Artto, Karlos; Turkulainen, Virpi

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It takes two to tango: Product-organization interdependence in managing major projects

Karlos Artto, Virpi Turkulainen,

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It takes two to tango

Product-organization interdependence in managing major projects

Karlos Artto
School of Science, Aalto University, Espoo, Finland, and
Virpi Turkulainen
UCD College of Business, University College Dublin, Dublin, Ireland

Abstract

Purpose – The purpose of this paper is to develop further understanding of the interdependence between product and organization subsystems in the context of major projects by empirically elaborating the volume-variety matrix.

Design/methodology/approach – Projects are perceived as systems that include a product subsystem (the project outcome) and an organization subsystem (the temporary multi-firm organizational network that produces the project outcome). This study addresses product-organization interdependence by analyzing product and organization subsystem components in terms of their uniqueness and reuse across multiple projects. The empirical analysis focuses on four global renewable fuels refinery projects implemented by Neste from 2003 to 2011. The refineries are based on the same proprietary technology but are unique at the project level.

Findings – The findings indicate interesting interdependencies between product and organization subsystems when analyzed at the component level: the findings suggest both diagonal and off-diagonal positions in the volume-variety matrix. An example of an off-diagonal position is a reused organization subsystem component associated with a unique product subsystem component, meaning that choosing the same organization in a future project can be used for acquiring an improved and, thereby, unique product subsystem component.

Originality/value – The study elaborates upon the volume-variety matrix in the context of major projects. The findings related to off-diagonal positions in the matrix provide new knowledge on combinations at the component level where a reused organization can be associated with a unique product, and vice versa. This has direct implications for management of projects.

Keywords Product-organization interdependence, Project operations, Project subsystems, Uniqueness in projects, Volume-variety matrix

Paper type Research paper

1. Introduction

Projects are defined as "temporary endeavors, undertaken to create a unique product, service, or result" (PMI, 2017), while "major project" are projects producing highly complex systems (Maylor and Turner, 2017; Turner *et al.*, 2014)[1]. The products of major projects include power plants, railways, Olympic parks, airports, and other long-term assets (e.g. Gil and Tether, 2011; Hobday, 2000; Turner *et al.*, 2014). In recent decades, the number and importance of such major projects has continued to grow significantly (Browning, 2010; Bryde, 2003; Maylor and Turner, 2017) and in general we live in a "projectified world" (Geraldi *et al.*, 2011).

Projects can be perceived as systems, consisting of a combination of at least five subsystems: product, process, organization, tools, and goals (Browning *et al.*, 2006; Ramasesh and Browning, 2014). The product subsystem is the result of the project (product or service, such as airport or power plant), which itself is a system of components, while the process subsystem is the work done to achieve that and the organization

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subsystem consists of individuals, groups, teams, or other organizational units doing the work (Browning *et al.*, 2006; Ramasesh and Browning, 2014). Compared to manufacturing operations, a project's product is typically characterized as new and unique (Ramasesh and Browning, 2014) and its process is characterized by high variety and low volume (Davies and Frederiksen, 2010; Maylor and Turner, 2017; Oltra *et al.*, 2005). The organization – essentially the production system for creating projects – is a temporary network of for example engineers in a product development project (Gokpinar *et al.*, 2010) or a temporary network of multiple firms, including contractor firms and service providers, in the context of major projects (Artto and Kujala, 2008; Bryde, 2003)[2].

One of the key challenges in projects is how to match the organization subsystem to the product subsystem to ensure successful production of the project (Baldwin and Clark, 1997; Gokpinar *et al.*, 2010; Sosa *et al.*, 2004). This similar interdependence of product and organization is also established in one of the fundamental frameworks in operations management (OM) research in the manufacturing setting – the volume-variety matrix (Hayes and Wheelwright, 1979) – which Davies and Frederiksen (2010) elaborate and add projects to it, suggesting that high variety, unique project products are associated with one-off project organizations that develop and complete the product. The existing research on product-organization interdependence focuses on firm- or project-level analysis, suggesting that unique product is associated with a unique/one-off organization. This is challenging as we know well from practice that projects are not all-unique products produced by a one-off organization but can include product components that are similar across projects, which are completed partly by same network of organizations (e.g. Geraldi *et al.*, 2011; Oltra *et al.*, 2005). This calls for a more detailed investigation at the level of product and organization subsystem components, to develop understanding of the nature of product-organization interdependence in major projects.

This study addresses the question:

RQ1. How are product and organization subsystem components interdependent in the context of major projects when analyzed by the dimensions of their uniqueness vs reuse?

It elaborates upon the volume-variety matrix (Davies and Frederiksen 2010; Hayes and Wheelwright, 1979) in the context of major projects by analyzing the uniqueness and reuse of the components of project product and organization systems (Ramasesh and Browning, 2014; or "microstructures of projects" Engwall, 2003) across multiple projects. This elaboration is based on analysis of empirical data collected by a single embedded case study of four projects to design and build renewable fuel refineries planned and executed by Finland-based oil company Neste[3] to establish and expand its operations globally: two in Finland, one in Singapore, and one in the Netherlands (Rotterdam). This multi-project setting allows examination and comparison of project product and organization subsystems at the component level (Bendoly and Swink, 2007; Browning, 2010; Engwall, 2003)[4] by looking at the uniqueness and reuse of those components across projects. Product-organization interdependence is analyzed across five distinct project elements: automation system, hydrogen plant, catalyst system, pretreatment system, and reactor unit.

This study makes the following contributions. The study provides further understanding of project product-organization interdependence by elaborating the volume-variety matrix (Hayes and Wheelwright, 1979) in the context of major projects. Through a detailed analysis of project product and organization subsystem components, the study supports the argument that product and organization are interdependent in the project context (Davies and Frederiksen, 2010; Gokpinar *et al.*, 2010), while simultaneously giving more in-depth understanding of the interdependence of the project subsystems (Browning *et al.*, 2006; Ramasesh and Browning, 2014). The findings illustrate off-diagonal positions in the matrix when analyzed at the subsystem component level and we then provide explanations for these findings. The findings indicate that uniqueness of the product subsystem component is not necessarily associated with unique organization subsystem component. In this respect, these findings about off-diagonal positions are somewhat contradictory to Hayes and Wheelwright (1979). Providing explanations for such off-diagonal positions also supports the contingency view rather than the best practice view dominating OM and PM research (Boer *et al.*, 2015; Geraldi *et al.*, 2011; Ketokivi and Schroeder, 2004). And finally, whereas OM research has tended to focus on manufacturing operations, this study responds to the call for providing more detailed understanding of project operations (Maylor *et al.*, 2015).

2. Literature review

2.1 Product-organization interdependence

Building on the fundamental works on operations strategy by Skinner (1969) and operations processes by Woodward (1965) and Hayes and Wheelwright (1979) proposed that product and production process are tightly linked in the manufacturing context. The resulting matrix – the volume-variety matrix – is one of the fundamental frameworks of OM research. The matrix indicates that products and production processes vary from one of a kind (low volume) to highly standardized (high volume), and from highly flexible to highly standardized, respectively, and that product and process are tightly interdependent; for example, high volume, standardized products are produced by mass production or flow processes.

Hayes and Wheelwright (1979) focused on manufacturing operations and did not explicitly include projects in their discussion. Projects, however, could be placed in the matrix toward one end of the spectrum as being products with unique (low volume) to medium volume associated with medium to highly flexible (variety) processes (Maylor *et al.*, 2015; Oltra *et al.*, 2005). The volume-variety matrix has more recently been elaborated in the project context; Davies and Frederiksen (2010) suggested that projects represent a distinct process type in their own right, with a unique product and one-off temporary organization as the production system. The research by Davies and Frederiksen (2010) in the project context, however, takes a project-level approach, ignoring potential similarities or differences between project parts (see e.g. Engwall, 2003).

The prescriptive value of the matrix is widely established and it has been subjected to numerous tests (e.g. Ahmad and Schroeder, 2002; Helkio and Tenhiala, 2013; Safizadeh *et al.*, 1996; Schmenner and Swink, 1998). The matrix, however, has also been challenged (e.g. McDermott *et al.*, 1997), and most empirical studies have found no support for its performance implications (see literature review of Helkio and Tenhiala, 2013). Others emphasize only its descriptive nature (e.g. Schmenner and Swink, 1998).

Major projects and complex systems delivered by multiple firms and other organizations, each specializing in designing and completing specific component of the product (Brady *et al.*, 2007; Flyvbjerg *et al.*, 2003; Gil and Tether, 2011). Thus, a temporary organizational network as a one-off production system produces the project product (Artto and Kujala, 2008; Brusoni and Prencipe, 2006). Both early (e.g. Sayles and Chandler, 1971) and recent (e.g. Morris, 2013; Browning *et al.*, 2006; Engwall, 2003; Ramasesh and Browning, 2014) research suggests that projects can be seen as systems that include subsystems composed of components or "a large number of parts that interact in a nonsimple way" (Simon, 1962, p. 468). The components in product subsystems can be considered equivalent to product modules (Salvador *et al.*, 2014) and, similarly, the organizational subsystem includes organizational components. Similar to the project level, the components of product and organization subsystems are assumed to be interdependent.

2.2 *Product-organization interdependence in the project context*

This section presents a synthesis of the research addressing product-organization interdependence in the project context under three paragraphs with the following rubrics: the product determines the organization in the project context; organization determines the product in the project context, and; the connection between the product and organizational architectures.

Product determines the organization in projects. Since the inception of modern project management in the 1950s, it has been widely believed that a project's product is defined, designed, and pre-set in the initial plan (Gaddis, 1959), and only then is the project organization structured on "divisions organized around the end-product" (Morris, 2013, p. 23). Hence, there is a tight link between project product and organization; in addition, the organization is working on a pre-determined set of product specifications (Gaddis, 1959; Morris, 2013). This stream pays attention to establishing detailed product specifications in terms of, for example, the physical product and its functionality (Morris and Hough, 1987), capacity for creating long-term value in operations after the project's completion (Artto *et al.*, 2016; Morris, 2013), and outcomes that contribute to the overall business success (Shenhar *et al.*, 2001). These then allow the establishment of a detailed project plan in terms of organization, resources, and processes. This stream emphasizes the uniqueness of the end-product and adopts a product-centric view with detailed, pre-determined product specifications that are used to hold control over the production of this unique product.

Organization determines the product in projects. Another stream of research suggests that the organization determines the product, building on the idea of "vanguard projects" (Brady and Davies, 2004) and "designing in the making" (Artto *et al.*, 2016). This research suggests that mutual adjustment, negotiation, and interaction among actors and individuals in the organization – rather than a detailed plan – are required in projects with high system complexity and dynamism to enable finding the joint system-level direction and the path toward an appropriate end-product (Artto *et al.*, 2016). In a similar vein, Dvir and Lechler (2004, p. 1) argued that "plans are nothing, changing plans is everything," suggesting that the prescriptive approach and adhering rigidly to pre-established plans is not necessarily always appropriate. The general idea in relying on the project's organization – and not on the product and the plan – is the following: as projects are unique, the most valuable solution is not known, and accordingly, the end-product cannot be defined in detail at an early stage. Consequently, the project organization's task is to design the product, and the product-organization interdependence is intimately intertwined with the uncertainty related to both the end-product and the organization (e.g. Brady and Davies, 2004; Gil and Tether, 2011; Ramasesh and Browning, 2014). The project organization's activity of designing the product during the project is often associated with innovation, for example, developing a product jointly with the customer and supplier (Davies, 2004; Hobday *et al.*, 2005).

Connection between product and organizational architectures. Finally, studies on complex systems address product and organizational designs and their interdependence (e.g. Colfer and Baldwin, 2016; Gokpinar *et al.*, 2010; Sosa *et al.*, 2004). The research in this stream suggests that product-organization architectures are interdependent. This research focuses on three levels – project, firm, and industry – and often links to the mirroring hypothesis and the concept of modularity. At the project level, research focuses on the context of new product development (NPD) and suggests that creating a product architecture with appropriate modules, interfaces, standards, and design rules helps to establish an organizational architecture that is isomorphic with the product architecture, and this makes the NPD process more efficient and controllable (Baldwin and Clark, 1997; Sosa *et al.*, 2004) or that a mismatch between product architecture and organizational structure is associated with product quality problems (Gokpinar *et al.*, 2010). Research at the firm level builds especially on the classic mirroring hypothesis, concluding that technical dependencies and organizational ties mirror each other (Colfer and Baldwin, 2016; Henderson and Clark, 1990; Sanchez and Mahoney, 1996). This same argument about the mirroring of product and organization has also been extended to the industry level and transactional boundaries in a supply chain, concluding that the supply chain or industry structures mirror the technical architecture (Baldwin, 2008; Colfer and Baldwin, 2016; Sanchez and Mahoney, 1996).

2.3 Analysis framework

Figure 1 illustrates the analysis framework by using the form of a multidomain matrix (MDM) (Danilovic and Browning, 2007; Eppinger and Browning, 2012). The analysis framework builds on the volume-variety matrix (Davies and Frederiksen, 2010; Hayes and Wheelwright, 1979) as well as research on product-organization interdependence in the project context (e.g. Cleland and King, 1983; Gaddis, 1959), with a focus on the interdependence between product and organization subsystem components in a project when analyzed by the dimensions of the components' uniqueness vs reuse. The evaluation of a subsystem component's uniqueness vs reuse requires that the project is compared to other projects in the multi-project system.

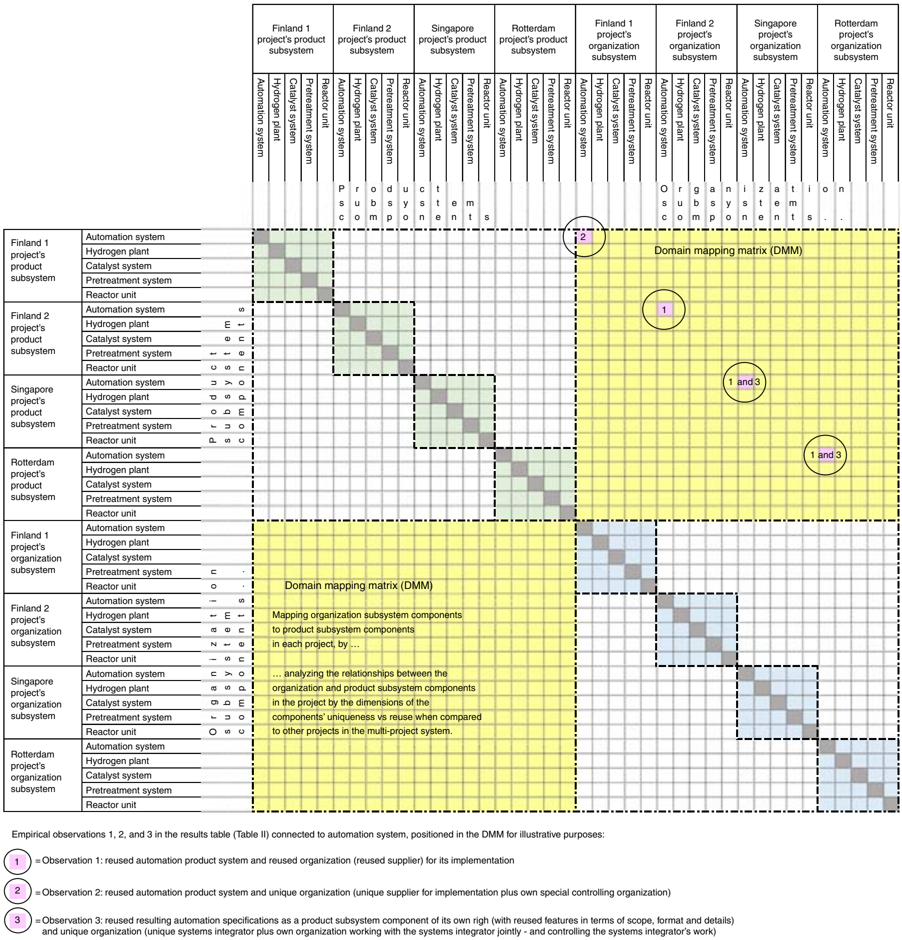

Figure 1. Analysis framework: relationships between product and organization subsystem components in four projects, illustrated through a multidomain matrix representation

The study adopts the view of projects as complex systems, composed of product and organization subsystems and their components (Browning *et al.*, 2006; Ramasesh and Browning, 2014); in Simon's (1962) terminology these "nearly decomposable systems" are defined as ones in which interactions among themselves are weak but not necessarily negligible. This view allows the product and organizational elements to be considered at a detailed subsystem component level and potentially reveals interesting findings about the interdependence of products and organization in the context of major projects.

Figure 1 illustrates the analysis framework and ties it to the setting in the present empirical study of four projects (Finland 1, Finland 2, Singapore, and Rotterdam) with five subsystem components (automation system, hydrogen plant, catalyst system, pretreatment system, and reactor unit). These entail product and organization subsystem components which are either unique or reused in the multi-project system. Even though we use the real names of the projects in our empirical study in Figure 1, as well as real names of the project subsystem components, we do this for illustrative purposes only. In other words, as Figure 1 is intended to illustrate our research setting at the conceptual level only, we submit the notion that the number of projects and number and content of project subsystem components will vary depending on the context. Figure 1 is a MDM representation with distinct design structure matrices for each project's organization and product. Our research question motivates the inquiry on interdependence of product and organization subsystem components when analyzed by the dimensions of their uniqueness vs reuse; these relationships can be positioned in the intersections of organization and product subsystem components of multiple projects in the domain mapping matrix (DMM) areas illustrated in Figure 1. To illustrate the idea of the MDM representation in Figure 1 further by notional examples from our empirical observations, we have indicated by circles (and observation numbers) how our empirical observations connected to the automation system (i.e. observations 1, 2 and 3 explained later in Table II) fall into project and component specific product-organization intersections in the DMM areas of the matrix.

3. Research method

3.1 Research approach

This study aims to develop the understanding of product-organization interdependence by analyzing project uniqueness at the subsystem level by engaging in theory elaboration research. The main idea is that a framework (Figure 1) is elaborated with empirical data in a specific context (Ketokivi and Choi, 2014). A theory elaboration approach is suitable when conceptual ideas exist that can be used as the basis of empirical research (Ketokivi and Choi, 2014; Lee *et al.*, 1999). This study elaborates on the volume-variety matrix, developed for manufacturing organizations, in the context of major projects (Hayes and Wheelwright, 1979) and analyzes project components. It builds on the assumption that projects include both unique and reused product and organizational subsystem components and examines how product-organization interdependence plays out at the component level.

Empirical data were collected following a single embedded unit case study design (Yin, 2009) for the following four reasons. First, the case study approach supports the aim of theory elaboration (Ketokivi and Choi, 2014). Second, a single embedded unit case study allows controlling for the effect of project management practices, company context, governance regime, company history, organizational culture in the management, and external context (Ryu *et al.*, 2008). Third, the case study design enables detailed data collection, and embedded design is well suited to developing in-depth understanding of interdependencies between project product and organizational components across projects. Only such an embedded unit design allows building on the assumption that projects include both unique and reused aspects of product and organizational components and enables comparing projects. Fourth, recent research on organization designs in general strongly recommends the use of qualitative studies when studying contemporary complex settings (Greenwood and Miller, 2010).

3.2 Case selection

The selected case firm is the global oil company Neste. Selection of the case firm and the embedded cases went hand in hand and was based on the underlying theoretical framework; the firm was chosen to enable the selection of embedded case projects that are unique but simultaneously similar enough in their technical or other aspects to facilitate comparative analysis. Neste provided a suitable research context in this regard because it started a new business in the renewable fuels sector and developed global operations in the business, engaging in several complex refinery projects, partly separate, partly parallel, and built refineries in multiple locations around the world. This allowed the study of multiple linked projects in real time. To facilitate access to data, the authors established a multi-year research project with Neste to study the theme of this paper and, accordingly, Neste committed to providing extensive access to the company and its projects.

Four refinery building projects are analyzed as embedded cases, named Finland 1, Finland 2, Singapore, and Rotterdam according to their geographical locations. Such globalization of operations in a multi-project setting is well suited to the present study: the projects are similar in terms of the basic process technology and hence require similar discipline-related process knowledge and technical knowledge. This facilitates comparison of the projects (Figure 1). However, the selected embedded cases also differ in many characteristics, for example size, geographical location, product requirements, and organizations of varying suppliers. The four embedded cases facilitate analysis of uniqueness and reuse in project product and organizational subsystem components, while simultaneously, the small number of embedded cases facilitates a rich and detailed analysis. In each of the embedded case projects, five distinct project parts were analyzed: automation system, hydrogen plant, catalyst system, pretreatment system, and reactor unit. Together these five parts form the central technical and functional core of the refineries and are key parts of the projects.

3.3 Research context: Neste and the four embedded case projects

Neste focuses on oil refining and marketing, specializing in low-emission, high-quality traffic fuels. At the time of the research it had three main business areas: oil products, renewable fuels, and oil retail. The company's strategy has been based on growing both its oil refining and premium-quality renewable diesel businesses. Neste has a market capitalization of around 15 billion euros, an annual turnover of around 15 billion euros, and employs around 5,000 people. The four embedded case projects analyzed in this paper together embody Neste's response to the EU directive on the promotion and use of biofuels for transport[5]: setting a goal to become the world's leading supplier of renewable diesel and subsequently developing multiple refinery projects in the renewable fuels business. Neste aimed at gaining quick entry to market with small-scale production and rapid expansion of production capacity on a global basis. Figure 2 illustrates the timeline for the projects.

3.4 Data collection

The case study included a real-time study of the projects to expand operations globally and simultaneously develop the new product and process technology by selecting more advanced and improved technical product solutions from project to project. Data were collected via several methods. Primary data were collected via semi-structured interviews (Patton, 1990). Altogether, 36 interviews were conducted with 28 key individuals involved in the studied projects, including senior managers, project directors, and project managers in Neste's organization, as well as managers in its engineering subsidiary RefineryEng (pseudonym). Interviews were conducted in four rounds between October 2009 and June 2012, during which the projects' operations were ongoing. Most of the interviews (32/36) were conducted in-person

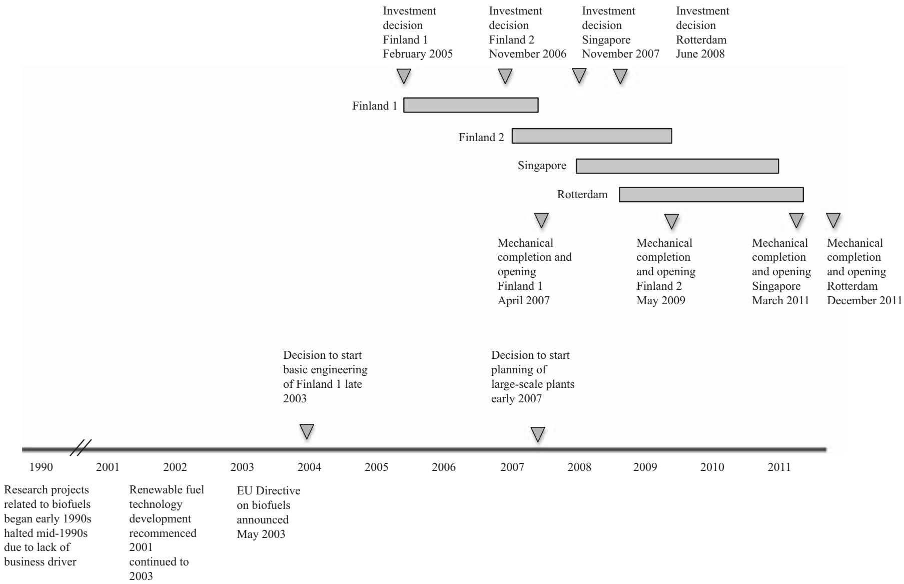

Figure 2. Timeline of the four embedded case projects studied at Neste

at the sites and access to the facilities was granted, allowing an understanding of the project operations. Four of the interviews were phone interviews. Details of the interviews are presented in Table I. The interviewees were selected based on their central role in designing and implementing the embedded case projects or making central decisions concerning them. After identifying the key individuals, snowball sampling was also used. The need to gain access to data during the implementation of projects was also considered; hence, six individuals were interviewed twice and one individual was interviewed three times over the project lifecycles. Interviews involved open-ended questions on interviewee's professional background, previous and present roles in Neste's organization and its projects; details of the projects in which the interviewee was involved, management of projects, potential project-to-project interdependence, project subsystems with a special emphasis on their product and organizational designs, project lifecycles and stakeholders, choices of suppliers in and between projects, technical product solutions and how they have been developed in projects and from project to project, and internal and external project organization and environment. In addition to the interviews, project documents, such as project descriptions and organizational charts, as well as the company's website, reports, post-project evaluations, press releases, and articles in the press were used as complementary material.

Several procedures were implemented to ensure high reliability and validity of the data. First, a research protocol was developed based on the theoretical framework to ensure systematic data collection and to enhance validity (Yin, 2009). The research protocol included discussion topics and interview questions, but to foster dialog and allow the interviewees to describe the phenomena without being constrained by the questions, interviewees were frequently asked for clarification and posed more detailed questions. However, the research protocol was modified over the course of the study based on the expertise area of the respondent. Second, at least two members of the research team conducted each interview; one led the interview and the other member(s) took notes to ensure detailed capture of the content (Eisenhardt, 1989). Third, a case study database was developed to facilitate data transparency and enhance reliability (Yin, 2009). Fourth, interviews were recorded and transcribed into text to enhance data quality and validity (Voss *et al.*, 2002). Fifth, although some data was collected

No.	Position in the organization; and project-related role	Date	Min.	Pg[a]	Rd[b]	i[c]
1	Business development manager, renewable fuels BU; business development of Rotterdam	November 19, 2009	78	12	1	i01
2	Section manager, plant engineering department; project manager, Finland 2	November 24, 2009	55	17	1	i02
3	Project manager, Finland 2	November 24, 2009	86	21	1	i03
4	Manager, renewable fuels BU; business development of Finland 1, Finland 2, Singapore, and Rotterdam	November 25, 2009	103	20	1	i04
5	Manager, technology office; coordination of technology in Singapore and Rotterdam	November 25, 2009	58	10	1	i05
6	Director of business development and strategy, Neste; business development of Finland 1, Finland 2, Singapore, and Rotterdam	November 26, 2009	90	18	1	i06
7	Manager, renewable fuels BU; business development of Finland 1 and Finland 2	November 26, 2009	80	19	1	i07
8	Engineering manager, Rotterdam	November 26, 2009	112	20	1	i08
9	Senior vice president, Neste; business strategy related to Finland 1, Finland 2, Singapore, and Rotterdam	December 7, 2009	79	15	1	i09
10	Process design manager, Finland 1; process design manager, Singapore	December 29, 2009	110	20	1	i10
11	Engineering manager, Rotterdam	December 3, 2009	115	16	1	i11
12	Project manager, Rotterdam	December 21, 2009	115	25	1	i12
13	Business unit manager, renewable units BU; business related decision-making with Finland 1, Finland 2, Singapore, and Rotterdam	March 2, 2010	95	19	1	i13
14	Project manager, systems integrator's organization, Rotterdam	May 10, 2010	64	14	1	i14[d]
15	Project manager, Singapore	April 12, 2010	48	10	1	i15[d]
16	Managing director, Singapore	April 12, 2010	46	10	1	i16[d]
17	Project manager, systems integrator's organization, Singapore	May 20, 2010	58	10	1	i17
18	Safety manager, Finland 1, Finland 2	May 12, 2010	98	23	2	i18
19	Design manager, Singapore	May 12, 2010	102	24	2	i19
20	Project manager, Singapore	May 16, 2010	93	23	2	i14
21	Project manager, Finland 2	May 16, 2010	83	22	2	i03
22	Manager of licensor services, technology office	May 16, 2010	114	24	2	i20
23	Director of business development and strategy, Neste; business development of Finland 1, Finland 2, Singapore, and Rotterdam	May 17, 2010	93	18	2	i06
24	General manager, technology office	May 17, 2010	75	13	2	i01
25	Manager, technology office	May 17, 2010	66	11	2	i21
26	Manager, technology office	May 17, 2010	48	16	2	i22
27	Project manager, Rotterdam	May 18, 2010	129	26	2	i12
28	Managing director, Singapore	May 20, 2010	63	12	2	i15[d]
29	Deputy project manager, Rotterdam	May 26, 2010	59	13	2	i23
30	Human resources manager, renewable fuels BU	November 10, 2011	73	21	3	i24
31	Manager, renewable fuels BU; business development of Finland 1 and Finland 2	May 16, 2010	98	28	4	i07
32	Manager of systems integration, Singapore	May 21, 2010	118	21	4	i14
33	engineering manager, Rotterdam	June 5, 2012	45	13	4	i25
34	Managing director, Rotterdam	June 5, 2012	48	11	4	i26
35	Engineering manager, Rotterdam	June 5, 2012	44	13	4	i27
36	Manager, technology development; engineering manager, Rotterdam; technical manager, Rotterdam; NEXBTL development since 2003; technology development of Finland 1, Finland 2, and Rotterdam	November 11, 2012	80	20	4	i28

Notes: [a]Transcribed number of pages; [b]interview round; [c]interviewee number; [d]phone interview

Table I.
Details of data collection interviews

retrospectively, most of the interviews focused on ongoing projects to avoid recall bias and to enhance data accuracy (Miller *et al.*, 1997). Archival data were also collected, such as various project documentations. Combining both a retrospective approach and a real-time approach provides a rich picture of the case projects and how Neste globalized its operations through these projects and also allows triangulation in the data analysis process. Sixth, the aforementioned primary and archival data were analyzed to facilitate triangulation and enhance validity (Barratt *et al.*, 2011; Voss *et al.*, 2002; Yin, 2009). Finally, after initial analysis, findings were presented to key knowledgeable persons in the company to validate the findings (Voss *et al.*, 2002). The participants concurred that their experiences were consistent with the study's conclusions.

3.5 Data analysis

Following the guidelines of qualitative research (Patton, 1990), the data were analyzed as text. The analysis was conducted in multiple parts, within-case and cross-case at both the project and subsystem component levels (Eisenhardt, 1989). The focus of the analysis at the project level was to develop an overall understanding of the projects; the within-case analysis focused on developing a narrative and a detailed understanding of the inherent characteristics as well as the product and organization of each project part. This was followed by cross-case analysis.

Within-case analysis was also carried out at the subsystem component level focusing on developing understanding of the product and organizational subsystem components. According to the logic of theory elaboration research, the theory and data were constantly compared (Ketokivi and Choi, 2014). This meant that attention was paid to any data related to product and organizational subsystems or their components, which was collected in spreadsheets. This facilitated comparison and identification of features related to reuse or uniqueness of the product and organizational subsystem components and subsequent identification of interdependencies between them. In terms of the organizational subsystem, the analysis focused on the inter-firm organizational network responsible for delivering the project part (e.g. who the suppliers were).

During the within-case analysis, all data were first combined that related to the projects as well as the product and organizational subsystem components. Key facts were established for each project, including size, purpose, technical and product-related data, stakeholders, suppliers, and important dates and activities during the project; these facts were established mainly based on archival data. The interviews were then analyzed. Based on these analyses, extensive case reports and spreadsheets were generated for each embedded case project as well as the product and organizational subsystem components within the projects. These embedded case reports and spreadsheet databases explicitly note product-organization interdependences at the component level. The cross-case analysis compared the embedded case projects and their product and organizational components to identify patterns. It was noted whenever data indicated a similar pattern across projects and their components and differences between the projects and their components were also noted. This process was iterative; whenever a new type of interdependence or connection between product and organizational subsystem components was observed in a single project, this observation was brought back and compared with the previous case projects.

4. Analysis and synthesis

The following first presents a brief project-level analysis of the four projects: Finland 1, Finland 2, Singapore, and Rotterdam. Then next section analyzes the uniqueness and reuse in product and organizational subsystem components of the five project parts in each of the four projects to develop understanding of the interdependence between project product and organizational subsystem components.

4.1 Project level analysis

At the project level, from Neste's perspective the four projects: Finland 1, Finland 2, Singapore, and Rotterdam are unique in terms of their product and organization. The capacity of Finland 1 and Finland 2 refineries is 380,000 ton/a, whereas Singapore and Rotterdam refineries have a capacity of 800,000 ton/a each. The technical solutions that work in smaller scale refineries are not always feasible in larger-scale refineries, which lead to uniqueness in product designs. Learning from previous projects and from operation of the refineries, combined with continuous development of technologies during the long implementation period of the four projects, led to many technological innovations and new and different elements and technologies to be used in the later projects. Furthermore, contextual factors of the different geographical locations required uniqueness: for example, the nature and quality of the raw material varies across the refineries, implying that the requirements for production process specifications are different; hence, the refinery building projects differ from each other in terms of the product subsystem. Furthermore, differences in local regulations and requirements imply adoption of unique product designs.

Each of the four projects was managed and organized differently and also had an internal organization of its own. In Finland 1 and Finland 2, the site personnel of the existing Porvoo refinery site participated in Neste's project organizations of those specific projects. Singapore and Rotterdam were staffed separately selecting and assigning capable individuals to these two large international projects. Separate organizational bodies – owner's teams – were also assigned to both the Singapore and Rotterdam projects to serve as a support body for the project director of each of those projects. Furthermore, whereas Neste served as a systems integrator in the first two smaller scale projects, the organizational design changed for the latter two international large-scale projects: Neste made an agreement with a large international engineering firm, SysTech (pseudonym), for SysTech to serve as a systems integrator in these two large-scale plant projects. SysTech's involvement as a systems integrator naturally changed the organization and working practices in these two large projects, and the global dimension and SysTech's knowledge and relationships also had implications for which suppliers were selected from the international market arena to deliver to these different geographical locations. Therefore, different suppliers were often used in the projects, fostering the uniqueness of the organization across the four projects.

4.2 Analysis of product and organizational subsystem components

Uniqueness and reuse in the product and organizational subsystem components were analyzed across the five project parts: automation system, hydrogen plant, catalyst system, pretreatment system, and reactor unit.

Automation system. With regard to Finland 1, the requirement for the product design of the automation system was that the user interface and the information content concerning the process instruments were in accordance with Neste's standards and that they could be used in Neste's other plants. The automation system in project Finland 1 was delivered by a new supplier, AutoNew (pseudonym). Neste did not have a previous business relationship with AutoNew in delivery of plant automation systems. A previous partner, AutoTrad (pseudonym), was selected as the automation system supplier in Finland 2, Singapore, and Rotterdam. Many of Neste's own employees from their Porvoo refinery site were assigned to the project organization of Finland 1 and it was natural for the Finland 1 project organization to use a project process that Neste was accustomed to: in designing the automation, the plans are required to be more extensive in scope than what automation suppliers in the markets are used to. Neste used the global systems integrator SysTech in the Singapore and Rotterdam projects. Neste had to guarantee the reuse of the automation system's design through customized organizational processes, that is, by requiring the systems integrator SysTech to deviate significantly from its own standard practices and, accordingly, to adapt to integrating this broader scope of automation and to require from the automation system supplier this broader scope of work in the delivery process in its integration task as well.

Hydrogen plant. Because there is continuous need for hydrogen in the production of NEXBTL fuel, a typical solution for hydrogen supply in the plant projects was to build a separate hydrogen plant within the larger refinery to supply hydrogen to the production process. In Finland 1, the plant was designed capacity-wise to use the excess hydrogen from the existing hydrogen plant originally connected to another Neste refinery at the same refinery site. However, the hydrogen plant in Finland 2 was designed jointly with another investment for a traditional diesel plant at the same site, and therefore the design was based on receiving hydrogen from this newly invested hydrogen plant within the site. From the perspective of the organizational design, organizing included building technical interfaces and pipeline connections to the pre-existing plant, upgrading the plant for capacity, coordinating the timing with another process investment at the site, and more importantly, organizing the agreements concerning the sharing of the plant with another refinery in terms of joint maintenance, refurbishment, and modernization of the upgraded old hydrogen plant in the future. The product design of the hydrogen plant for Singapore and Rotterdam were quite different. Neste's original plan in both Singapore and Rotterdam was to build a hydrogen plant, but eventually, the hydrogen plants were not built at all by Neste; instead, the hydrogen supply was outsourced to an external hydrogen supplier, HydSup.

Catalyst system. The catalyzing process that takes place after the pretreatment of raw materials is central to successful production at the plants; the catalyst must be developed as a chemical compound to have ideal features to facilitate the production process. In Finland 1, Neste used an international catalyst supplier, CatSup (pseudonym), to deliver the catalyst system. The product design of the catalyst system was not ideal in the Finland 1 project. A lot of development effort was needed to enhance the product design of the catalyst system for the other three plants. A renewed catalyst was used in Finland 2, where the learnings from Finland 1 were taken into account. As the catalyst is critical to the production process, in addition to how the catalyst is used in the process, Neste participated in developing the catalyst jointly with CatSup while simultaneously developing its own production process to optimize the effectiveness and efficiency of the production process. In Singapore and Rotterdam, Neste then engaged in a deeper partnership with CatSup so that both parties were highly dependent on each other. In this partnership, Neste wanted to invest more of its own personnel and monetary resources into joint R&D and continuous improvement of the catalyst system, in order to guarantee an ever-improving and more unique catalyst system for the larger-scale Singapore and Rotterdam plants.

Pretreatment system. The raw material is processed in a pretreatment system at a NEXBTL plant in order to remove harmful impurities before the next process phases. The potential impurities that are left after pretreatment may hinder the effectiveness of the catalyzing process. It may be beneficial to run the plants with different raw materials, thus setting different requirements for the quality of the pretreatment system to cope with various qualities of the raw materials to be purified. The pretreatment system that Neste implemented in Finland 1 was originally based on licensed technology; the license was acquired from an agricultural company and the pretreatment system was based on a rather straightforward use of washing and centrifugation equipment. Neste used its own project organization to plan and design the pretreatment system in Finland 1. However, the design of the pretreatment system in Finland 1 proved to be insufficient to purify the raw material. In Finland 2, a different product design for the pretreatment system was used and the pretreatment was based on bleaching technology. Furthermore, with regard to the organization in Finland 2, an international supplier, PreRaw (pseudonym), was selected to bring in its technological know-how in implementing the pretreatment system in Finland 2 in combination with Neste. The Singapore project reused the product design of Finland 2's pretreatment system, but the system in Singapore has a larger capacity. With regard to the organizational design, the supplier PreRaw was reused in the Singapore project. Furthermore, PreRaw was also reused in the Rotterdam project for pretreatment system delivery, but the product design of the pretreatment system in Rotterdam was unique due to anticipated differences in the raw material. With regard to organizational designs carrying out pretreatment systems in these four projects, Neste put a significant amount of its own work into developing appropriate technologies for pretreatment systems in different projects.

Reactor unit. Reactors are the main equipment in NEXBTL plants. They are huge containers (one empty reactor at the Singapore plant weighs 800 tons), in addition to the catalyst and processed liquids. The product designs of the reactors for each of the projects were different. In Finland 2, significant changes were made to the product design of Finland 1's reactor unit. With regard to the organization, an international supplier, ReaCon (pseudonym), was used in both Finland 1 and Finland 2, but the changes in product design caused significant work for Neste in terms of changing the product design for Finland 2. In Singapore and Rotterdam, the same reactor supplier was reused. In these projects, the reactors' product designs were scaled up in size and were therefore different from those of Finland 1 and Finland 2. However, although reactors in Singapore and Rotterdam were originally planned as being physically identical, EU regulations and certification procedures led to different organizational and work procedures, which significantly increased the cost of Rotterdam's reactor unit. The product designs in Singapore's and Rotterdam's reactor units were finally different (unique) in some specific details, mostly due to lessons learned from Singapore that gave rise to changes in the reactor unit in Rotterdam. Furthermore, the organizing of project work in Singapore and Rotterdam reactor unit implementation on-site was different than in the previous projects in Finland. In Finland 1 and Finland 2, reactors were installed at a late phase of the project, whereas in Singapore and Rotterdam, the reactors were installed at the site first and then everything else was built around them. In sum, the product designs of the reactor units were unique in all four projects. Also, unique organizations were used to carry out the reactor unit design and implementation in these four projects, mostly due to emerging needs to invest in redesigning and changing the products but also due to contextual factors such as regulations that caused additional work or changes in organizations and work.

Synthesis. The findings regarding uniqueness and reuse of product and organizational subsystem components in each project part across the embedded projects are synthesized in eight observations in Table II (the third column of the table shows interview sample quotes connected to the observations). The observations (in the second column of Table II) are positioned according to different combinations of unique and reused product and organizational subsystem components (the first column of Table II). The findings indicate interesting and unexpected interdependencies between project products and organization at the component level; paradoxically, reusing something (e.g. organization) was associated with creating uniqueness in something else (e.g. product), and vice versa. For example, the catalyst system product was unique in all refineries due to product innovations, but the catalyst system was designed and implemented jointly by the same supplier and the same strong and experienced internal development organization in all projects. Conversely, the automation systems product was identical in all projects but the automation system organizations were all different.

Table II. Observations about interdependence between unique vs reused product and organizational subsystem components in the five project parts of case projects

Uniqueness vs reuse of product and organizational subsystem components in project parts	Observations of product-organization interdependence	Sample quotes from interviews
I. Reused product subsystem component and reused organizational subsystem component	1. *Repeating automation system product for the purpose of having Neste's own method of designing and implementing automation, by reusing the same experienced automation system supplier*: Neste devised reuse of the product design of the automation system in Finland 2, Singapore, and Rotterdam projects by reusing the organizational subsystem component connected to the automation supplier: Neste used the same automation supplier AutoTrad (in Finland 2 just using the same supplier and repeating Neste's own organization and working processes from previous projects were sufficient, but in Singapore and Rotterdam where an external systems integrator SysTech was used Neste had to create new work practices jointly with the systems integrator in designing and implementing the automation system in collaboration with AutoTrad)	"The automation system in Neste is traditionally a separate and centralized system. If you buy a package, then it usually implies that it is difficult to include specific instruments which you have defined in your own specification, plus the supplier wants to deliver a localized operating logic for a fixed price. This kind of localized operating logic does not fit to Neste's system because we want all individual instruments to be integrated into our centralized system" (Design Manager of Singapore project) "We have implemented recently four, no five, five projects with the same automation system. I think this is a key strength of Neste of course. So […] it is the same whether you go to run diesel, or NEXBTL Finland , Singapore, or Rotterdam plants. It helps to run operations with our personnel when there is exactly identical automation system, the screens are identical, the logic is identical. We could have done this with the SysTech way, but then it would have been different [in large-scale projects in Singapore and Rotterdam]. So this is the logic here" Project Manager of Rotterdam project)
II. Reused product subsystem component and unique organizational subsystem component	2. *Controlling the work of the automation system supplier excessively, for the purpose of helping and controlling a new supplier organization to get the product right, i.e. making the product to match the requirements*: as a result of reusing the product design (as a non-unique component) in the automation system in Finland 1 project, Neste ended up to using an unique organizational design by using a new supplier organization and organizing Neste's own project work differently by focusing more on helping and controlling this new supplier's work 3. *Creating new work practices jointly in coordinating the automation system design work, and putting effort into changing a systems integrator's work practices and product designs*: the	"But of course, if they [Finland 1 and Finland 2 projects] would be really copies and alike, […] but they aren't and I think it's good thing that we have different automation system now at least [in Finland 1] in the beginning because now we really have to learn both systems and learn the process. […] [But eventually, regarding projects implemented later], of course it's reasonable to have same kind of main equipment [like automation system and] compressors and so you don't have to have that much spare parts for example, and […] it would be easier for operators to operate if you have just the same process, of course. It's easier to train [operators] and so […]" (Project Manager of Finland 2 project)

(*continued*)

Table II.

Uniqueness vs reuse of product and organizational subsystem components in project parts	Observations of product-organization interdependence	Sample quotes from interviews
	product designs of the automation systems in Singapore and Rotterdam projects were reused, but despite using the same known automation supplier AutoTrad, the organizational design for implementing the automation was unique. In order to accomplish the goal, Neste required the use of a unique organizational design by requiring that the systems integrator to conduct work scopes outside its core capability, and Neste needed to participate in the systems integrator's work, in order to support and guide the systems integrator in implementing the automation system 4. *Reusing the hydrogen plant product by having a hydrogen plant, but sharing a pre-existing plant with another refinery in the same site, which required a different and unique organizational arrangement compared to organizing the building of a hydrogen plant specifically for this newly built refinery*: product designs of the hydrogen plants in Finland 1 and Finland 2 followed the typical reuse patterns of having separate own hydrogen plants on-site, in terms of acquiring hydrogen from Neste's pre-existing hydrogen plants at the site that were connected to the operations of another refinery. Due to the use of these pre-existing hydrogen plants, the organizational design of not needing to build the hydrogen plant can be considered unique. Instead of building hydrogen plants, the organizational component in these cases included building pipeline connections to the pre-existing plant, upgrading the plant for capacity, and more importantly, organizing for agreements concerning the sharing of the plant with another refinery in terms of joint maintenance, refurbishment, and modernization of the upgraded old hydrogen plant in the future	"It [supporting and guiding SysTech in automation system design] was a significant investment from us and it required a lot of work but it was worthwhile. There were also many of our [Neste's] specialists working on that activity almost on an everyday basis" (Deputy project manager of Rotterdam project) "Yes, we [Neste] took a responsibility for the appropriate functionality of the automation system, when we said [to SysTech] that you must do it in this way. This is probably the most dangerous thing that you can do in these kinds of projects. […] Because they can then say to us that it is okay: you wanted it in this way and you got what you wanted" (Project Manager of Rotterdam project)

(*continued*)

Uniqueness vs reuse of product and organizational subsystem components in project parts	Observations of product-organization interdependence	Sample quotes from interviews
III. Unique product subsystem component and unique organizational subsystem component	5. *Outsourcing the hydrogen supply to two large greenfield projects completely, where the actual product component was unique hydrogen-supply-as-service instead of having a hydrogen plant on-site*: with the two large projects in Singapore and Rotterdam, the product design of outsourced hydrogen supply was unique, and the organizational design including outsourcing (and not following the typical pattern of building an own hydrogen plant) can be considered as being unique as well 6. *Continuous improvement by adjusting the pretreatment system products based on the experience in previous projects, and selecting appropriate suppliers that can implement the pre-defined improved product designs in an appropriate manner:* product designs of pretreatment systems were finally different (unique) in all four projects Finland 1 and 2, Singapore, and Rotterdam. Also, unique organizational designs were used in pretreatment systems in these four projects, ranging from Neste's own planning, implementation and testing work with licensed third-party technology, to use of an external supplier with Neste's varying involvement in different projects 7. *Improving reactor unit products based on experience from using the products of previous projects in operations, and selecting specialized suppliers for changed work scopes:* product designs of reactor units were unique in all four projects, and unique organizational designs were used in implementing reactor units in these four projects, mostly due to emerging needs to invest work into redesigning and changing the products, but also due to contextual factors such as regulations that caused additional or changed organizational arrangements and work	"Originally, we had the idea to build a hydrogen plant [in Singapore], because propane and some other light hydrocarbons are produced as a side product from the process, and these side products can be used as a feedstock for the hydrogen plant" (Process design manager of Singapore project) "If we had built our own hydrogen plant in our site, the risk would be still there and we would be relying only on this one plant. And I think most likely we would be a bit less efficient operator of that plant because they [HydSup] have 170 hydrogen plants around the world" (Senior vice president of Neste) "For the pretreatment system [of Finland 1 project] we used a licensor, which had used this kind of technology in pretreatment processes in the food industry, […], but in fact we have had to design it all again from scratch by ourselves, so we have had to put a lot of effort into research and development […]" (Director of business development and strategy of Neste) "Everything there is our proprietary and [to us] a little bit underestimated the pretreatment system, because similar systems have been applied in the food industry for ages, and there were a number of vendors and technology providers. However, we found out that at the end of the day, our requirements are different from theirs. We have therefore improved also the systems for the Porvoo unit [= Finland 1 and 2], and I think we have gained all the time valuable information, knowledge, and therefore we are not dependent on the technology suppliers" (Business development manager in Neste Renewable Fuels Group) "[…] they [different reactor unit designs in different projects] are quite big changes. But I think that we managed to do it so that we made a process design very carefully and we have risk analyses

(*continued*)

Table II.

Table II.

Uniqueness vs reuse of product and organizational subsystem components in project parts	Observations of product-organization interdependence	Sample quotes from interviews
		from these changes, so we had very tight control about these change procedures." (Project manager of Finland 2 project) "The site in Singapore looked in last May a bit strange as there were 10,000 poles sticking from the ground, and then the reactor stood there in the middle as a huge totem pole. This scene was not what we were used to, as the equipment that normally comes as last, did come to Singapore as the first one. From the perspective of the construction process, this was an ideal arrangement as everybody at the site must then build around this already installed equipment" (Process design manager of Singapore project)
IV. Unique product subsystem component and reused organizational subsystem component	8. *Using the same strong own specialized unit to build and simultaneously develop the catalyst system product, and using the same supplier for the catalyst system for continuously improving the product jointly:* due to continuous development of the critical catalyst system that is at the core of the production process, unique product designs for the improved catalyst system were introduced to all plants: Finland 1, Finland 2, Singapore, and Rotterdam. The organizational design was repeated by reusing the same catalyst supplier CatSup for all of these plants, and also Neste's own organization for implementing the catalyst system product was the same in all projects. The catalyst system implementation can be characterized as joint innovation in all projects, including experimenting, testing, and modeling new designs of the catalyst system and its use	"[…] with the old catalyst, but it was in the NEXBTL 1 [Finland 1] […] the quality of that catalyst was not so good […]" (Project manager of Finland 2 project) "In the first one [Finland 1] we did conduct all necessary technical developments of the catalyst, and long-term durability tests of the catalyst in our research unit. We had a tight collaboration with [CatSup] and they did a lot of piloting. They had many suppliers and we were also engaged in a lot of development work with their suppliers. We were also conducting a lot of development work separately within our own organization. We modeled the whole process – modeling is an important part of the development and we have good capabilities in that – then planning and building of the plant, then lessons learned from this first commercial plant, and we used the learnings very systematically in Finland 2, Singapore, and Rotterdam" (Director of business development and strategy of Neste) "[…] so both for our hydrotreating reactors and isomerization reactors, they [CapSup] developed a catalyst for our purposes, and we are depending on them of course. But they are also depending on us, because we provide the business for them […]" (Senior vice president of Neste)

5. Elaboration of the volume-variety matrix in the context of major projects – interdependence of project product and organizational subsystem components

Based on the empirical findings, elaborated understandings of the product-organization interdependence in the context of major projects are synthesized in Figure 3. The figure includes four quadrants, which were developed based on the eight empirical observations presented in Table II. Below, the framework in Figure 3 is explained. This elaborates the volume-variety matrix (Davies and Frederiksen, 2010; Hayes and Wheelwright, 1979) in the context of major projects by providing examples of as well as explanations for both on-diagonal and off-diagonal positions. In order to emphasize the new knowledge that our study brings to existing project management research, we also want to refer here to the goals-and-methods matrix by Turner and Cochrane (1993) and relate our findings to similarities to and differences from the matrix in their study. The goals-and-methods matrix is a project level (and not subsystem component level) representation and its purpose is to classify whole projects by their characteristics, according to the criteria whether their goals and methods are being well defined vs ill defined. In contrast, our analysis on the subsystem component level of a project attempts to unfold the anatomy of a single project by looking at the component parts of the project and how they interact (i.e. how the product and organization subsystem components are interdependent). We can see analogies with "goals and methods" (in Turner and Cochrane, 1993) vs "product and organization" (in our study), but our parameters of project's component parts being either "unique or reused" does not necessarily directly mean that the inherent goals and methods are being "ill or well defined" as there may be also other parameters that affect the project's goals and methods definition at the outset, and vice versa, either ill or well defined goals and methods do not directly imply that the project's component parts are being either unique or reused.

Quadrants I and III are intuitive and support the ideas of Hayes and Wheelwright (1979) and Davies and Frederiksen (2010): reused product subsystem components are associated with reused organizational subsystem components (I), and unique product subsystem components are associated with unique organization subsystem components (III). The empirical study provides profound insights that explain the underlying logic in these quadrants. Regarding Quadrant I "Using proven product and process technology,"

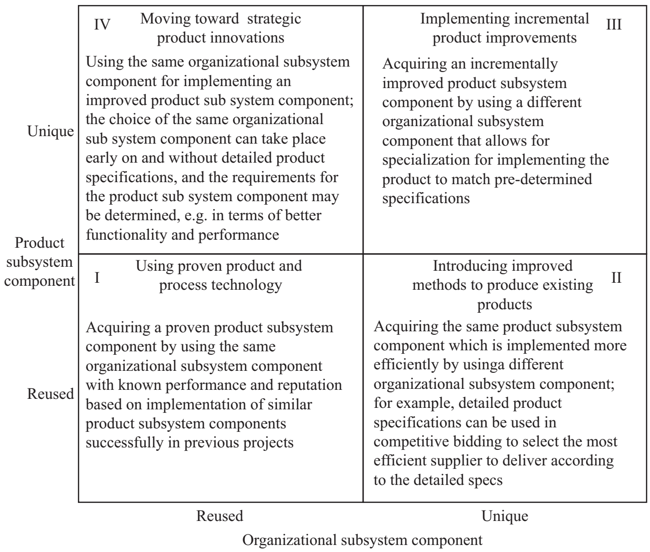

Figure 3.
Product-organization interdependencies in the five project parts of four embedded case projects

one explanation is that product subsystem components that are of strategic importance often include embedded capabilities, such as in the automation system. Hence, it is crucial that the design of the product subsystem component complies with standard design across all projects (Observation 1). This explains the reuse of the organizational subsystem component; as the supplier of the automation system in Finland 2 gained a good reputation for having implemented a successful product in a good and trustworthy collaboration, Neste repeated the organizational design in the automation system in Singapore and Rotterdam. The view of reusing organization with products of strategic importance complements existing knowledge in the extant project management research, building on the assumption that the product determines the organization (Gaddis, 1959; Morris, 2013).

Quadrant II, "Introducing improved methods to produce existing products," in contrast, suggests that new and unique organizational subsystem components can facilitate the introduction of new methods to implement similar products more efficiently. For example, when the product is not strategically critical and safeguarding its design and implementation is not of such high priority, a unique organizational subsystem component can be used, taking more risk by implementing the same product more efficiently by a different organization (Observation 4). This could be explained by the widely accepted notion that the project is a temporary organization merely working on a given pre-determined product specification, guided by plans and within pre-established constraints of specification, time, and cost (Lundin and Söderholm, 1995). Building on this, this paper argues that for a reused product subsystem component, selecting any organizational subsystem component to do the work is possible, as long as it follows the product specifications that have already been documented at a very detailed level in a previous project or projects.

Quadrant III, "Implementing incremental product improvements," includes a unique product subsystem component with a reused organizational subsystem component. In the case of a need to improve a product subsystem component, the respective unique product subsystem components can be designed based on the need to improve it after previous projects (Observation 7). This unique product subsystem component could then require a different (unique) organizational subsystem component to implement this new product. Another way to explain this is to first identify a potential opportunity for a unique organizational subsystem component, which could then lead to a favorable change in the product subsystem component (i.e. a unique product) as a consequence (Observation 5, Observation 6).

And finally, Quadrant IV, "Moving toward strategic product innovations," suggests that the same organizational subsystem component can be reused to implement a unique (and better) product subsystem component in the following project. Detailed product specifications of better and unique product subsystem components are not available because of the lack of explicit knowledge in the project's early phase about the final best product solution. Plausible theoretical explanations for Quadrant IV include the reused organization's learning from past projects (Prencipe and Tell, 2001) and exploratory learning (Brady and Davies, 2004). Furthermore, learning through probes and experiments and learning from failures (Brown and Eisenhardt, 1997) could provide an explanation; if the organizational subsystem component did not succeed in a previous project, then this organization could have learned how to do it right this time. Alternatively, Quadrant IV could also include the purpose of introducing innovations by continuously "designing in the making" while producing a different and better unique product (Observation 8). This can be explained, for example, through the selection of the same systems supplier that has proven itself capable of producing successful unique end-products – even radical innovations – thus providing benefits for the buyer's business over and over again in different delivery projects (Möller and Törrönen, 2003). This could especially be the case when the product is of critical importance, e.g. having a significant impact on the effectiveness of the operations.

In both Quadrants I and IV, the reuse of the organizational subsystem component is important but for different reasons: for strategically critical project parts, the organizational subsystem component in Quadrant I is reused to safeguard the proven technology, whereas in Quadrant IV the organizational subsystem component is reused to guarantee that the strategically important project part will become better. Hence, this study suggests that reusing the organizational subsystem component is important with products of strategic importance, irrespective of whether the aim is to produce a similar or different outcome. Furthermore, the idea that the product design cannot necessarily be determined in the beginning of the project but is designed in the making by the selected organization (Observation 8) complements existing research by providing concrete explanations of managerial activities and mechanisms concerning suggestions that the final product depends on the organization (e.g. Brady and Davies, 2004; Gil and Tether, 2011).

6. Discussion

6.1 Contributions and research implications

First, this study provides understanding of project product-organization interdependence by elaborating on the volume-variety matrix (Davies and Frederiksen, 2010; Hayes and Wheelwright, 1979) in the context of major projects by analyzing product and organizational subsystem components. In the context of major projects, the project product is a complex system and the organization is a temporary multi-firm organizational network (Artto and Kujala, 2008; Lundin and Söderholm, 1995). This paper elaborates on the volume-variety matrix through empirical analysis of product-organization interdependence with data from a multi-project setting and provides specific observations about connections between unique and reused product and organizational subsystem components. The findings support the argument that product and organization are interdependent in the context of projects (Davies and Frederiksen, 2010; Gokpinar *et al.*, 2010; Hayes and Wheelwright, 1979), but they simultaneously reveal interesting findings about uniqueness and reuse of components of product and organizational subsystems. Interestingly, the findings indicate that uniqueness of the product subsystem component is not always associated with uniqueness of the organizational subsystem component, indicating that projects have both diagonal and off-diagonal positions in the volume-variety matrix when engaging in analysis of subsystem components. Particularly, the findings suggesting off-diagonal positions in the volume-variety matrix are interesting: deliberate decisions to take these positions were made to manage the projects effectively. While Hayes and Wheelwright (1979) encourage manufacturing firms to take positions on the diagonal, and similarly, Davies and Frederiksen (2010) suggest that projects as a whole are positioned on the diagonal, the present analysis of product and organizational subsystem components provides deeper understanding by showing that off-diagonal positions are also possible and explaining the reason it might be desirable to take off-diagonal positions. Simultaneously, these findings provide further understanding about interdependence of project product and organizational subsystems (Browning *et al.*, 2006; Ramasesh and Browning, 2014).

This study also complements previous research testing the volume-variety matrix in the manufacturing context (Ahmad and Schroeder, 2002; Collier and Meyer, 1998; Helkio and Tenhiala, 2013; Safizadeh *et al.*, 1996; Schmenner and Swink, 1998). This is important considering the ever-increasing projectification of society (Geraldi *et al.*, 2011), as the number and importance of major projects continues to grow significantly (Bryde, 2003; Maylor and Turner, 2017). Simultaneously, it also responds to the critique and calls for more research on the volume-variety matrix, reflecting today's complex operations context (McDermott *et al.*, 1997). Moreover, by elaborating the volume-variety matrix (Hayes and Wheelwright, 1979) in the major project context, the study contributes to research on OM, which has mainly focused on manufacturing operations (Maylor *et al.*, 2015).

The findings provide illustrations on how unique projects still have standardized elements among their product and organizational subsystem components. This finding gives further insight into the attempts to standardize project operations (Geraldi *et al.*, 2011; Oltra *et al.*, 2005). This study's findings show the ambiguous nature of the argument that a project is either unique or standardized within a specific batch (Browning, 2010; Hobday, 2000); although a project can be characterized as unique at the project level, a closer look reveals that there may be a significant amount of purposeful reuse in product and organizational subsystem components and that the interdependence between the product and organization as well as their unique vs reused components is complex. The findings give support to the view of projects as systems, consisting of subsystems and their components (Browning *et al.*, 2006; Ramasesh and Browning, 2014). These results further imply that future research in OM could potentially also benefit from a more fine-grained level of analysis of the volume-variety linkage in the manufacturing context (cf. Hayes and Wheelwright, 1979). This could potentially provide an explanation for the mixed results of tests of the product-process matrix (Helkio and Tenhiala, 2013; McDermott *et al.*, 1997). Finally, providing explanations for the off-diagonal positions at the component level gives support to the contingency view as opposed to the best practice view, which has strongly dominated operations and project management research (Boer *et al.*, 2015; Geraldi *et al.*, 2011; Ketokivi and Schroeder, 2004).

6.2 Managerial implications

In addition to academic contributions and implications, this study also has implications for the "practitioner problem," that is, how to gain competitive advantage via project-based operations (Maylor *et al.*, 2015). At the overall level, the results challenge the normative element in PM based on best practice view (Geraldi *et al.*, 2011) by suggesting that project management practices must be adapted to the specific context.

Project managers aim to reduce a project's uncertainty by reusing specific parts, selecting components that have previously been used. The findings presented here demonstrate the importance for project managers of considering "what" is being reused (product subsystem component or organizational subsystem component) and "why." Therefore, when referring to uniqueness vs reuse in the context of a project, one message to managers is to carefully consider the potential benefits of unique and/or reused product and organizational components, taking into account the interdependence that makes the organizational component affect the design in the making of a corresponding product component.

Based on the above, increased understanding of product-organization interdependence provides a useful tool for project managers in terms of how this interdependence can be used in the management of projects. The results indicate that reusing organizational subsystem components (or alternatively, selecting a unique component) can serve various purposes. For example, reusing an organizational subsystem component can result in creating either a unique or a similar product subsystem component. The findings also help managers to see the interdependence between product and organization. The findings concerning subsystems that are mission-critical to the buyer are especially critical and include new knowledge: the reuse of the organizational subsystem component, rather than the product subsystem component, is important in strategically critical project parts but for different reasons. For example, the organizational subsystem component can be reused to safeguard proven technology in terms of ensuring successful reuse of the product subsystem component, or alternatively, the organizational subsystem component can be reused to guarantee that the product subsystem component will become unique and better through anticipated innovation on the part of the organization.

Furthermore, the project-to-project view in the analysis has important practical value as it indicates that projects can be built at least partly on reusing product and/or organizational subsystem components from previous projects. This can be expanded outside the project's parent organization; a project manager might want to seek a project from another firm to acquire appropriate organizational or product subsystem components. This encourages project managers to ignore organizational boundaries and take a broader look at how similar technologies have been developed and implemented. Therefore, these results can serve as a framework for practicing managers when defining new projects and designing organizations to plan and execute them. Considering the purpose of the project, managers could use the framework to assess whether to reuse or build a new product and/or organization. The key message here is encouraging project managers to think outside firms' boundaries and consider how projects – despite being unique at the project level – do not start from scratch but can build on and utilize knowledge and experience gathered from project components in either product or organizational subsystems.

6.3 Pedagogical implications

This research provides new knowledge to students, practitioners, and scholars interested in project operations in complex projects, by suggesting that choices on project components' product designs and organizational arrangements should be made by carefully considering the effects arising from product-organization interdependence. In other words, choices on the product and organization should be made with regard to the implications that the organization may have on the respective component's product design, and vice versa, with regard to the implications that the potentially pre-determined product design of the component may have on the organization that implements the component during the project.

In elaborating the volume-variety matrix in the context of major projects with both on-diagonal and off-diagonal observations, another pedagogical lesson for students, practitioners, and scholars from our study is that major projects are complex multi-firm organizational systems which have the capacity to adapt and change their produced outcomes from one project to the next. Therefore, we can argue that the way how the product-organization interdependence is actually manifested, is project specific, and depends on the project's unique context. In other words, while the on-diagonal position suggesting that the assumption of unique organization being associated with unique product component is true in one project, we observed that in the next project there may be an off-diagonal setting where the same (reused) organization (e.g. supplier) is associated with a unique and therefore different (e.g. improved) product component.

The pedagogical lessons above are connected to the notion that major projects are more complex than what can be illustrated by modeling the project at the outset. This occurs as the project's product components and the required processes to produce such components cannot be known in the beginning of the project, as it is often the case with major projects that the most valuable solution and how it will be achieved cannot be defined in detail at an early stage. Therefore, at least in case of producing some component parts of the project, the project system must rely on adaptive rather than prescriptive approaches. This means, for example, that the specific processes and tasks cannot be defined in the beginning of the project, but the project's organization and its appropriate architecture can be chosen early on, and the organization then has the capacity to define the processes and tasks later during the project. In this way, the chosen project organization will be designing the product in the making by adapting to the continuously changing project-specific and situation-specific circumstances at hand, for the purpose of adjusting the product design continuously during the project toward a more valuable solution for the project's owner or other firms participating to the project.

6.4 Limitations and future research

Although a single case study setting has limitations in terms of generalizations, it is suitable for the theory elaborative research approach (Ketokivi and Choi, 2014). Moreover, a single embedded unit case study was necessary to facilitate the project-to-project view, wherein potential connections between project subsystem components were assessed. Our findings open up avenues for further research, which are explained in the following.

First, in order to reach more detailed conclusions about interdependence between products and organizations, future research could study embedded unit projects in other project contexts. Research could take a design science approach (Holmström *et al.*, 2009) and make interventions in managing projects via product-driven and organization-driven approaches, testing different combinations of uniqueness and re-use in project product and organizational subsystem components. Considering the recent support for more institutional explanations for organizational arrangements in the OM context (e.g. Turkulainen *et al.*, 2017), future research could also assess institutional explanations regarding project product and organizational interdependence.

Second, while projects are suggested to have five subsystems (Browning *et al.*, 2006; Ramasesh and Browning, 2014), the choice of addressing only product and organization subsystems in this study is based on the focus on elaborating the volume-variety matrix (Davies and Frederiksen, 2010; Hayes and Wheelwright, 1979). The process subsystem is in between the product and organization subsystems, as the organization does the work to produce the product[6]. Therefore, aspects of the process subsystem are embedded in analysis of the organization, which is also illustrated in the original high-level process representation of the volume-variety matrix. A natural extension of this study is to include the process subsystem in the analysis of major projects and assess at a detailed level how choices of product and organization subsystem components are connected to the choices of processes and tasks in the process subsystem. Especially, the question of a project's organization making choices about processes and specific tasks continuously during the project's lifecycle is intriguing. The rationale for such project organization's behavior of dynamically choosing and adjusting the processes during the project could be in designing the product in the making, for the purpose of adjusting the anticipated to-be-product-design at the project's completion toward a more valuable solution for the project's owner or other firms participating to the project. These continuous adjustments and changes can be justified due to, for example, changes in external or internal conditions, changed targets, or new knowledge that is continuously acquired as the project and its product unfolds. Moreover, digging deeper into team level in the organization subsystems could provide opportunities to develop further understanding of product-process-organization interdependence in projects.

Regarding project uniqueness, further research comparing how the project parts contribute to characteristics of project uniqueness would be beneficial. Understanding the nature of uniqueness in projects is important as it is related to uncertainty in the project and, therefore, has an impact on how the project and its inherent uncertainty can be managed effectively. For example, depending on the underlying project goals, the reuse of an organizational subsystem component can be a device to manage uncertainty, or alternatively the reuse of an organizational subsystem component can be a source for additional uncertainty. This research could build on Helkio and Tenhiala (2013) and use a contingency theoretical lens to analyze the interdependence between project products and organization to develop further understanding, especially on the off-diagonal combinations. Future research should also take the project lifecycle and related dynamisms into account and analyze the project product and organizational interdependence and its evolution in different phases of the project lifecycle.

Finally, research on product-organization interdependence in projects that builds more strongly on research on modularity and, for example, complementing, expanding, and elaborating the concept of mirroring (e.g. Baldwin and Clark, 1997) provides another potential research avenue. Research could also develop further understanding of the organization's role in successful management of projects that lack initial plans or product specifications and where product designs are based on continuous "designing in the making" activity by the project organization.

Notes

1. "Major project" is a well-established concept in research on project management (Morris and Hough, 1987). Research also sometimes refers to "megaprojects," which are defined as major projects, involving investments of $1 billion or more (Davies and Mackenzie, 2014).
2. While operations management (OM) research discusses the "production process" as a way to manufacture end-products within a single manufacturing firm's organization (e.g. Hayes and Wheelwright, 1979; Woodward, 1965), such production processes are fundamentally different in the context of major projects in two ways. First, the production system at the project level is referred to as a "project organization," which is a multi-firm network working on the project outcome (Artto and Kujala, 2008) – in a typical single-firm product development project, this is equivalent to a network of engineers (e.g. Gokpinar *et al.*, 2010). Second, such organization is temporary; it is formed only for the purposes of the focal project and is dissolved after project completion (Lundin and Söderholm, 1995). Hence, "production system" or "process" at the project level differs from what the traditional OM research typically refers to as a single manufacturing firm's production processes (Hayes and Wheelwright, 1979; Maylor *et al.*, 2015).
3. During the time of data collection, the name of the company was Neste Oil.
4. The product in such a building project is the refinery that is being build. The organization, on the other hand, is the multi-firm network, which is responsible for designing and building the refinery. This study focuses on projects and hence, we do not include the operational phase of the refinery in the analysis.
5. Directive 2003/30/EC of The European Parliament and of The Council of May 8, 2003 on the promotion of the use of biofuels or other renewable fuels for transport suggests that renewable fuels should account for 10 percent of all fuel consumption in Europe by 2020.
6. The authors thank the Guest Editor for pointing out this observation.

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Corresponding author
Karlos Artto can be contacted at: karlos.artto@aalto.fi