooperation when required.

In terms of governance and coordination, key network partners and associated inter-firm governance mechanisms are prioritised in a mature supply network setting (likewise in maintaining key inter-firm relationships with partners, in a mature context). For emerging networks, balancing commercial and engineering control is now an area of focus. Partner and process selection (customers and suppliers) and developing longer-term relationships (new and existing) are critical in an emerging context. When opportunities for the commercialisation of novel technologies arise, actors may often partner for a single commercial opportunity. This may open up different challenges for supporting infrastructure of an emerging network at different stages of development in terms of cooperation (e.g. allocation of critical resources and building of trust) and potential for competition (e.g. concerns over IP) with multiple partners.

Finally in terms of product, mature networks focus on modularity, SKU portfolios and profiles while in the case of emergent, focus is somewhat blurred given a lack of certainty, in terms of product definition and end-user requirements. In an ideal case, a rapid consolidation of concepts would lead to the lock-in of a defined product.

The stages model also extends theoretical understanding of 'stages' and 'emergence', from a traditional technology and product perspective, towards that of supply networks. Although some research may have spoken of 'network', in terms of organisation and business structure, few have considered the role of the supply network and the stages through which an industry may 'transition' from emergence to a mature industrial system. While the configuration dimensions, presented in table 3, have been used to represent established mature networks with multiple archetypal forms, it could be argued that some of these dimensions may not be applicable in an emerging network context. Hence, there is a requirement to validate which network configuration dimensions and sub-dimensions remain relevant in emerging industry contexts and to refine accordingly in order to best capture configuration profiles associated with technology emergence and disruptive business models. In theory, this validation could be used as a basis to further extend network configuration concepts to capture 'transitions' between both emerging and mature stages. This may only be achievable with a sufficient level of granularity and discrimination, through the use of multiple cross-sector case studies involving industries at different levels of maturity.

**Table 3** Network configuration dimensions - applied in an emerging supply network context

Operations Management Research on Network Configuration						
Domain	Production Networks	Engineering Networks	Supply Networks	Service Supply Networks	Emerging Supply Networks	
<b>Supporting Literature</b>	(Shi and Gregory, 1998)	(Zhang <i>et al</i> , 2007)	(Srai and Gregory 2008)	(Srai, 2011; Harrington <i>et al</i> , 2012; Harrington and Srai, 2012; Harrington and Srai, 2016b)	This study	
<b>Summary of cases</b>	Ten cases in aerospace, electronics, heavy engineering and pharmaceuticals	Seven in-depth cases in aerospace, automobile, electrics and electronics and FMCG sectors	Ten exploratory and ten in-depth cases in aerospace, electronics, FMCG, garments and pharmaceuticals	Four case studies involving complex 'product-service solutions' in aerospace, naval, power and telecoms	Eight case studies in the plastic electronics sector	
<b>Configuration elements</b>	<b>Structure</b>	Plant role characteristics; geographic dispersion; network evolution	Geographic dispersion; resources and roles of engineering centres; rationales for network structure design	Supply network tier structure and shape; geographical dispersion; supply network mapping; integrating mechanisms	Multi-organisational network structure; service archetypes	Leveraging existing locations and linkages; Initial partnering arrangements; Emerging clusters
	<b>Network Dynamics</b>	Response mechanisms	Operational processes supporting engineering information flows	Flow of materials and information between and within key unit operations; replenishment mode and supply-demand dynamics	Service supply contracting mode; through-life perspectives	Hybrid of customised and established processes; Actors demonstrating their 'value' to the network
	<b>Governance and Coordination</b>	Horizontal and vertical coordination	Governance, including authority structure and performance measures	The role of key network partners and inter-firm governance mechanisms	Service network governance modes	Balancing commercial and engineering control
	<b>Support Infrastructure</b>		Support, including engineering tools and IT systems		Support systems	Critical resources; Trust building
	<b>Relationships</b>	Intra-firm dynamic capability building		The role of key network partners and inter-firm relationships	Partnering modes; firm and network value sets	Partner and process selection (customers and suppliers); Developing longer term relationships (new and existing)
	<b>'Product'</b>	Product lifecycle and knowledge transfer		Product modularity; SKU portfolio/profile	Service offering; outcomes/effects	Consolidation of concepts; Product focus and definition

### 7. Conclusions and suggestions for future research

The focus of this research paper has been to better understand what role supply networks may play in the successful commercialisation of emerging technologies. One critical challenge is that there is no



defined pathway for emerging firms to follow, with great uncertainty and risk inherent in final product definition and end-user requirements. In terms of supply network strategy, new actors and enterprises often fail to coordinate the *external* resource capabilities and core non-technical activities they may require, often focusing on managing internal capabilities. This is also reflected in the academic literature, with relatively limited research in this area of supply network design and management for early stage technology enterprises.

In addition to new entrants, this research also considers well established and mature organisations looking to capture value and diversify their product portfolios through the technology commercialisation route. To this effect, 'mature' organisations often need to radically 're-configure' their legacy supply networks, leveraging existing capabilities where possible, to support the emergence of a new technology and business model. While organisations may be classed as 'mature', it is argued that their supply networks never quite reach a stage of 'maturity'. Supply network emergence, evolution, transition and reconfiguration is a constant - due to ever-changing competitive priorities, emerging market opportunities and the dynamic nature of today's 'industrial enterprise'.

It is also argued that existing research on 'stages' for emerging industries are largely conceptual and descriptive, providing limited content and substance on what the *supply network* features of evolution may be. This can result in both subjective identification and classification and may not provide insights on optimal 'pathways' and 'operational actions' that firms need to consider. Hence, a generic 'stages' model to better understand supply network evolution - in the context of emerging technologies - was developed (underpinned by literature on industrial emergence and network theory) and then tested using a series of existing commercialisation case studies within PE. The aims of model development were two-fold, namely, to extend theoretical understanding of 'stages' and 'emergence' from a traditional technology and product perspective towards that of supply networks, and inform existing network analysis approaches previously used, to good effect, in mature contexts. Application and refinement of the stages model, using these case studies, has demonstrated that supply network emergence may be described as a hybrid process of forming new and restructuring existing legacy linkages.

At the practice level, the stages model may inform how best to manage critical network resources, and support the development and design of alternative business models and effective supply network strategies for transforming new technologies into marketable products. The approach has recently been adapted for a review of inkjet printing research and manufacturing in the pharmaceutical sector (Daly et al., 2015). In summary, the 'stages' model may serve as:

- An evaluation tool for emerging actors and enterprises to appraise their existing supply network competencies, their 'fit' with respect to business strategy, and overall interactions within an emerging industrial system
- A supply chain strategy demonstrator to inform effective supply network design for specific industrial emergence modes and new entrants
- A performance indicator of emerging industry development, as a whole, from a supply network perspective
- An network analysis approach with the potential of capturing emergent and mature contexts

There are a series of limitations to this study, which present interesting opportunities for future research. First, and inherent to the nature of emerging industries and sectors, was access to a significant number of case examples. While the stages model of supply network emergence was first developed using an extensive literature review, validation and insights were restricted to eight case studies (with supporting secondary data) across the PE sector. However, the selection criteria set out did allow a diversity of enterprises operating at different (and multiple) points across the value chain to be identified and targeted. These case organisations could be further segmented into clusters, allowing some insights into cross-cluster and within-cluster synergies and differences. In summary,

additional validation with a more extensive set of cases would be beneficial. Secondly, this initial study was based on an industrial ecosystem map of the PE sector in 2011, where key institutional, industry sector specialists and supply network actors (at that time) had been captured. Access was limited to two SMEs and six OEMs at this juncture. This is understandable given sensitivities over IP and high rates of turnover/attrition, with respect to respondents and smaller firms. Hence, and as reflected in figure 2, the study may be biased towards the 'more mature' organisation case involving legacy supply networks and the leveraging of existing capabilities, where possible, to support the emergence of a new technology and business model.

However, one of the interesting aspects of engaging with industry is that it is possible to identify the practice need for new avenues of research (Childe, 2011). As part of project *ReMediES (Reconfiguring Medicines End-2-End Supply)*, the PE industrial ecosystem map will be revisited in 2016 to chart industry evolution over this 5-year period, and to specifically assess emerging concepts and opportunities across the pharmaceutical value chain. Specific focus here centres on PE enabling alternative and novel routes to medicines production, and the delivery of added value to 'end-users' (patients and healthcare providers), in terms of e.g. improved product traceability and patient compliance. This activity is one of five application workstreams informing two advanced manufacturing supply chain platform projects - End-2-End (E2E) clinical trials (including both the physical and regulatory supply chain) and E2E commercial supply chains (from raw materials and production, right through to the patient). Product concepts in PE - linked to 'smart' packaging, 'intelligent' packs and flexible supply - are currently in development, supporting the design of E2E digital pharmaceutical supply chains (one of three flagship projects commissioned as part of commercial platform activities).

As discussed in section 6, future studies in the network configuration domain will look to validate the dimensions and sub-dimensions that are applicable for 'mature' industries and were used here in an emerging industry context. In order to capture configuration profiles associated with technology emergence and disruptive business models, this validation exercise will be used as a basis to further extend the network configuration approach to capture 'transitions' for both emerging and mature firms. Secondly, in order to achieve a sufficient level of granularity and discrimination, our research strategy will look to (i) target more 'nascent' and 'emergent' cases (for example, current studies involve developing supply networks for renewable feedstocks) and extend these analyses to other emerging industries in order to further test the stages model in a series of cross-sectoral studies (ii) explore if particular 'archetypes' or 'forms' of supply network may best support industrial system emergence and (iii) develop a generic set of performance measures for institutional stakeholders, that may be used to track emerging firm progress.

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