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Managing integration in complex product systems: The experience of the IR-150 aircraft design program

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ABSTRACT

The design of a modern aircraft as a complex product system (CoPS) requires a broad range of knowledge in various fields of science and engineering that often exceeds the capability of a single firm. Effective innovation networks are indispensable for executing CoPS projects, but integration among the main project players is a challenging issue. This paper addresses two main CoPS integration problems: (i) the structure and integration mechanisms of an innovation network, and (ii) the necessary capabilities of an integrator. These problems are examined within a single case study that looks at the design phase of the IR-150 Aircraft, which is the first passenger plane designed using the capabilities of Iranian firms. In the product design phase, 12 crucial challenges were identified, and subsequently, led to the development of 17 integration tools by the project management team. Some of these tools were utilized in other similar projects, such as Boeing Dreamliner 787, while others were exclusively related to the IR-150 project. The main project findings relate to the integration of players' knowledge and capabilities, funding and distribution of financial resources, policy-making and regulation in CoPS innovation networks, and highlight the need to carefully consider the dynamics of CoPS projects, the deep linkages among network players and their activities, and the uniqueness of integration tools, in order to successfully manage such projects, especially in developing countries.

1. Introduction

Complex product systems (CoPS) are characterized by customized, interconnected components that have high cost, are produced in low volume, require a wide range of knowledge and capabilities, and involve multiple players (Sauser, 2008). Aerospace systems, telecommunications systems, and offshore oil and gas equipment can be included in this category. CoPS are different from mass-produced commodity products, such as cars, semiconductors and consumer electronics (Hobday, 1998). They can account for a significant percentage of a nation's industrial investment (Dedehayir et al., 2014) and also for a significant value added to a country's GDP (e.g. 11%, according to Moody and Dodgson, 2006 or 19% of the United Kingdom's GDP for manufacturing and construction at the end of the 1990s, according to Acha et al., 2004). CoPS also have a high impact on other product categories (Moody and Dodgson, 2006).

CoPS imply a vast array of knowledge to produce the significant number of customized components and whole products (Hobday, 1998). For example, the production of a modern aircraft requires a broad range of knowledge in new materials, software technologies, fluid mechanics and communications systems. Although CoPS are typically purchased by a single user, the vast knowledge base needed to manufacture these products often exceeds the engineering capacity of a single firm, necessitating their supply by a temporary project-based network of companies (Dedehayir et al., 2014). This network includes specialist suppliers, subcontractors and system integrators, as well as overseeing organizations, such as governmental and regulatory agencies (Hobday et al., 2005a,b).

As CoPS producers do not have all the skills and resources to manage all technologies and requirements needed, external sources are a crucial issue in CoPS projects (Gunawan et al., 2002). A wide range of theoretical explanations have been developed to investigate issues related to the increasing number of firms relying on external sources and their integration (Gunawan et al., 2002). Some of these theories include technological collaboration (Dodgson, 1993), strategic technology partnering (Hagedoorn, 1993) or innovation networks (Wissema and Euser, 1991). In spite of many advantages arising from the distribution of activities within innovation networks, the integration of activities

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into an interconnected system is a challenge for researchers and managers. Some research was done on the needs and mechanisms of integration in CoPS projects (Gunawan et al., 2002; Brusoni et al., 2001; Brusoni and Prencipe, 2001; Davies and Brady, 2000; Hobday et al., 2005a,b; Dedehayir et al., 2014).

In addition, integration difficulties are increased by some characteristics of developing countries like Iran. For example, the lack of large, specialized and integrator firms, the lack of experience and the shortage of financial resources to do these projects, as well as the weak integrated regulatory system are some particular problems that may prevent developing countries from being successful in CoPS development. There are very few studies dealing with a latecomer's success in developing CoPS (Park and Kim, 2014).

This article addresses two main problems of integration in CoPS innovation networks: (i) the structure and integration mechanisms of an innovation network, and (ii) the necessary capabilities of an integrator in CoPS projects. To answer these research questions, the case study of the design phase of the Iranian regional jet airplane IR-150 was chosen. This product involves advanced technologies, and its development required a deep collaboration and integration efforts among different players across Iranian and foreign firms. The IR-150 airplane represents a breakthrough product as it is the first passenger plane designed and built using the capabilities of Iranian firms as a developing country. The qualitative study of this distributed, complex project provides an excellent context for examining a CoPS innovation network and its players' integration.

Different types of integration challenges faced by this product were explored, and a description is provided of the ways in which these issues have been solved, emphasizing the process of building CoPS project integration capability. In the given context, in addition to traditional mechanisms, some other interesting integration mechanisms could be identified. Our research focuses on different integration dimensions in developing the product, and our empirical findings contribute to a better understanding of the CoPS integration capability, adding to the largely theoretical debate around this issue.

The remainder of the paper is structured as follows: Section 2 presents relevant literature to the topic. Section 3 is devoted to methodology. Section 4 presents the analysis of the case study and its results, and finally, Section 5 provides a discussion and conclusions of the study.

2. Research background

CoPS are designed, developed and produced by several firms that often operate in a market oligopoly, and are user-specified rather than market-driven, with a high degree of user involvement (Moody and Dodgson, 2006; Gunawan et al., 2002). The user-driven characteristic comes mainly from the fact that, in contrast to many mass-produced systems that are commercialized to meet specific market needs and dynamics, CoPS production only begins after an order from a user has been placed, and follows specific user requirements. This results in a customer-pull, rather than a supplier-push trend in generating innovative products. The capabilities required to manufacture these products often exceed the ability of a single firm, and necessitate their supply by an innovation network of capable companies (Davies and Brady, 2000; Brusoni et al., 2001). Research on networks argues that the main benefits of such networks come from resource sharing and access to information spillovers (Ahuja, 2000). However, in spite of different network advantages, integration and convergence of network actors' activities have always been key issues in CoPS research. Different studies focused on various aspects of integration in CoPS projects (Brusoni et al., 2001; Brusoni and Prencipe, 2001; Davies and Brady, 2000; Hobday et al., 2005a,b).

These studies can be classified into two main categories. The first category looks at the network structure and integration mechanisms, and the second at the capabilities of network integrators.

In the first category, some studies explored the division of work within the networks. For example, Kotta and Srikanth (2013) investigated the activity distribution in the innovation network of Boeing Dreamliner 787, while Gulati et al. (2009) examined long-term collaborations, prior relations and cultural proximity that can facilitate the integration of network activities). In regard to knowledge integration mechanisms, a large amount of research has underlined the difficulty in integrating knowledge across locations and firms (e.g. Mudambi, 2011). Kotta and Srikanth (2013) highlighted three sets of integration tools, including: (1) co-locating the project players' engineers, (2) leveraging relationship-specific assets (RSA) developed in prior interactions, and (3) using modular product architectures. Working within the same environment facilitates the integration process among different players via enhanced transfer of experience, in-depth communications and more shared understanding (Olson et al., 2002; Kotta and Srikanth, 2013). Research suggests that when exchange partners create RSA such as the development of a common language, interaction routines and a better understanding of partner decision-making procedures, they are more effective in knowledge and capability integration (Gulati et al., 2009). And finally, another important approach to integrating supplier knowledge is a reliance on modular product and organization architectures. Although these tools have many advantages, they are not always effective to solve the unique integration challenges of CoPS programs. Integration tools designed to manage such programs are limited. High cost (Kotta and Srikanth, 2013), technological uncertainty (Zirpoli and Becker, 2011) and changes to the program task requirements (Garud and Munir, 2008) can preclude co-location, modularity and RSA tools, respectively. As Table 1 indicates, most of prior research was done on players' knowledge and technology (capability) integration and did not focus on other aspects of integration mechanisms, such as financial and regulatory integration. But, in fact, CoPS actors should leverage institutions and policies to be able to foresee future trends and regulate the economic, technological and social environment because the CoPS market is heavily regulated or controlled, (Park, 2012). Furthermore, because of high costs with long product cycles in CoPS projects, it is necessary to set an integrative financial program which is sustainable and efficient for a long product cycle.

In the second category that focuses on integrator firms, some studies investigate the role of integrators and the specific capabilities they need to handle a successful CoPS project (Brusoni and Prencipe, 2001; Park, 2012). Prencipe (2003) argues that system integrator firms configure the network in terms of number, type (direct and indirect), and intensity of relationships. Brusoni and Prencipe (2001) argue that systems integrators have to be knowledgeable in different technological fields, as well as in different activities such as conceptual design, detailed design and manufacturing. Ability to design the entire system, most key components and assemble components interface are some important capabilities of integrators (Prencipe, 2003). Other researchers argue that in addition to functional and strategic capabilities, integrators have to be capable in some other fields such as cost management, risk management, project management, conflict management and bid handling (Chandler, 1990), Davies and Brady, 2000).

This article considers simultaneously two different aspects of network integration: the structure and mechanisms of integration, on the one hand, and the integrator capabilities, on the other.

The framework presented in Fig. 1 draws attention to the initial configuration of these two integration aspects, the related challenges, the modifying tools and actions, and the general outcomes of the project over time, to reveal the integration tools of a CoPS innovation network in a developing country. The feedback arrows show the possible interactions among the different parts of the framework and also the dynamics of integration tools in different periods of the project. This framework provides guidance in studying different aspects of integration in CoPS innovation networks, especially in a developing country, by gathering evidence on the integration challenges and tools adopted to solve them, the contextual factors facing the players, especially the integrator, and the available data over time.