The coordination of technology development for complex products and systems innovations

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Abstract

Purpose – The purpose of this paper is to explore earlier stages of complex products and systems (CoPS) innovations, investigating how technology development can be coordinated.

Design/methodology/approach – This paper uses a case study methodology, adopting an abductive logic, characterized by a nonlinear and iterative process of systematic confrontations between theoretical framework, empirical fieldwork and case analysis. Specifically, the authors study the Swedish aerospace network, which distinctly represents the CoPS characteristics of intense technology development with long-term goals and project-based activities with universities, research institutes, small medium enterprises and leading firms.

Findings – By adding the network perspective in the CoPS literature, the authors found that technology development can be coordinated within the technological and the business dimensions and according to different strategic nets. Also, the authors found that strategic nets co-evolve when their related projects are connected and advance in maturity, and their actors change their network position.

Originality/value – Current research on CoPS often recognizes that the survival and growth of a firm depend on its ability to coordinate innovative projects that are usually implemented during technology development. The findings contribute to this literature by showing how such projects can be implemented through agenda construction and the simultaneous coordination of strategic nets, leading to the synchronization of resources and activities. As such, this study's framework offers a novel and integrative view of how the short-run and long-run strategies of leading firms can be aligned, and how other actors can contribute to the direction of the innovation path.

Keywords Technological innovation, Network coordination, Technology development, Complex product and systems, Strategic nets, Technology readiness levels

Paper type Research paper

1. Introduction

Complex products and systems (CoPS) are defined as high-cost, engineering and software-intensive goods, systems, networks, infrastructure, engineering constructs and services (Davies and Hobday, 2005). Flight simulators, military and commercial aircraft, telecommunication networks, aircraft engine control systems and gas turbines can be included in this category (Hobday, 1998).

Innovations in CoPS play a critical role in society as many firms in mass-production industries rely on CoPS for their production (Acha *et al.*, 2004). For instance, each of the technologies that make the iPhone so "smart" can be traced back to investments in complex technologies, such as the internet, the touch-screen display and microprocessors, that were originally designed for military products (Mazzucato, 2013). In addition, CoPS are also an important part in achieving societal critical infrastructures, such as electricity supply, transportation and telecommunications (Acha *et al.*, 2004).

CoPS have been characterized as distinctly different from mass-produced goods (Hobday, 1998). For instance, production in CoPS is limited to a unit or small tailored batches instead of the high volume produced by mass production industries. CoPS are often customized for specific customers and are located at the forefront of technology, very seldom relying on off-the-shelf components. Their development requires large investments and is characterized by long-life cycles and lengthy stages of design, systems engineering and systems integration phases.

Prior to CoPS development, to prepare for new product generations incorporating technology advancements, CoPS firms may engage extensively in technology development. The technology development phase differs from the product development phase, with the former tending to be long-term

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with unclear completion points, whereas the latter is more short-term with pre-defined deadlines derived from expected market launch (Magnusson and Johansson, 2008). During technology development, projects are implemented to explore innovative alternatives to technological architectures, meet evolving customer requirements and integrate knowledge from external sources (Davies and Brady, 2016).

While technology development projects often provide emerging insights for the future direction of a firm (Davies and Brady, 2016), they require the challenging task of coordinating diverse actors of a CoPS network as these actors are dependent on each other for shaping the future of the industry (Prencipe, 2003). As relevant knowledge to develop technologies needed for CoPS are often distributed among a broad network of diversified actors, such as small medium enterprise (SMEs), suppliers, customers and universities, that have distinct short-term goals and objectives, these actors' long-term strategic goals may be highly intertwined (Davies *et al.*, 2011; Hobday, 1998).

In this context, a CoPS network can be considered as an evolving organization having leading, or core, firms with both strong and weak ties with constituent members – that is, other firms, research centers, universities, etc. (Prencipe *et al.*, 2003). In CoPS networks, multi-party projects are the primary form of coordination (Hobday, 1998) and are often implemented and led by CoPS leading firms (Hobday *et al.*, 2005). A leading firm can be considered an organization that sets up the network and coordinates it from an organizational and technological viewpoint (Prencipe *et al.*, 2003), using projects to launch new products organized as a portfolio, and achieve strategic objectives (Davies *et al.*, 2011).

Hence, coordination in this paper is referred to as any activity or mechanism implemented jointly by different parties to synchronize distinct value systems of a network and pursue specified mutual goals (Möller and Halinen, 2017; Möller and Rajala, 2007; Möller and Svahn, 2003). Therefore, coordination needs to be understood as a holistic and evolutionary process of combining management and orchestration (Ritala, 2012). Orchestration is associated with "coordination by enabling," where the "orchestrator," instead of exercising authority, provides a common vision, facilitates the process of collaboration and makes sure that the necessary structures and discussion mechanisms are in place when needed, thus supporting innovation activities. Management is associated with "coordination by commanding," where usually one or two actors of a network have a leading role and, therefore, high influential power (Ritala, 2012).

Several contexts drive research on CoPS. Some studies adopt an intra-organizational setting to discuss key capabilities (Davies and Brady, 2000; Naghizadeh *et al.*, 2017; Su and Liu, 2012), organizational structure (Hobday, 2000; Hobday *et al.*, 2005), managerial methods (Magnaye *et al.*, 2014; Yeo and Ren, 2009) or government policies (Hobday *et al.*, 2000; Ren and Yeo, 2006). Within an inter-organizational setting, many studies emphasize the management side of coordination with customers and suppliers (Abrell *et al.*, 2018; Crespin-Mazet *et al.*, 2019; Roehrich *et al.*, 2019). Other studies include the orchestration aspect, bringing other actors to the analysis, such as universities, communities of practices and funding agencies, to have a more broad view of the coordination phenomena (Ciarmatori *et al.*, 2018; Crespin-Mazet *et al.*, 2021; Rubach *et al.*, 2017).

While those two aspects of coordination (orchestration and management) are analyzed in many network management studies, more research is needed to understand how their outcomes are linked, when different configurations of business networks are driven by common goals (Möller and Halinen, 2017). This issue can be particularly important for the CoPS literature that lacks the view of business relationship management, as acknowledged by Appio and Lacoste (2019), and has the coordination of technology development as a crucial challenge for CoPS innovations (Davies *et al.*, 2011; Prencipe, 2003). By coordinating their network, CoPS leading firms may discover new technological opportunities, being able to influence technology development, so that its outcomes become more aligned with the firm¨s strategy (Prencipe, 2003). Therefore, to better understand this issue, we aim to answer the following research question:

RQ1. How can technology development be coordinated to support CoPS innovations?

To address the above research question, we use the *strategic nets* perspective (Möller, 2010; Möller and Halinen, 1999; Nordin *et al.*, 2017), sometimes referred to as "intentional business networks," "value nets," "nets" or "strategic nets." The strategic nets perspective has been developed in a stream of the literature, disconnected from the CoPS literature, but can be considered particularly relevant due to its focus on intentionally created networks. Strategic nets are purposefully designed by a few actors pursuing mutual goals and having jointly agreed and contractually defined roles and responsibilities (Möller and Svahn, 2003; Möller *et al.*, 2005; Möller and Rajala, 2007). Another stream of the network management literature is the industrial network approach (IMP), which emphasizes the evolutionary character of borderless and self-organizing networks that emerge in a bottom-up fashion from local interactions (Håkansson and Ford, 2002; Häkansson and Snehota, 1995). In this view, a network cannot be fully managed by a single firm, and therefore, desired outcomes are not guaranteed from network interactions.

While we agree that both views are relevant in understanding how technology development can be coordinated in CoPS networks, our emphasis on the strategic nets perspective is due to its focus on mutual goals and intentional value-creating activities, which is a key feature of CoPS developments (Prencipe, 2003), that allows us to identify network outcomes. Therefore, the strategic nets level provides a suitable lens to explore coordination, given its goal specificity and focus on outcomes.

To explore this, we study the Swedish aerospace network. This network distinctly represents the CoPS characteristics of intense technology development with long-term goals and project-based activities with universities and SMEs partly led by a focal firm, partly emerging through the activities of certain actors and partly stimulated by policy-stimulated activities (Calignano *et al.*, 2018). Therefore, we adopt the focal net level of analysis that utilizes the leading firm's perspective and its relationships with other actors of a network (Möller and Halinen, 1999).

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Following the introduction, Section 2 reviews the key literature presenting our theoretical framework and Section 3 presents our methods. A description of the dynamics of coordination mechanisms implemented to support the technology development process is offered in Section 4. Section 5 discusses and concludes the key theoretical and managerial implications. Finally, Section 6 draws out research limitations and directions for future studies.

2. Theoretical framework

To answer the research question, it is essential to understand three aspects. First, because projects are the primary form of coordination to support CoPS innovations (Hobday, 1998), we describe the nature of CoPS projects in Section 2.1.

Second, since technology development tends to be long-term and is marked by technical uncertainties (Chesbrough, 2003; Jean *et al.*, 2015), its coordination can be aided by a system that assesses the actual maturity stage of a certain technology. Therefore, in Section 2.2 we introduce the Technology Readiness Levels (TRL) as a measurement system widely used in many CoPS industries (Jean *et al.*, 2015; Mankins, 2009).

Third, in Section 2.3, we bring the perspective of strategic nets (Möller and Rajala, 2007). In contrast to other network views, and aligned with the CoPS literature, the strategic net perspective acknowledges the coordination role of a hub or leading firm. Moreover, it provides specific coordination mechanisms suited for different types of nets, utilized to create value for the whole network (Möller and Rajala, 2007).

Next, we present a literature review of these three aspects that will help with our analysis and interpretations of the results.

2.1 Nature of complex products and systems projects

Projects are usually considered the basic unit for achieving innovation when a firm attempts to shape its future (Davies and Hobday, 2005; Obeng, 1996). The survival and growth of a firm depend on its ability to coordinate innovative projects, or technology development projects, that are usually implemented at earlier stages of the innovation process (Davies and Brady, 2016; Moody and Dodgson, 2006), establishing the path to potential new business opportunities (Davies and Hobday, 2005).

CoPS projects can last for years, if not decades, resulting in long-term relationships. CoPS projects are usually formed by multiple actors from a CoPS network of firms, producers, users, regulators, universities and other bodies (Hardstone, 2004). As such, projects are fundamental tools for coordinating R&D and innovation activities within a wide network of diverse actors (Hobday, 1998).

The type of actors involved and relationships within innovative projects varies substantially during technology development and according to different types of strategic nets (Möller and Rajala, 2007). In the case of CoPS networks, a hub firm usually coordinates business functions across various projects and programs with diverse organizations (Achrol, 1996; Davies *et al.*, 2011; Davies and Hobday, 2005) and plans for the future over the innovation process (Aarikka-Stenroos *et al.*, 2017).

Because CoPS are composed of several technologies that are developed at unsynchronized rates, their production requires systems integration and project management, considered core capabilities for effective and efficient coordination (Davies *et al.*, 2011; Davies and Brady, 2000). In this context, to achieve coordination, organizations need to successfully integrate their work, identifying and managing the relevant technological and organizational interfaces (Brusoni *et al.*, 2001). To secure such integration in a fast-moving technological evolution, systems integrators rely on networks to achieve collaborative agreements with distinct external sources, such as external suppliers and universities (Brusoni *et al.*, 2001).

Such networks have also been referred to as Project Network Organizations (PNO) (Manning, 2017). PNOs are inter-organizational arrangements with a coordination capacity beyond the time limitation of particular projects, which allow them to learn and transfer resources from projects. PNOs are flexible networks that combine hierarchy control with reciprocity, trust and interdependence. Such networks should be able to align the "collective interest" and each actor's "self-interest." Such dynamics build on activities within intentionally constructed networks but also by networks that are emerging from the interactions of the actors in a less planned manner as well as the interaction of the two types of networks (Håkansson and Waluszewski, 2012; Rubach *et al.*, 2017). Such a perspective expands the current understanding of CoPS networks, which seem to focus on relatively stable networks that are gradually building a supply chain for a CoPS (Davies and Hobday, 2005).

2.2 Technology readiness levels

During the evolution of technology development, firms usually focus on maturing and conceiving key technologies that will be integrated into future CoPS. In many CoPS industries, the TRL scale is used as a tool to understand and manage technology maturity (Jean *et al.*, 2015; Mankins, 2009; Sauser *et al.*, 2010; Straub, 2015). First introduced by NASA, the TRL scale was used to determine the maturity of aerospace technologies in a product life cycle, where each level corresponds to a different stage of a technology evolution (Table 1). The TRL scale allows the assessment of, and communication regarding, the maturity of complex technologies (Mankins, 2009).

Lower TRLs (TRL 1–3) are focused on scientific research, with basic principles observed and feasibility proved. On medium TRLs (TRL 4–6), the technology maturation starts with the development of components, breadboards and demonstrators validated in laboratories and/or an operational environment. On higher TRLs (TRL 7–9), the integration of mature technologies begins to conceive a complete product (Mankins, 2009).

As such, the TRL scale reflects the different stages in the technology development process. By analyzing various CoPS programs in different organizations, Héder (2017) found that TRLs have often been used to define boundaries between different organizational and financial modes of technological development and innovation. A strategic combination of these

Table 1 Technology readiness level scale

TRL	Description
9	Actual system flight proven through successful mission operations
8	Actual system completed and flight qualified through test and demonstration
7	System prototype demonstration in an operational environment
6	System/subsystem model or prototype demonstrated in a relevant environment
5	Component and/or breadboard validation in relevant environment
4	Component and/or breadboard validation in laboratory environment
3	Analytical and experimental critical function and/or characteristic
2	Technology concept and/or application formulated and analyzed
1	Basic principles observed, reported, and theoretically analyzed

Source: (Mankins, 2009)

modes enables technology development from TRL 1 to TRL 9, which is often interpreted as the path from "idea to market," even though it is acknowledged that increasing technology readiness does not mean nearing a successful product (Héder, 2017).

This association is also made by Sauser *et al.* (2010) and Sauser *et al.* (2008) who propose System Readiness Level and the Integration Readiness Level as system tools based on the original TRL scale. Through various modifications, the TRL has been applied in a variety of contexts, even outside the aerospace and other CoPS industries. For instance, several funding agencies within the European Union (EU) use the TRL scale to assess the stage of many enabling technologies for the mass production industry such as nanotechnology, advanced materials and biotechnology (Héder, 2017).

2.3 Strategic nets

Research on network management has evolved since late 1990s, extending vastly in terms of perspectives applied and broadening new research domains (Möller and Halinen, 2017). At the same time, conceptual ambiguity has also increased in this field. To grasp the theoretical fragmentation created, some scholars have tried to categorize the different, and sometimes contradictory, research streams (Aarikka-Stenroos *et al.*, 2014, 2017; Manser *et al.*, 2016; Möller and Halinen, 2017; Rubach *et al.*, 2017). For instance, networks have been classified according to the goals that they try to achieve, i.e. horizontal networks seeking market power, supply-oriented networks and technology-oriented networks (De Man, 2008). Networks have also been discussed according to their different ontological characteristics (Rubach *et al.*, 2017). Among the many perspectives, two main complementary, yet partly contrasting, streams of research can be identified.

First, the IMP emphasizes the evolutionary character of borderless and self-organizing networks that emerge in a bottom-up fashion from local interactions (Ciarmatori *et al.*, 2018; Håkansson and Ford, 2002). In this view, hub firms that try to achieve complete control over the network, to achieve specific outcomes, might reduce variety and specialization advantages of the net. In terms of organizational learning, too much control, although increasing the benefits of exploitation, can destroy the potential for exploration and generative learning (Håkansson and Ford, 2002). Instead of control, this approach suggests that firms are only able to manage within networks by mobilizing or influencing other actors by creating relationships, managing frictions (Rubach *et al.*, 2017) and understanding the different logics of actors (Baraldi *et al.*, 2007).

Second, the strategic nets perspective advocates that networks can be orchestrated and are intentionally constructed by a specific set of organizations that perform agreed-upon roles (Möller *et al.*, 2005). In this view, networks can be constructed through the direction of network outcomes toward specific mutual goals (Rampersad *et al.*, 2010). This perspective matches with the CoPS network characteristic where a wide range of actors cooperate, often with a system integrator as the leading firm. Such a leading firm is often equipped with capabilities to coordinate the network by influencing others to achieve consensus about common objectives (Prencipe, 2003). However, while CoPS networks are relatively stable and gradually building a supply chain for a CoPS (Davies and Hobday, 2005), resembling current and/or renewal nets (Möller and Rajala, 2007), strategic nets can also reflect an intentional or purposeful coordination that not necessarily aims at only creating a supply chain with all network partners, i.e. they may focus on emerging value systems together with a subset or sometimes expanded set of new and old actors to create for instance a system-wide change or facilitate the adoption of new technologies (Möller and Rajala, 2007). Such strategic nets may serve the actors, despite their overall distinct and different goals, in different ways by coordinating to achieve certain common outcomes. This may result in the creation of a net that enables a long-term well positioned industry.

In such nets, organizational relationships cannot be fully controlled by any actor or hub firm, but they can be coordinated to some extent, according to different opportunities and challenges that arise (Möller *et al.*, 2005; Möller and Halinen, 2017; Möller and Rajala, 2007). It has been argued that the strategic nets perspective can offer a solid framework for studying coordination in extended actor settings (Möller and Halinen, 2017). Hence, the strategic net perspective offers an opportunity to study the coordination of technology development for CoPS that include technologies and their potential integration, ranging from incremental refinement of existing technologies (primarily in current business networks), via substantial technology steps that lend themselves to a planned and relatively controlled development (primarily in business renewal networks) and finally novel potentially disruptive technologies (primarily in emergent networks).

In current business nets, their actors have their business process, capabilities, resources and activities clearly specified according to a stable value system. A typical illustration is the multi-tiered vertical supply nets in the automobile industry (Dyer, 1996). Horizontal nets are also in place, with competing firms implementing projects to combine their products, establishing channel relationships or customer-service systems to achieve a stronger position in the global-level competition. These nets typically aim to achieve high systemic efficiency through integration and coordination. A well-established system integrator firm is considered essential in these networks, as a strong position can attract first-tier vendors, integrated manufacturers, competitors and complementors to form a stable value net (Möller and Rajala, 2007).

Business renewal nets are basically dominated by temporal and goal-oriented multi-party projects aiming to create incremental innovations on top of existing offerings. Stability and incremental change coexist, as these nets require a balanced position between knowledge exploitation and exploration rather than the more exploitative character of current business nets. Being able to bridge the borders of different communities of practice with involved firms is an essential capability, which highlights the importance of actors with experience in coordinating multi-functional and multi-actor teams and projects (Möller and Rajala, 2007). In these nets, a leading firm is a knowledge-creating company that operates in an open system, exchanging knowledge with consumers, suppliers, universities and affiliated firms (Mowery *et al.*, 1996; Nonaka and Takeuchi, 1995).

In emerging business nets, new technologies and concepts are being created, igniting the birth of new business fields (Rubach *et al.*, 2017). In such nets, new and existing actors may explore broad science networks, through collaborative R&D projects with universities, research institutions and SMEs (Ciarmatori *et al.*, 2018). Dispersed and unclear ideas are discussed in self-organizing groups of members, such as communities of practices, permeating these nets through scientific research, looking to an uncertain future (Crespin-Mazet *et al.*, 2021).

The uncertainty characteristic of emerging business nets can be addressed when organizations build their capabilities of sense-making, framing, visioning and agenda construction (Moller, 2009; Möller, 2010; Paquin and Howard-Grenville, 2013). For instance, sense-making delineates a firm's visioning capability, enabling the identification of opportunities for future business development, leading to a change in roles and positions in networks (Nyström *et al.*, 2017). By combining visioning with a learning culture, a company can encourage explorative risk-taking (Möller, 2010). A clear vision ahead paves the way for collective action that influences and shapes industrial networks (Brito, 2001).

Agenda construction helps participants from a network to increase their commitment if there is a consensus about their shared objectives, rather than by imposing decisions (Möller and Rajala, 2007; Provan and Kenis, 2007). To align their goals, actors develop a joint view of their business, trying to foresee the pathway ahead with a focus on their core capabilities (Möller, 2010). Such an agenda helps managers to keep members motivated and to adjust network goals as their business field changes.

Finally, in strategic nets, their actors and their roles and positions change dynamically (Möller *et al.*, 2005; Nyström *et al.*, 2017; Valkokari and Helander, 2007). The types described above are snapshots of strategic nets at a given time. As such, they co-evolve continuously not only through intricate patterns of strategic intent but also through emerging activities and interactions over time (Valkokari, 2015). However, strategic intent can be used purposely to align the nets' goals and coordinate evolution, reaping long-term outcomes for the whole network (Valkokari, 2015). Strategic intent enables the parallel functioning of strategic nets and is paramount for their managers to reconfigure their networking and development practices in different situations, changing their network position (Turnbull *et al.*, 1996; Valkokari, 2015).

3. Method

3.1 Research design

The main objective of this study is to explore *how can technology development be coordinated to support CoPS innovations*. To have an in-depth understanding of this under-researched phenomenon we used a case study methodology, which can be considered as an intense and holistic description and analysis of a bounded phenomenon such as a program, an institution, a person, a process or a social unit (Merriam, 1998). As a qualitative method, "the richness of the picture produced by case research, is suitable to handle the complexity of network links amongst actors and can be used to trace the development of network changes over time" (Easton, 1995, p. 480).

Under the case study methodology, we adopt an abductive logic, as case study research within industrial marketing may gain new insights on research subjects with multiple perspectives if based on abduction (Järvensivu and Törnroos, 2010). Also referred as systematic combining, an abductive approach is characterized by a nonlinear and iterative process of systematic confrontations between theoretical framework, empirical fieldwork and case analysis (Dubois and Gadde, 2002).

Hence, after many iterations between literature review and data analysis, our understanding of the phenomena evolved and the initial research objectives changed, allowing us to continuously refine our theoretical framework.

3.2 Selection of the case

To select a case for investigating our phenomena, the most obvious choice would be a CoPS network, which is usually composed of diverse actors, such as universities, research institutes, funding agencies, SMEs, and have a CoPS leading firm as a large systems integrator (Hobday *et al.*, 2005). The aerospace industry strongly represents this setting, as it is well known for its tradition of establishing and leading networks to integrate complex technologies from a wide range of diverse players in CoPS projects (Naghizadeh *et al.*, 2017). The complexity of aerospace networks has been attracting attention resulting in several qualitative studies capturing the richness and nature of relationships in this industry (Alberti and Pizzurno, 2015; Ferreira *et al.*, 2013; França, 2018; Prencipe, 2001).

Therefore, we selected the Swedish Aerospace Network. Aerospace companies in Sweden today account for a direct turnover of €2.1bn and employ around 12,000 people within their own business, with an equivalent number of people employed outside of the aviation sector through the dissemination of technology.

Preliminary data indicated that projects implemented in this network aimed to develop generic technologies, demonstrators and commercial products aligned to long-term common goals (NRIA, 2013), implying an attempt to direct the path of technology evolution through the coordination of several diverse actors. This initial analysis suggested the adoption of a network perspective throughout the research process.

According to the Swedish Aerospace Research and Innovation Agenda (NRIA, 2013), the Swedish Aerospace Network has several key players, with Saab AB and GKN Aerospace having a central position. These characteristics represent a striking attribute of CoPS networks with long-term project-based activities coordinated by focal firms. All of this makes this case suitable to investigate technology development and its coordination in a CoPS setting with the purpose to influence the path of innovation.

We delimited this network to the players that are strongly involved in the coordination of the Swedish Aerospace Network, based on the descriptions of our key informants and secondary information. This is visualized in Figure 1.

3.3 Data collection and analysis

The data were collected and analyzed during four years of study, using an abductive approach (Dubois and Gadde, 2002). The whole data collection process can be divided into two major phases. In the first phase, we collected several public documentation and reports about aerospace technology projects funded by VINNOVA, the Swedish innovation agency. We collected data from INNOVAIR, Sweden's national strategic innovation program for aeronautics that coordinates the development of a joint research and innovation agenda to formulates a strategy and prioritizes technologies from a range of diverse stakeholders (INNOVAIR, 2016). We had access to several reports from Saab related to their main projects, in the form of internal and public documentation and PowerPoint presentations.

In addition, we interviewed three key managers from Saab, the director of future business, the director of aeronautics R&T strategy and the project manager of an international project (MIDCAS). These managers were selected due to their roles in managing the company's internal processes that had an interface with large projects coordinated by Saab. The semi-structured interviews took about 1.5 to 2 h and were guided by an open and exploratory interview guide. The interviews were recorded and transcribed afterward.

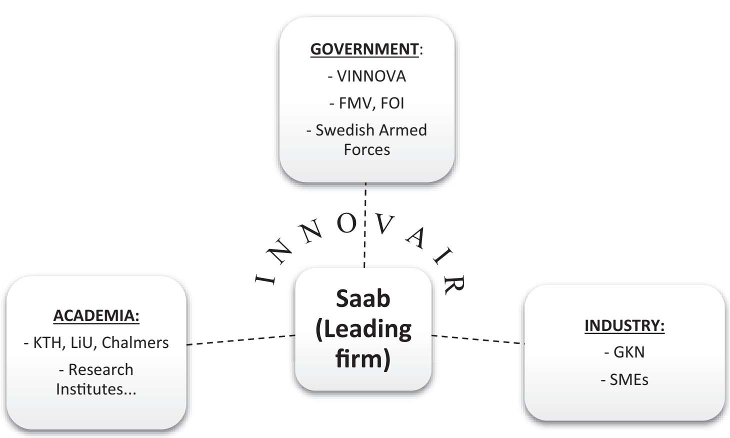
The interview guide in this phase was designed with an intra-organizational perspective, aiming mainly to investigate the internal process of Saab related to its strategies for R&D collaborations and its coordination role. However, at some point in the abductive process, we started to identify strong evidence of "coordination by enabling." As suggested by the literature, coordination is an evolutionary process of combining "management" and "orchestration" where the latter is achieved when the "orchestrator" facilitates the process of collaboration providing a common vision, without necessarily exercising authority (Ritala, 2012).

Hence, in the second phase of the research, the aim was to complement our data with more sources of evidence from different actors, other than Saab, to find indications of mutual goals being achieved and outcomes of individual works being integrated. This objective drove our data collection and analysis process and the design of the next interview guide. We started to collect data from other key stakeholders representing the different value-creating systems of the Swedish Aerospace Network. For that we tried to access these key stakeholders by participating in executive courses, congresses and workshops in aeronautics and defense relating to the Swedish aerospace industry, provided by representatives of governmental agencies, universities and companies. From these events, we were able to gather an abundance of PowerPoint presentations from which we could identify their participation in different projects and programs and their links with other programs (past and future) potentially representing current business, business renewal and emergent network settings in a CoPS context.

Moreover, we conducted seven additional semi-structured interviews with stakeholders selected based on their participation in the INNOVAIR board, and therefore their coordination roles in developing a research agenda. These interviews made use of a second interview guide, took about 1.5 to 2 h and were recorded and transcribed. The design of this interview guide changed its focus to a network perspective trying to capture the collective endeavor attempt to direct innovation. For that, we tried to understand how common goals were achieved and identify linkages between the main programs and projects of the Swedish Aerospace Network.

In summary, our abductive logic followed mainly two phases. In the first phase, we designed the study based on a literature review, collected secondary data and selected the first interviewees based on the general research question. After data analysis, we confronted our findings with the literature and reformulated the research question. Following this, we

Figure 1 Main actors of the Swedish aerospace network



collected additional secondary data and performed new interviews. Finally, a new round of analysis of the findings was performed.

Table 2 summarizes this abductive process along with the two phases. The interview guides, the extensive database accumulated and the data coded during our research process ensured the reliability of the research (Dubois and Gibbert, 2010).

3.4 Data coding

For coding, we used the software ATLAS.ti to code the large amount of text from the secondary documentation and interviews. This tool enabled us to identify patterns within the different kinds of data, and also between data and literature, thus ensuring our internal validity (Riege, 2003). Our coding procedure was an iterative process of going back and forth between framework, data sources and analysis (Dubois and Gadde, 2002). Every iteration created or discarded themes using a process of continuous refinement.

The first phase enabled us to verify that the TRL scale plays an essential role in facilitating coordination across different types of projects and programs. Hence, our final themes were framed in terms of program characteristics categorized according to their TRL targets. Seven large programs, each of them comprising many related projects, receive specific attention in this study (Table 3).

To find evidence of coordination in the network, we have searched for connections between programs in different TRLs that would indicate an evolution of the technology toward a mutual goal. For that, we created categories and codes in the data that revealed a directional link between programs from their outcomes. These links were identified as knowledge, new technologies created, new patent applications, scientific publications, spin-offs, new courses at universities and any other direct or indirect outcome generated in one program that was input for another.

For instance, in the category "NFFP Program," we have the codes "NFFP2FLUD" and "NFFP2GF-DEMO" indicating a directional link from Nationella Flygtekniska Forsknings Programmet (NFFP – The Swedish National Aeronautics Research Programme) to FLygtekniskt UtveckLings and Demonstrations Program (FLUD – The Swedish Green Engine Demonstrator) and Grön Flygtekniskt Demonstrations Program (GF DEMO) programs, respectively. Likewise, in the category "FLUD program" we also have "NFFP2FLUD" indicating the same directional link. These links are presented in the "program outcomes" column of Table 4. As an example, in the "NFFP Program" category, the spin-off companies, created as a result of NFFP, that participated later in FLUD and GF DEMO programs, was coded as "NFFP2FLUD."

From the outcomes of the programs, we could draw the interconnections between them, in terms of TRLs (Figure 3), allowing us to observe the evolution, not only of the technology but also of the players of the network. This coding process ensures our construct validity (Yin, 2017), as it was performed from different sources of evidence, allowing for viewing of the phenomena from different perspectives.

4. Evidence from the Swedish aerospace network

Our theoretical framework suggests that projects are an important coordination tool for CoPS innovations and are implemented in different TRLs and different types of networks, reflecting a variety of common strategic outcomes. The Swedish Aerospace Network case is used to further explore such coordination of activities in strategic nets through aerospace programs in different TRLs.

4.1 Complex products and systems projects in low technology readiness levels

Intending to create a broad national consensus regarding the goals, direction and extent of Swedish aeronautics research, Saab collaborated with members of academia to start an ongoing program called The Swedish Aerospace Research and Innovation Agenda (NRIA) (INNOVAIR, 2016). This national collaboration strategy primarily aimed to show potential investors (such as government agencies and international partners) that the national aerospace industry is aligned with common technology research. This agenda is updated regularly such that participating actors are continuously sharing their experiences and improving the agenda on how best to build and renew Sweden's aerospace capabilities.

The main outcome of this forum is the development and update of a roadmap for the next 35 years, with intermediate objectives at 15 and 25 years based on the TRL (Figure 2). This roadmap addresses specific technologies already agreed upon in NRIA. Participants of the agenda synchronize programs and projects in a timeline sequence from TRL 1 to 9. This sequence is executed for future generations of an envisioned product. Therefore, for a portfolio of products, many sequences are executed in parallel, where at any given point in time, higher TRL programs are being executed to develop the 1st product generation, medium TRL programs for the 2nd generation and low TRL programs for the 3rd.

To coordinate the execution of such projects, participants in NRIA acknowledge that a major concern in planning a long-term endeavor between so many actors is to assess the technology maturity of their portfolio and technologies (INNOVAIR, 2016). Therefore, the TRL concept is perceived by the whole network as fundamental in providing a major understanding of how the R&D competence of different organizations contributes to the entirety of the innovation system according to different ranges of TRLs. For instance, in an NRIA report, the key funding organizations are mapped according to the different ranges of TRLs, indicating different types of projects they can finance. As evidenced by the program director of INNOVAIR:

> [. . .] there is no way that an OEM would contract someone that has not shown that TRL capability in a joint program, so this TRL system we have is a sort of technology logic, but it also becomes part of the business logic at the same time [. . .]

One important low TRL program that is highlighted by the NRIA is the National Aeronautics Research Programme (NFFP). The NFFP is an ongoing program in Sweden that best represents the support and investments at lower TRLs. It started in 1994 with NFFP1 and, in 2017, was in the sixth stage (NFFP6). NFFP aims to develop emergent technologies

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Table 2 The abductive approach along the two main phases of the research process

Abductive process	1st phase	2nd phase
Sources of data	• SAAB • VINNOVA • INNOVAIR	• SAAB • VINNOVA • INNOVAIR • Aerospace Cluster Sweden – ACS • Chalmers, Royal Institute of Technology • Linköping University (LiU)
Secondary Data	• PowerPoint presentations from Saab about the Swedish Aerospace Network (Internal documents) • National Research Innovation Agenda from INNOVAIR (NRIA, 2013) (available at INNOVAIR website) • Funding Programs Reports from VINNOVA (NFFP) (available at VINNOVA website)	• PowerPoint presentations from LiU, FMV, FOI, Saab, Chalmers and KTH about the Swedish Aerospace Network (Internal documents) • National Research Innovation Agendas from INNOVAIR (NRIA 2016 and 2019) (available at INNOVAIR website) • Funding Programs Reports from VINNOVA (FLUD, and GF DEMO) (available at VINNOVA website) • Website public documents about, Clean Sky, Gripen NG and Neuron Programs
Interviews	• director of future business (SAAB) • research and technology (R&T) strategy director (SAAB) • project manager of the MIDCAS project (SAAB)	• director of business development research and technology (SAAB) • director commercial aircraft systems and Clean Sky program (SAAB) • managing director of ACS (ACS – SAAB) • INNOVAIR program's director • Head of the department of Management and Engineering (LiU – INNOVAIR) • Head of the Division of Fluid and Mechatronic Systems (LiU – INNOVAIR)
Main objectives of the Interviews	• To explore internal processes of Saab related to coordination during technology development • To explore how Saab influence the innovation direction	• to identify how common goals were achieved • to identify connections between interdependent projects and programs, framed by TRL, towards a common product
Main outcomes of data analysis	• "coordination by enabling" is more evident than "coordinating by commanding" within the Swedish Aerospace Network during technology development • The innovation direction is highly influenced by Saab, but is shaped with the agreement of common goals between key members of the network • TRL play a key role in helping coordination across different kinds of projects	• technology development can be coordinated within the technological and the business dimensions and according different strategic nets • agenda construction can facilitate the direction of innovation when it mobilizes all strategic nets towards a simultaneous coordination, aligned with a common goal • strategic nets co-evolve when their related projects are connected and advance in maturity, and their actors change their network position

through basic and applied research in the field of aviation, such that the research ideas initiated at universities are proven to be feasible for the defense and civilian market. This dual-use of technologies has facilitated public financing in the aerospace sector, resulting in collaborations between civilian and defense organizations.

The key actors of the NFFP program belong to organizations from industry, government and research institutes and academia forming an emergent network driven by policy. As reported by the Swedish funding agency, VINNOVA, the NFFP program resulted in increased research funding for the sector, stronger industry competitiveness and prerequisites for greater participation of industry and academia in international programs. The financial contribution for this program was divided between industry and government, with VINNOVA contributing 35%, the Armed Forces 15% and the industry 50%. The government primarily funds the activities of academia but may also fund some SMEs. Academia typically contributes to research and, in some cases, testing in their research laboratories. The projects in the NFFP program usually have three to four members from the industry partners, and about the same from universities. Saab, for instance, had 35 projects in the fifth stage of NFFP (NFFP5). The technical objectives of these projects are usually to advance one level in the TRL scale. Some projects are designed to advance from TRL 3 to 4, others from 2 to 3 and so on.

Early on in the program, the industry decided what projects they wanted to pursue by choosing what projects receive funding and the directions that these projects take. For researchers in academia, this adaptation to the industry's strategy is advantageous since it creates paths for them to continue their careers in the industry. For instance, up to NFFP5, the program produced 75 doctors, of whom 68 (91%) still operate in Sweden. Of these, 21 went to work for Saab and

Table 3 Description of the programs studied in this paper

Programs	TRL target	Program duration	Description	Main participants
NFFP	TRL 3–4	Ongoing since 1994	The Swedish National Aeronautical Program aimed to develop and research basic technologies in the Swedish aerospace industry	Saab, GKN, LiU, Chalmers, KTH, VINNOVA
FLUD	TRL 5–6	2006 to 2010	The Aeronautical Development & Demonstration National Program aimed to support development and demonstration of new technologies and production techniques	Saab, GKN, LiU, Chalmers, KTH, VINNOVA
GF DEMO	TRL 5–6	2012 to 2016	The project "Next generation composite structures for commercial aircraft" aimed to demonstrate how advanced composite technology, both in materials and production methods, as well as electric actuators can reduce airframe weight of commercial aircrafts	18 Swedish partners from SMEs, institutes, universities and colleges led by Saab
CLEAN SKY	TRL 5–6	Clean Sky 1: 2008 to 2013. Clean Sky 2: Ongoing since 2014	The largest European research program in aviation technology had the aim of reducing CO_2, gas emissions, and noise levels produced by aircraft	European private and public organizations from industry and government institutes
MIDCAS	TRL 6–7	2009 to 2015	The MIDCAS (Mid Air Collision Avoidance System) consortium, together with the European Defence Agency (EDA), aimed to develop automatic avoidance maneuvers for a Remotely Piloted Aircraft System relying on fusion of non-cooperative sensors	Industrial group - Saab, Sagem, Thales, Airbus D&S, Diehl BGT Defence, DLR, ESG, Alenia Aermacchi, Selex ES, CIRA and Indra
nEUROn	TRL 7	2006 to 2012	The aim was to integrate and validate UCAV (Unmanned Combat Aerial Vehicle) technologies in a technology demonstrator	Saab, Dassault, Alenia, EADS, Hellenic Aerospace Industry, RUAG
GRIPEN NG	TRL 8–9	Ongoing since 2013	The next generation of the Swedish multi-role fighter aircraft	Saab

GKN and 26 remained at universities and institutes (Åström *et al.*, 2008).

Saab prioritizes and supports only one or a few research groups among the partner universities for each relevant topic, to avoid creating duplication between them and to focus on the best-suited groups. When selecting an academic partner, preference is given to relationships with close proximity to facilitate recruitment and knowledge transfer.

Some members from industry and universities remained the same throughout the phases of NFFP, along with many subsequent projects, which has led to a sense of continuity, familiarity and competence strengthening. This long-term collaboration had a strong impact on the evolution of this network, since increased trust among partners and the overlap of common knowledge, enabling high levels of knowledge assimilation from universities and firms. This accumulation of knowledge during the phases of NFFP was recognized as being of interest to funding agencies and other international partners.

It was reported that NFFP1 to NFFP4 resulted in the creation of five spin-off companies, with about 65 employees, many of whom worked on demonstrator programs such as FLUD and GF DEMO in medium TRLs (Åström *et al.*, 2008).

4.2 Complex products and systems projects in medium technology readiness levels

The experience and knowledge acquired within the NFFP programs were reported as being crucial for the development of several national demonstrator programs, such as FLUD and GF DEMO, giving participants the necessary conditions and expertise to participate in subsequent international projects. For instance, in one of NFFP's subprojects, Saab achieved TRL 3 in a vehicle cooling system. This result helped Saab to become the work package leader in the international program Clean Sky, aiming to achieve TRL 4–5 for this same technology. Similarly, NFFP contributed to Saab's key roles in the national FLUD program, and in the European programs nEUROn and MIDCAS (Åström *et al.*, 2008, Åström and Blom, 2010).

A major objective of these medium TRL programs (Clean Sky, FLUD, GF DEMO and MIDCAS) is to demonstrate the technology to a mature level, supporting national SMEs and allowing them to be accepted as credible suppliers internationally. This level is typically TRL 6. Up to this level, military and civilian products and systems are integrated.

One example is the FLUD program, which only supports projects that are directly related to international civilian demonstrator programs, primarily Clean Sky. The program ran from 2006–2010 and its public budget was SEK 107 million. Within the program, Volvo Aero Corporation (VAC) (today GKN Aerospace) and Saab carried out one project each, including several subprojects, which were co-financed by SMEs. FLUD aimed to raise the TRL of many technologies to 5 or 6.

Consequently, a change in this network occurred, with SMEs becoming increasingly connected internationally. This international collaboration gave valuable and strategic access to knowledge and technologies developed by other state-of-the-

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Table 4 Main outcomes of programs studied in the paper and source of data

CoPS programs in different TRL ranges	Program outcomes	Source of data
Low TRL projects (NFFP programs)	KTH and LiU gained coordination roles for EU framework program projects partly based on NFFP achievements and improved international recognition Increased attractiveness for more research funding from financial organizations. For GKN, the competence acquired from the 12 projects in NFFP1 to NFFP3 resulted in five additional projects in NFFP4 NFFP1 to NFFP4 resulted in five spin-off companies, with about 65 employees, many of whom worked on demonstrator programs such as FLUD and GF DEMO More students are choosing flight-related programs at graduate level. LiU increased its international attractiveness and reputation by receiving more foreign students to study in the aerospace field Up to NFFP5, the program produced 75 doctors, of whom 68 (91%) still operate in Sweden. Of these, 21 went to work for Saab and GKN and 26 remained at universities and institutes	Funding Agency (VINNOVA reports)
	". . .if we go back years ago, large companies were responsible for all the inventions and R&D. Today there are small companies out there conducting very interesting R&D. . . Many of them started from universities in low TRL programs"	SMEs (Aerospace Cluster Sweden Chair's quote)
	"We have our aeronautic program and that is more stable now with like 28 students this year in aeronautic engineering. I think we wouldn't have that if we didn't have this research program [NFFP]"	University (LiU Professor's quote)
	"Some of the development methods that we're using. . . processes that we're using in Gripen E were developed through this kind of industry-university collaboration ten years ago, so that kind of process development that was done previously in NFFP programs maybe six, ten years ago, we can now see being part of the development process and we are also trying to show that in different ways in these kinds of agendas"	Hub Firm (Saab Manager's quote)
	"It is very important for us to work together with the European Aviation Agenda (ACARE) in order to make sure we don't have national goals in disagreement with the international goals. . .we make sure that we align the NRIA in terms of environmental goals, time lines etc." "NFFP was always the basic mechanism for us to fund university research at low TRL, and the main focus is to produce technical doctors in areas where we need them for industrial purposes"	INNOVAIR (Director's quote)
Medium TRL projects (FLUD, GF DEMO, CLEAN SKY and MIDCAS)	In one of FLUD's subprojects, Saab achieved TRL 3 in a vehicle cooling system. This result enabled Saab to be the working package leader in Clean Sky, aiming to achieve TRL 4–5 for this same technology In one of FLUD's subprojects, Saab developed a technology demonstrator for UAVs to "detect and avoid". Specifically, Saab has received a coordinator role in the multiparty MIDCAS consortium, with 13 participating partners, to further develop this technology In one of FLUD's subprojects, Saab developed a hardware computer system that simulates critical flight functions with high reliability. This project has reached TRL 5 and it was used in other projects, including nEUROn and SKELDAR	Funding Agency (VINNOVA reports)
	"Clearly, SMEs don't have the same resources, they don't have experience of writing research proposals and frequently they don't even have personal who are really competent to handle research issues, so because of this we started a special support system for SMEs for them to be involved in higher TRLs."	Industrial Group (INNOVAIR Chair's quote)
High TRL projects (Gripen)	"We have learned manufacturing technologies in nEUROn that we have used in Gripen E, for instance. . ."	Hub Firm (Saab Manager's quote)
	"Several results from medium TRL programs have been incorporated in technologies for the Gripen NG program, such as flight control systems, G-force impact, cockpit design, simulation systems, composite materials, helmet systems, HDMI displays, voice recognition etc."	Funding Agency (VINNOVA reports)

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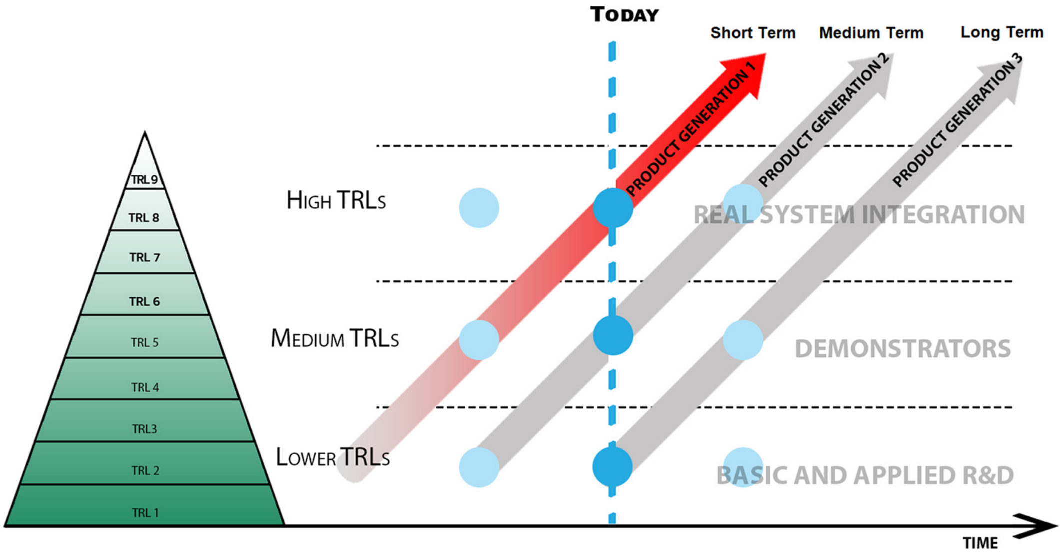
Figure 2 Technology roadmap strategy for different generations of a product



Source: Adapted from the Swedish Aerospace Research and Innovation Agenda INNOVAIR, (2016)

art actors. It also created interpersonal relationships, as these international programs were designed for a long duration in many versions. As outcomes from most of these national and international projects in medium TRLs, some patents were applied for, and technology processes were implemented in CoPS projects such as the Gripen program (Åström *et al.*, 2008, Åström and Blom, 2010).

4.3 Complex products and systems projects in high technology readiness levels

The Gripen NG (Next Generation) development program was conceived by Saab back in late 2005 as an upgrade from the current generation, Gripen E. In this program, new systems and capabilities are being integrated into Gripen NG (Saab, 2022).

Several results from medium TRL programs have been incorporated in technologies for the Gripen NG program, such as avionics, cockpit design, simulation systems, helmet systems, head-mounted displays, voice recognition. Manufacturing methodologies learned during the nEUROn program were also integrated into Saab's engineering processes for Gripen. Even NFFP had direct spillover effects. As one of Saab's managers said:

> Part of the development methods that we're using [...] processes that we're using in Gripen NG were developed through this kind of industry-university collaboration ten years ago, so that kind of process development that was done previously in NFFP programs maybe six, ten years ago, we can now see being part of the development process.

This means that some of the established suppliers of Saab in the Gripen program were once companies that participated in medium TRL programs, indicating a change in the position of this network. Differing from projects in medium TRLs, where many partners are involved with similar stakes in the outcome, Gripen had other types of cooperation with customers and suppliers. Many subsystems of the Gripen are being developed together with suppliers e.g. from UK, Germany and South Africa. Brazil not only is one of the main customers for the Gripen NG but is also cooperating in the development program.

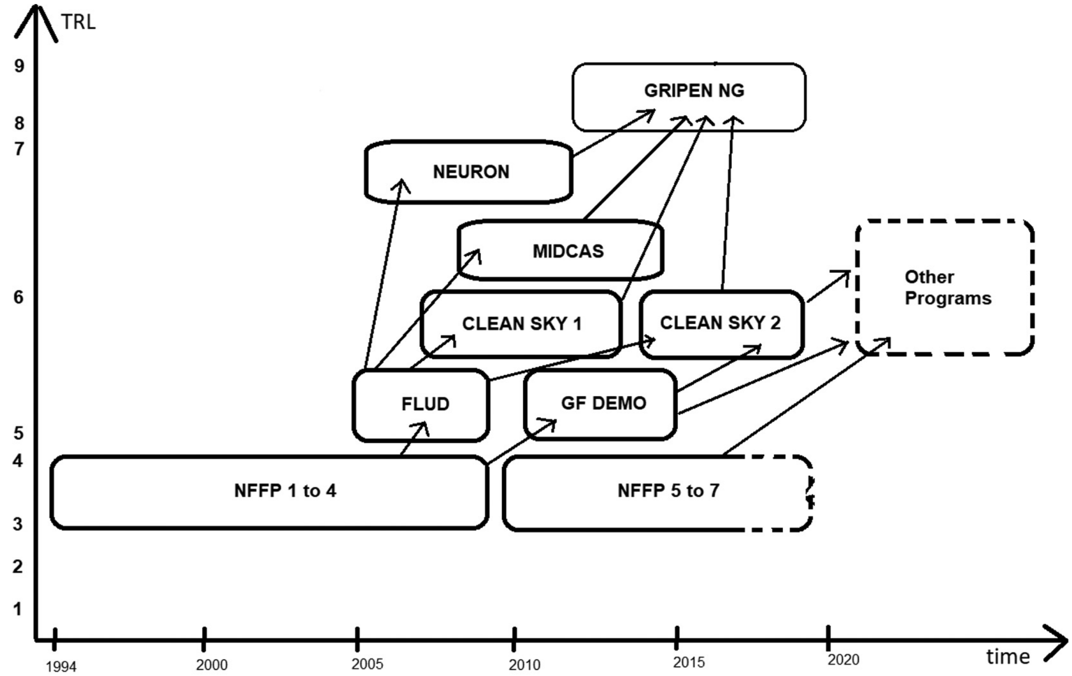
To sum up, Table 4 shows a summary of all outcomes and characteristics of the programs in low, medium and high TRLs, whereas Figure 3 represents the interconnections between the projects described in this section.

5. Discussion

Despite an increasing interest in how CoPS innovations can be supported through the coordination of technology development, prior CoPS studies offer limited insights into the dynamics of coordination in networks. By adopting a strategic nets perspective (Möller *et al.*, 2005; Möller and Halinen, 2017; Möller and Rajala, 2007) and covering the technology development phase with the TRL scale (Mankins, 2009), we shed light on this topic by illustrating how CoPS innovations can be coordinated.

Our analysis of the coordination activities of the Swedish Aerospace Network showed that in earlier stages of the innovation process when the generated ideas need to be tested, low TRL projects and programs were required to conceptualize the basic principles of technologies and test their viability through experiments and validation in a laboratory environment (Mankins, 2009). In these stages, business renewal and emergent nets (Möller and Rajala, 2007) were formed depending on the level of novelty. Funding agencies, leading firms and customers created and funded low TRL programs to develop emergent technologies to be used in the future, influencing the technological path. Researchers and students participated in these projects and improved their probability to position themselves in business renewal nets by being invited to work in the industry, creating spin-offs or participating in national and international medium TRL

Figure 3 Interconnection of the main programs funded in the Swedish aerospace network



Note: The arrows represent knowledge and resource flows

programs, maturing corresponding technologies and business opportunities.

These technologies were carefully selected and prioritized jointly by key universities and leading firms. This prioritization was based on not only the competencies of the actors but also the requirements of future demonstrators and products to be developed within business renewal and current business nets, respectively. Funding agencies identified this consensus-based prioritization and created funding mechanisms for low TRL programs.

Hence, we argue that in business renewal and emergent nets, the joint prioritization of novel technologies becomes essential for coordinating the activities in earlier stages of technology development. Moreover, the selection and further development of these emergent technologies need to be aligned with major CoPS projects to attract the implementation of funding mechanisms and strengthen the competencies of universities.

In medium TRL, projects and programs were implemented to validate and test technological demonstrators in the form of breadboards, components or prototypes in a laboratory or relevant environment (Mankins, 2009). These projects were mainly constituted by actors of renewal nets (Möller *et al.*, 2005), such as SMEs and industry, and were co-funded by public funding agencies. Many were implemented in a national context, to prepare for later participation in international programs, and as a crucial step to enter the product development phase with CoPS projects. Indeed, in one of FLUD's subprojects, Saab achieved TRL 3 in a vehicle cooling system, enabling Saab to change its position in the renewal net by becoming the working package leader in Clean Sky, aiming to achieve TRL 4–5 for this same technology.

The results suggest that the implementation of medium TRL programs needs to be aligned with future products envisioned by leading firms in current nets and use new technologies developed in renewal and emergent nets. In addition, in renewal nets, the joint prioritization of demonstrators works as a crucial coordination mechanism to attract funding for medium TRL projects and support SMEs to become established suppliers.

The relation between the national FLUD program and the European program Clean Sky further highlights the dynamics of shaping and reshaping of networks that benefit the involved actors in different ways. Within FLUD, the current business networks centralized around Saab and GKN formed a business renewal network that carried out projects aimed to raise the TRL of several technologies to level 5 or 6. Some of these projects led to emergent networks centered around a technology, such as cooling, involving new actors. The participation in the national business renewal network for aviation industry then became a steppingstone for Saab to become a member of one European business renewal network for aircraft within Clean Sky, and similarly GKN for aircraft engines. These networks are part of the European aviation industry business renewal network Clean Sky with the intentional outcome to provide an industry-wide response to sustainability issues based primarily on orchestrated coordination. Each of these networks includes components of current business networks (e.g. Airbus central in Clean Sky, and Saab and GKN in FLUD) and emergent networks (e.g. are technologies such as battery technology and electrification explored based on technologies that originate outside the aviation industry). Consequently, the case provides insights into the intricate dynamics of coordination within and across business renewal as well as emerging nets, extending perspectives on strategic nets (Möller and Rajala, 2007) as well as illustrating the interaction of different types of networks (Rubach *et al.*, 2017). Further, it highlights the challenges of CoPS where the different types of networks use more and less coordinated activities reshaping and interacting dynamically, beyond existing stable networks. This indicates the necessity to understand coordination as the intertwinement of different types of network logic, including constructed and emergent activities of the actors involved (Häkansson and Waluszewski, 2012), toward long-term outcomes for the whole network (Valkokari, 2015), yet materializing in different ways for different actors.

In later stages, CoPS projects were managed by leading firms to integrate mature technologies into a new product, to test and evaluate it for delivery to the user (Mankins, 2009). These projects were usually executed by actors in a current net (Möller and Halinen, 2017), where established suppliers of stable and mature components and subsystems participate together with customers. Some of these suppliers were once SMEs that were involved in medium TRL programs of the past, and are, at the present, part of the supply chain of Saab. This situation indicates a change in the position of the current network, with Saab and suppliers involved in the development of the envisioned product.

In summary, the CoPS literature acknowledges the importance of technology development coordination to direct innovation (Davies *et al.*, 2011; Davies and Brady, 2000; Prencipe, 2003). Our study contributes to this literature by offering an understanding of the dynamics of and tools used for coordination in networks. We found that technology development can be coordinated within the technological and the business dimensions and through different strategic nets logics:

- Within the technological dimension: key technologies are identified; their maturity assessed; low and medium TRL projects are implemented and aligned to a common product or product portfolio for a future evolved business network.
- Within the business dimension: a common long-term vision is presented to align the outcomes across CoPS projects, a research agenda is created to mobilize the key stakeholders and emergent technologies and demonstrators are jointly prioritized.

In Table 5, the coordination of technology development in these two dimensions is summarized.

Moreover, as a tool for coordination by orchestration, prior studies about agenda construction argue that agenda-setting is a necessary condition for mobilizing a net of actors for developing new business fields (Möller, 2010) supported by policy-related activities (Calignano *et al.*, 2018). However, research on this topic lacks the perspectives of CoPS networks, such as aerospace, led by one or a few leading firms and stakeholders, with a central common vision, that need to coordinate strategic nets. Agenda construction has been discussed mainly around emergent nets (Moller, 2009; Möller and Halinen, 2017; Möller and Rajala, 2007), with less attention to renewal and current nets and the interplay between these different types of nets and their co-existence.

Therefore, our findings complement this view by focusing on agenda construction in the context of CoPS networks, e.g. few leading firms and stakeholders having a strong influence over their network and in need to synchronize the work of different value systems from all strategic nets for the long-term relevance of the industry. In IMP-related industrial network studies, agenda construction has been suggested to drive the common outcomes of emergent networks (Rubach *et al.*, 2017). In this view, the perspectives and goals of each of the actors can, for the particular intended outcome, be aligned toward a collective interest. Projects have found to be an important mechanism, different than discussed in current CoPS literature (Davies and Hobday, 2005) ensuring that desired resources are used across the different types of networks (Rubach *et al.*, 2017; Möller and Rajala, 2007).

Hence, we suggest that agenda construction in CoPS settings can influence novel technology development when it mobilizes all strategic nets toward simultaneous coordination, aligned with common goals and objectives for the particular intended outcome. The case study shows that such simultaneous coordination of current, renewal and emergent nets seem to require:

- a common vision on the future CoPS and related product portfolio;
- a consensus-based prioritization of technology demonstrators, aligned with the vision on the future CoPS; and
- a consensus-based prioritization of technology development, aligned with prioritized demonstrators.

6. Conclusion

By exploring how technology development can be coordinated to support CoPS innovations in networks, we argue that our findings add valuable insights to the CoPS literature, which is often focused on product development rather than technology development, projects as coordination mechanisms in CoPS delivery and relatively stable networks (Davies *et al.*, 2011; Davies and Hobday, 2005; Prencipe, 2003). Current research on CoPS often recognizes that the survival and growth of a firm depend on a CoPS firm ability to coordinate innovative projects that are usually implemented at early stages of technology development (Davies and Brady, 2016; Moody and Dodgson, 2006). Our findings contribute to this literature by showing the dynamics of and interactions between different network logics. In addition, it is showed how CoPS projects can be implemented through agenda construction. This leads to the synchronization of resources and the deployment of long-term strategic activities that are shaping innovation. The development of the agenda supports not only the alignment of focus and priorities but also potentially supports the identification of what areas to address according to what strategy (within current business, business renewal or emergent networks) and who should be involved (a subset of current actors or any new actors) (Valkokari, 2015). As such, the insights offer a novel and integrative view of how the short-run and long-run strategies of leading firms (Prencipe, 2003) and other actors can be aligned.

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Table 5 The coordination of technology development in technological and business dimensions

Dimension	Emergent nets	Renewal nets	Current nets
Business Dimension	– Universities have crucial participation in low TRL projects, which are usually funded by leading firms and funding agencies – Actors usually aim to improve their position aiming to participate in medium TRL projects nationally and internationally – A research innovation agenda usually lobbies for the creation or continuation of these projects aligned to a common vision (target product) to attract investments from funding agencies and attract other potential participants such as universities and SMEs – Emergent technologies are jointly prioritized – leading firms usually coordinate these projects, influencing the research direction, but also adapting to the competence of local universities and research institutes	– Multiparty R&D projects in medium TRL are formed mainly between firms (sometimes competitors), funded by these firms and funding agencies – Actors on national projects usually seek to participate in international projects – Bridging borders between SMEs and universities – A research innovation agenda usually emphasizes these projects as a bridge between scientific knowledge and new products in the market. Aligned to a target product, the agenda lobbies for investments in these projects to attract investments from funding agencies nationally and internationally – Technological demonstrators are jointly prioritized – Leading firms usually have a coordinating role in national and international projects that have several funding sources, such as international companies, funding agencies and governmental bodies	– New product development projects in high TRL managed by leading firms with the participation of suppliers and customers – A research innovation agenda sets an envisioned target product or product portfolio – Projects in high TRLs are usually implemented by leading firms "in house", giving them full control of the R&D
Technological Dimension	– Emergent technologies are identified and selected based on future demonstrators and on target products – Low TRL projects currently on levels 2 or 3 are implemented to raise the TRL of emergent technologies to levels 3 or 4	– Technological demonstrators are identified and selected based on future target products and on emergent technologies developed – Medium TRL projects currently on levels 4, 5 or 6 are implemented to raise the TRL of technological demonstrators to levels 5, 6 or 7	– One or few target products are selected – High TRL projects currently on levels 7 or 8 are implemented to raise the TRL of target products to levels 8 or 9

Likewise, we argue that our study is also relevant to the strategic nets literature (Möller, 2010; Möller *et al.*, 2005; Möller and Halinen, 2017; Möller and Rajala, 2007; Valkokari, 2015), which often discusses strategic nets as standalone networks, lacking an integrative view of how these nets evolve and can be coordinated simultaneously. By including the concept of TRL, we offer an alternative way to look at strategic nets and to show how strategic intention enables their parallel functioning and co-evolution (Valkokari, 2015). By showing how the different projects and programs of the Swedish Aerospace Network, with different TRL targets and value systems, were connected (Figure 3), we can argue that strategic nets co-evolve when their related projects are connected and advance in maturity and their actors change their network position (Figure 4).

In addition, even though this study focused on the strategic net perspective, we also contribute to the wider literature on industrial networks, by showing how activities with intended outcomes, emergent activities and mechanisms such as an agenda construction can influence and shape emergent networks without necessarily destroying the potential for exploration and generative learning (Håkansson and Ford, 2002). Hence, the outcomes of projects in low or medium TRLs can perhaps be considered as being the interface between emergent and constructed networks as conceptualized by Rubach *et al.* (2017), connecting the different types of initiatives in different strategic nets. It follows that CoPS networks can be viewed as PNO (Manning, 2017), that relate the emergent communities and interactions of diverse actors to project-based firms with some degree of control over established and matured businesses.

As the coordination of technology development, intending to direct innovation, is a joint endeavor, the adoption of a network perspective in this study allows us to draw important implications for three types of key actors of CoPS networks.

First, leading firms, as a hub of strategic nets, have an important role not only for aligning efforts in their networks but also to show this alignment to potential investors and stakeholders and attract funding for technology development

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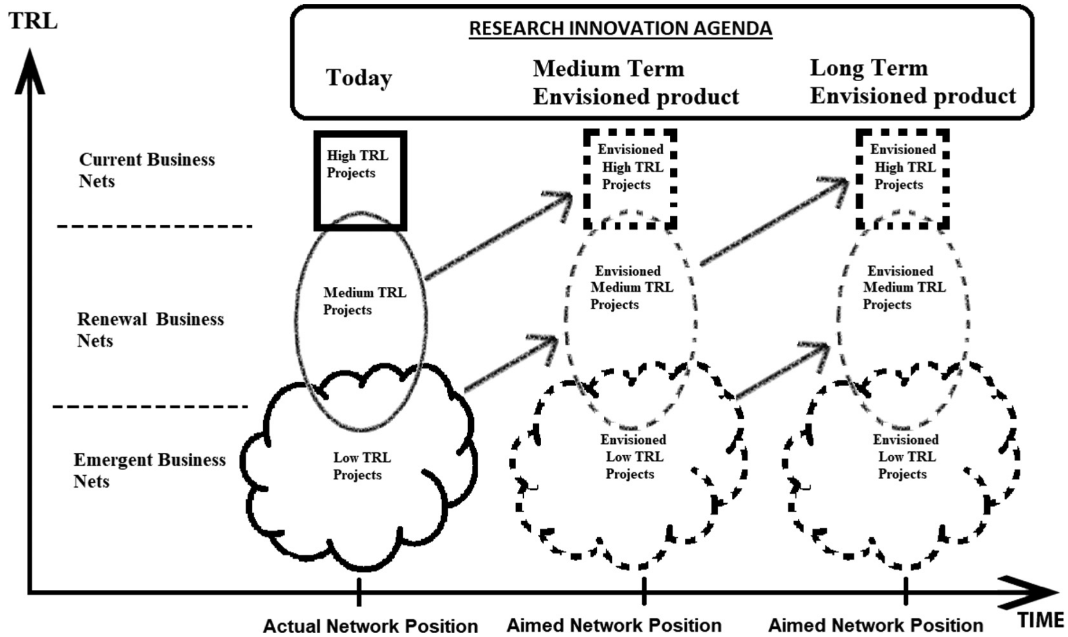
Figure 4 Co-evolution of strategic nets in CoPS developments



projects. Hence, they need to communicate their product aspirations and business vision that allow for concretization in discussions with key stakeholders forming a common research agenda and reaching consensus on the prioritization of technologies and demonstrators.

Second, universities with research in areas related to the key technologies may coordinate technology development, especially at low TRL levels. Universities can participate in and contribute to the creation or updating of a common research agenda.

Third, funding agencies, even though they do not participate directly in the creation and updating of research innovation agendas, can incentivize and support agenda-related activities.

Finally, our findings stem from analyzing one case in a Swedish context and the aerospace sector. Consequently, and as expected from case studies, our case might not be representative of all CoPS industries. Further studies could test our findings by investigating other contexts. Also, our attempt to broaden our understanding by collecting more data from other stakeholders was limited. The diversity of stakeholders in CoPS nets follows the length of its life cycle.

Therefore, other perspectives were outside the scope of our study, such as customers and established suppliers that sign large contracts with leading firms and have a high influence on the selection of target products. These players are important actors in current nets, where product development is more intense than technology development. Even though this paper focused on technology development, we found that its "coordination by enabling" (Ritala, 2012) is highly dependent on a common vision that comes mainly from the stable and well-defined value systems of current nets (Möller and Rajala, 2007). Hence, future research might find new insights by investigating the "coordination by commanding" (Ritala, 2012) that is more likely to happen in current nets.

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