Modularization and the Dynamics of Inter-organizational Collaboration Producing and Bridging Spatial and Organizational Distances

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Abstract:
In the past decades, the aviation industry has gone through a fundamental transformation from vertically integrated corporations to globally dispersed, more modular forms of production thereby profoundly affecting the inter-organizational collaboration between the diverse actors within the related production network. Drawing on empirical data from an aviation cluster in Germany, this paper analyzes from a multi-level perspective how Airbus' new strategy of modular and global sourcing lead to processes of disembedding on a geographical, cognitive and network level, while simultaneously processes of embedding and integration were initiated that become visible at the new module boundaries and have been captured using the heuristics of proximity and distance.

1) Introduction

In the past three decades, a lot of industry branches have gone through a fundamental transformation in their organization towards modular forms of production. On the product level, the term "modular" defines a product whose single components are interchangeable without adjustments in other components [1]. A modular product architecture is often connected to a corresponding organizational form, consisting of vertically disintegrated lead firms that interact with selected turn-key suppliers [2]. On the relational level, modularization results in a disembedding of inter-firm relations from their particular social and spatial context.

This trend was particular observed in complex high technology products (e.g. electronics industry, automotives, aircraft, missiles) [3,4]. These industries often transformed the architecture of their products and their organizational forms in an evolutionary way. Modularization processes also took place in the European aviation industry. Yet, the European aviation industry exhibits one difference to other industries. The industry is dominated by one firm, i.e. Airbus (EADS). Airbus decided a new strategy of global sourcing (i.e. strategic global relationships) in order to exploit the "best" knowledge resources and expertise across regional and national boundaries ten years ago [5]. This decision affected the whole industry immediately. While other industries rather incrementally evolved into modular production systems, Airbus redesigned the industry in a top down approach. While suppliers in other industries could choose between leaping forward or staying behind first modular attempts of lead manufacturers there was no choice for Airbus suppliers. While other industries had niches to experiment with modular forms, Airbus started its new production model with the A380.

This quite monolithic approach of Airbus gives particular insights in the process of disembedding of inter-firm relations taking place in the industry, which are also known from other modularizing industries [6]. In addition, the strategy of Airbus resulted in some counter-reactions. Suppliers started to embed industry relations into new contexts and started for example to vertically integrate and to establish industry wide knowledge infrastructures. We analyze the processes of disembedding and embedding of modules and relations using the proximity approach [7,8]. Modularization is a complex process that involves change of the product architecture, the production network and the place of production. The proximity approach allows to transform these different dynamics into a single nomenclature of proximity and distance, which allows to analyze their interrelations. We show that processes of disembedding, i.e. creating distances, are accompanied by processes of embedding and creating proximities, yet in different domains. In doing so, our case of Airbus shows the complex dynamics taking place in an industry during modularization.

In the following section we will make the relation between product modularity and systems integration as well as its organizational implications more clear. We will then describe the dimensions of proximity resp. distance that serve as an analytical framework for the following analysis. After describing the methodology used within this study, the case is introduced and major results of the analysis are presented and discussed. The paper concludes with an outlook that also indicates directions for future research.

2) The relation between product modularity and systems integration and its organizational implications

Product modularity refers to the number of components an artifact can be decomposed and matched in a variety of configurations. The components are able to connect, because of standardized interfaces. Compared to a tightly coupled integrated product, where each component is designed to work specifically or exclusively with another one, modular products are systems of components that are more autonomous by being only "loosely" coupled [9]. However, within a single artifact they take a certain fixed position. Murman and Frenken argue that "artifacts are structured in terms of a hierarchy of nested parts." [10]. A system, thus, consists of several sub-systems, i.e. smaller second- and third-order systems until the level of the basic components being recursively nested (see figure 1). An airplane consists, for instance, of fuselage, propulsion systems, and landing gear, which can be referred to as the first order subsystems or from a "purchasing perspective" as the first tier suppliers.

According to Baldwin [11], modularizations, whatever their intended purpose is, create new "module boundaries". The modules can be considered as networks of tasks. The boundaries are points of inter-firm transaction and interaction and offer access points for actors to participate. They represent both technical as well as organizational interfaces. On a more organizational level, industry modularity implies that each module is produced by a separate actor and that there is at least one separated firm that takes the form of a systems integrator [9, 12]. In the modular systems theory product modularity, industry modularity and outsourcing are claimed to be correlating with each other [13]. The result is the emergence of vertically disintegrating modular production networks. However, the dispersed value creation activities and their outputs have to be reintegrated. This is where the concept of systems integration comes into play. Systems integration has its origins in systems engineering that has been developed in the US military during the cold war in the 1950s [14].
"Systems engineering allows engineers to partition systems into smaller manageable subsystems (i.e. modules, components, parts), assemblies, and sub-assemblies, and, at the same time, to develop interface specifications for each component before they are designed and constructed." [12]

Whereas systems engineering solely relates to the technical domain, system integration in the theory of modular systems also has organizational implications. Since the major task is to integrate various kinds of technology, knowledge and hardware from other actors involved in the inter-organizational manufacturing process, it implies the creation of efficient external interfaces for interaction not only in a technological, but also in an organizational sense.

Gholz differentiates between three types of system integration: component systems integration, platforms system integration and architecture systems integration. Each type is located on a different tier level of the hierarchically structured architecture of the artifact. The tiers refer to a decreasing systems capability when moving downward from the top (see figure 1) [15]. Consequently, the hierarchical order is determined by the scope of functions/services. The more functions and services one can provide, the higher the position in the hierarchy. In the case of the aviation industry this hierarchy is also determined by the assembly order. However, this does not count for other sectors (e.g. automotives, electronics), because modularization actually decouples assembly and manufacturing processes [9].

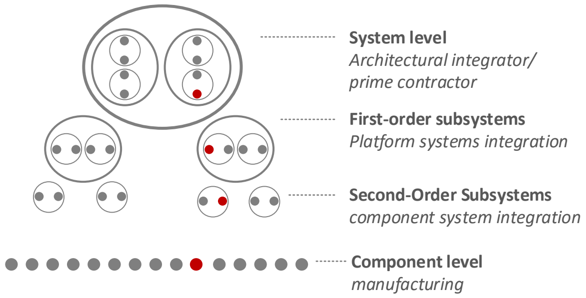

FIG 1: Hierarchical structure of the artifact and related levels of systems integration [10, 15]

Figure 1 illustrates the relations between the product architecture and the related system and manufacturing capabilities required on the different tiers. This hierarchy of systems, modules and assemblies is also reflected in the structure of the production network and the power asymmetries and relations between the actors. One can assume that the higher the horizontal distance between module A and B within the overall architecture of the artifact the higher the cognitive distance between actor A and B within the structure of the network. The higher the vertical distance the higher are the power asymmetries between them and the longer the path length of information flows. Within this hierarchical structure airframe assemblers or architectural integrators like Airbus and Boeing or first tier suppliers like BE Aerospace stand at the top of the pyramid.

In the last decades, system integration evolved from an engineering practice to a strategic business activity that becomes increasingly important for organizing production networks and is considered to be a core capability of high-technology corporations [12,16]. That makes the degree of modularity a strategic choice variable for the firm [3].

3) The heuristics of proximity and distance as an analytical framework

As has been shown in the prior section, modularization is a complex process. It involves a change of relation between product components, changing qualities and resources of suppliers, changing relations and network configurations and a changing spatial organization of the industry. The proximity framework serves to analyze these complex interrelations, as it integrates different dimensions and dynamics within a common nomenclature of proximity and distance [8]. The proximity approach focusses on relations. Its development started with the question, why location matters and when the benefits of being geographical proximate can be substituted by other forms of proximity [17]. While the first approaches started by contrasting geographical proximity with organizational proximity (i.e. within firms and relations) [18], new forms of proximity refer to cognitive, institutional or social proximity [19].

We use the framework presented in Menzel [8], which uses cognitive, network and geographical proximity to distinguish relations between actors and firms. Two reasons apply for this choice. First, this three dimensions cover those that change during modularization. Cognitive proximity covers the change in the (perception of) the product architecture. It bases upon Nooteboom's cognitive distance, that he describes as follows:

"For learning, partners should have on the one hand sufficient 'cognitive distance', i.e. possess different cognitive categories, to be able to capture knowledge that one could not have captured oneself, but on the other hand must be sufficiently close, in cognition and language, to enable meaningful communication" [20]

In most industries, this knowledge is inherently connected to artifacts. Fundamental changes in the technological artifact, its components or its architecture, as taking place during product modularization, reduces similarities in shared mental models and in doing so increase cognitive distances. To alleviate these effects, modularization involves pervasive codification processes.

Geographical proximity describes the physical closeness between firms. It favors economic relations between actors when tacit knowledge is involved [21,22]. Geographical proximity is considered the main reason why firms are clustered [23]. Studies show that firms in the same industry interact and collaborate twice as much when they are geographically close [24]. The aviation industry in the Hamburg metropolitan region is a typical example in this respect. Hamburg represents the third largest geographical concentration of firms in the aviation industry worldwide. Yet, modularization is sought to disembed relations from their spatial context [6].

Network proximity covers the organizational changes in network structure during modularization. Network proximity can be described as "the degree of how the network structure and positions in the network facilitate or impede knowledge diffusion" [8]. Knowledge flows between two nodes A and B in a network. It can take different ways, depending on the possible connections. If the path length is short, it diffuses quickly. If the path length is longer, knowledge flows depend on the network structure between A and B. If there is only one possible path between A and B, particular knowledge from A might never reach B. If there are different paths between A and B, knowledge might flow from A to B, even if A tries to prevent it. Changing network structures are always based on building new nodes or cutting ties between existing ones thereby creating new and affecting existing inter-organizational relations through mechanisms of in- and exclusion. Lead firms that modularize cut most of their supplier relations by focusing on several key suppliers [6], which again build up an own supplier network. While previously suppliers were directly connected to the lead firm, they interact with the lead firm via first or second tier suppliers after modularization, resulting in an increase in network distance between the lead firm and most suppliers.
Second, the framework presented in Menzel [8] focusses on the interrelations between different forms of proximity and distances, i.e. changes in one form of proximity might result in changes in another dimension. Especially, distances in one dimension might only be bridged by proximity in

other dimensions and generating proximity between actors simultaneously creates distances to others. For example, the artifact actors are co-creating and producing is reflected in the structure of the network. Another example refers to geographical and cognitive proximity. Global sourcing increases geographical distances between actors. As geographical proximity facilitates interaction involving tacit knowledge, tacitness of knowledge has to be decreased by codification processes, which decrease cognitive distances. Therefore, the framework allows to investigate complex interrelations between different forms of proximity and is applicable to a dynamic setting. Especially, it allows to analyze how processes of disembedding, i.e. creation of distances, are connected to processes of embedding, i.e. creation of proximities. Figure 2 summarizes the conceptual framework of this study.

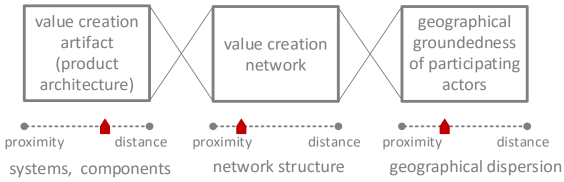

FIG 2: From the artifact to the geographical groundedness of the production network

Based on the premises outlined in the prior sections the following research questions have guided the analysis: On which levels of the Airbus production network do processes of disembedding and embedding occur that are caused by modularization? And how are they interrelated?

4) Methodology

The present study is in a preliminary stage and relies on field data collected during a BMBF-sponsored project on knowledge management in the Hamburg Aviation cluster in northern Germany. The exploratory and inductive approach allowed us to generate hypotheses from the data that went beyond the actual objective of the sponsored project to conceptualize and develop a knowledge management system. The data we rely on contain semi-structured qualitative expert interviews that have been carried out with representatives of the clusters' sectors (SMEs on different tier levels, lead firms, research institutions, public authority, cluster management). Moreover, protocols of inter-organizational strategic workshops, field notes from observations and firm data have been included in the data pool. The data has been coded with the Software Atlas ti thereby relying on principles of the Grounded Theory [25,26]. Codes have been further abstracted into categories, which can be represented in a semantic network that shows their interrelations and interdependencies.

In order to capture the dynamics and changes of an industry during modularization and its effects on inter-organizational collaboration within a complex production network one has to focus on the newly created module boundaries as well as pairs of firms that interact or used to interact at the old and new boundaries. The relevant pairs of firms we identified and exemplary investigated in our case entail three dyadic pairs:

1) Dyadic pair I: architectural integrator – first tier suppliers
2) Dyadic pair II: first tier suppliers – sub-suppliers (n-tier)
3) Dyadic Pair III: architectural integrator – sub-suppliers (n-tier)

Furthermore, we operationalize the dimensions of cognitive, geographical and network proximity in the following way. We use the relation between product components as proxy for cognitive distance. Disintegration of components therefore would increase cognitive distance. We use path

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length in the supplier network as proxy for network proximity. We use the geographical location of firms as a measure for geographical proximity.

Moreover, based on the qualitative data pool, we identified indicators for different degrees of proximity and their impact on IOC (see table 1).

Dimension	Indicators (Codes)	Impacts on IOC:
cognitive	level of standardization/ codification of knowledge; degree of heterogeneity between the actors and their knowledge bases	Communication, coordination, knowledge transfer
geographical	Geographical location; Frequency of face-to-face interaction;	Communication, coordination, knowledge transfer
network	path length of knowledge/ information flows;	Diffusion of knowledge within the system

Table 1. Indicators for different dimensions and related impacts

The respective peculiarity of the different indicators has been used to assess whether the dyadic pairs of actors are in a distant or proximate relation to one another. For instance, if the level of standardization is low and the heterogeneity between the actors is high (e.g. due to the disintegration of components) a cognitive distance among the two can be claimed. If the path length of knowledge and information flows is long (e.g. via various sub-contractors) this is a sign for a high network distance.

In the following section major findings from this analysis will be presented and discussed. First of all, the specific case of Hamburg Aviation is introduced and the pillars of Airbus' new systems policy are described in more detail.

5) The case of the aeronautical cluster Hamburg Aviation

The global aviation industry is agglomerated in only a very limited number of countries and regions due to the fact that air plane manufacturing implies a high degree of technology, engineering and innovation, highly qualified personnel, long product development and production times as well as capital intensive production facilities [27].

The regional cluster Hamburg Aviation consists of the anchor companies Airbus and Lufthansa Technik, Hamburg Airport, several associations, research institutes and universities, as well as about 300 small and medium-sized companies (SMEs), which are linked both vertically and horizontally with one another. The specific competences in the aviation industry in the metropolitan region Hamburg are in civil aviation and space technologies, final assembly of the Airbus A318, A319 and A321, the manufacturing of parts and the delivery center for the Airbus A380, as well as the fitting of aircraft cabins.

5. 1) Relational structure of the local aviation value chain (before implementation)

Even if a production network is basically dominated by the actors that take an integrating role, the internal behavior is considered to be organic as the chains and networks have evolved over time [5]. This has been also the case for the network relations between Airbus and the local supply base in the Hamburg metropolitan region. According to our interview survey and former studies on the regional cluster [28] the close long-term relationships building on a high level of trust as well as a high level of mutual dependence have evolved over time starting in the late 1960s when the Franco-German Airbus program started and Airbus installed a site in Finkenwerder. Direct face-to-face interaction (due to spatial proximity) and a rather low level of standardization (e.g. definition of standards, product specifications) characterized the interaction between the rather asymmetric partners. Orders came directly from Airbus to its diverse suppliers without passing through numerous sub-contractors thereby creating a high level of network proximity indicated by a short length of communication paths.

These relations are typical for German production networks and can be characterized as a relational production network, which is governed less by the authority of lead firms and more by social relationships based on trust, reputation and long-term interaction [4]. In this context geographical proximity between actors “provides the ‘relational cement’ for the network to exist” [29]. Figure 3 shows the proportions of the different dimensions of proximity within the cluster around Airbus before implementing its new strategy.

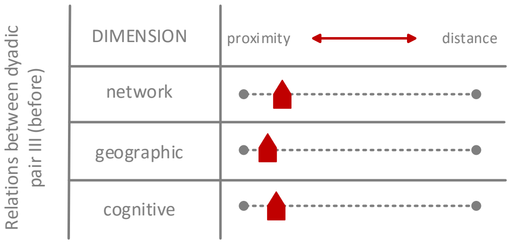

FIG 3. Different dimensions of proximity (before)

Another characteristic of relational value chains is the high amount of rather small and medium-sized companies [29] that is also the case in Hamburg with its numerous small and medium-sized engineering service providers.

However, their economic environment has fundamentally changed due to the implementation of Airbus’ new systems policy. In these terms, changing well established relationships also meant abandoning former routines and practices and, moreover, cutting ties to existing network partners.

5.2) Airbus’ “New Systems Policy”

Due to decreasing market shares and growing competition airframe manufacturers such as Airbus (EADS) and Boeing concentrated on a new strategy of global sourcing (i.e. strategic global relationships) in order to exploit the “best” knowledge resources and expertise across regional and national boundaries [5]. This global sourcing strategy has been accompanied by a concentration on their core competencies as an architectural or platform integrator leading to the outsourcing of considerable workloads accompanied by a rearrangement of systems and modules as figure 4 shall illustrate schematically.

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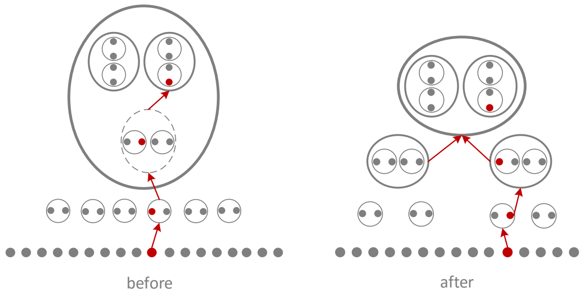

FIG 4. Rearrangement of modules and system integration responsibilities

This rearrangement reconfigured not only the technical, but also the organizational i.e. social interfaces to the diverse suppliers by creating new module boundaries as indicated by figure 4. The accompanying consolidation and restructuring of the supply base follows the new procurement policy of Airbus that has been based on four pillars described in table 2.

Strategies	**Implications**
Single/dual sourcing per (sub-)system	Strong reduction of the number of suppliers
Modular sourcing	Reduction of the in-house-manufacturing; purchasing of entire (sub-)systems and modules
Global sourcing	New network partners across national boundaries
Forward sourcing	Transfer of R&D activities and other tasks (i.e. certification, approval, integration, maintenance) to suppliers on lower levels

Table 2. Airbus' new procurement strategy [28]

Altogether these strategic decisions can be summarized as the "new systems policy" that is implemented in a still on-going process that started approximately 10 years ago [16]. It is important to note that Airbus did not only outsource former in-house manufacturing, but also systems integration by purchasing entire systems and modules that had been integrated in-house before. In this sense, the direct supply base has been reduced from 61 to 20 and so has been the number of small engineering service providers.

Consequently, the requirements for the new first tier or system suppliers increased dramatically and are either a high innovation potential and/or a strength in systems integration; high financial capacity for R&D projects with a long-term lead time (risk-sharing partnerships), a high level of flexibility; high technological system and management capabilities as well as spatial proximity to the prime contractors [28].

Outsourcing on a superior tier means in turn insourcing on lower tiers. In the given case, it also meant that the process of disembedding (i.e. vertical disintegration) initiated by Airbus new systems policy simultaneously initiated processes of embedding (i.e. integration) on different tiers of the production network. We will make this point more clear in the following section.

5.3) Processes of disembedding and embedding on the network, cognitive and geographic dimension

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The strategic reorientation as described in the prior section had significant implications not only for the systems suppliers and their interaction and knowledge exchange with the airframe assembler Airbus (dyadic pair I), but also for the inter-organizational relations to the smaller components suppliers and service providers (dyadic pair III), representing a major part of the local supply base located in the Hamburg Aviation cluster resulting in new challenges for suppliers on different tiers as well as frictions and conflicts at the new module boundaries.
Whereas the relation between the dyadic pair III used to be characterized through direct communication and contracting, this is now only possible via the first tier system suppliers as indicated by figure 5 resulting in a structural disembedding which is manifested in a higher network distance to the prime contractor Airbus. Former long-term established relations and routines of interaction, therefore, become obsolete.

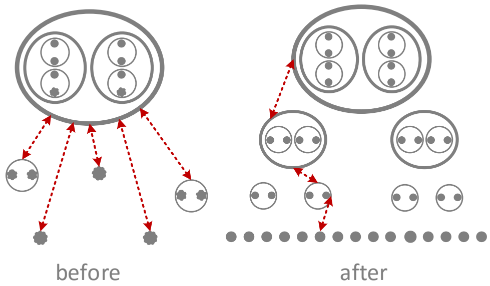

FIG 5. Disembedding of the former supply base

Since most of the regional SMEs do not fulfill the requirements of a system supplier as has been already estimated in a study by Pfähler and Lublinski 12 years ago [28], new system suppliers (i.e. system integrators) have to be formed on the regional level, if actors want to stay in the Airbus production network.

Comparable to the development in the automotive industry, suppliers are now trying to cope with these changes by acquiring and merging with other suppliers leading to the emergence of globally active and financially strong company groups in the US and Europe (e.g. BE Aerospace, Thales, GKN). However, within the Hamburg Aviation cluster this development has, until now, only very limited taken place leaving the intermediary markets of systems supply business to other predominantly French and US company groups. Only one merger has been successful so far, that is the case of Diehl buying two other aircraft interior companies to form a systems supplier and could, thus, gain a first tier position.
However, the new system supplier for air cabins has been formed as a reaction to Airbus new systems policy, therefore, well designed organizational and technical interfaces, standardization as well as system and management capabilities have not already been given, but have to be incrementally established.

„[This] implies huge efforts for specification, certification and documentation and the process end to end capability may result in conflict with the OEM [i.e. Airbus]" (Interview: 1st Tier).

Whereas the outsourcing of system integration to suppliers on lower tiers certainly leads to a vertical disintegration, however, in the given case, the vertical disintegration only took place between the dyadic pair of architectural integrator (i.e. Airbus) and the new first tier or system suppliers. Those in turn, in order to cope with the new challenges and to reduce uncertainty, vertically embedded suppliers on lower tiers as a reaction to the new environment.

Suppliers on lower tier levels that managed to stay in the value chain around Airbus now face longer communication paths via the system supplier and a lack of transparency with regard to product specifications and requirements. There were a lot of examples where sub-sub-contractors in manufacturing only got construction drawings without any information on where this part is to be integrated and what are the exact requirements, which in the end affected the fitting of parts and led to reclamations by the architectural integrator.

However, most of the SMEs did not manage to keep their former supply status and are deeply threatened by the recent developments. A statement of an interviewee shall illustrate the perception of the new economic environment:

> *„How can we manage to survive as medium-sized companies [Mittelstand] in this region in an environment that only deals with first tier companies? Everybody here lost their status as a direct supplier to AIRBUS. This is only reserved to the first tiers […] Access points to the value chain are not here anymore, but somewhere else in the world, namely, where the first tier companies are located." (Interview: Representative of regional SME Association)*

Figure 6 illustrates this kind of structural disembedding and cutting of ties of the spatially close former supply base of Airbus Hamburg as well as the global integration of the latter.

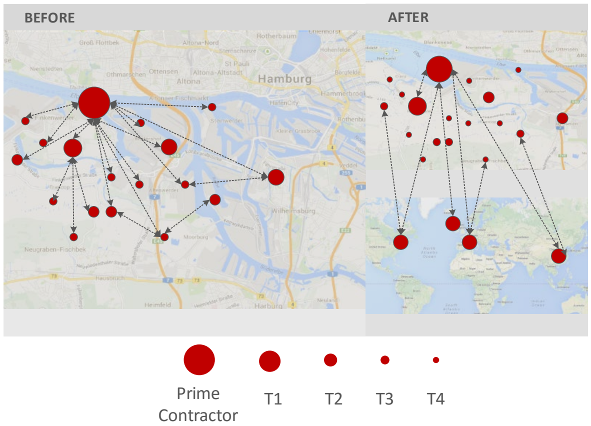

FIG 6. From local concentration to global integration

By creating a spatial and network proximity to distant first tier companies in order to tap out their knowledge and skills, simultaneously, a network distance to the actual spatially and cognitively proximate actors in the regional cluster has been produced (see figure 8).

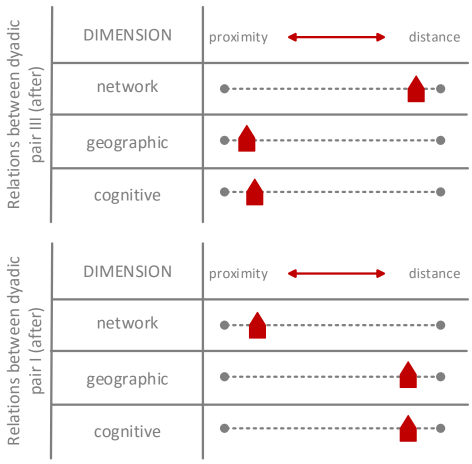

FIG 8. Different dimensions of proximity (after)

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Even if they manage to get into a first- or second tier supply chain, (e.g. in France or the US) not only will the communication path be much longer, but also the cognitive distance will be approximately high thereby deeply affecting the communication and interaction with the new partners due to different cultural and organizational backgrounds and a lack of international experience and standardization. Airbus in turn, created a structural network proximity to geographical distant companies that also results in a higher degree of cognitive distance between these new network partners (see figure 8) probably affecting the interaction, communication and knowledge transfer at the new interfaces.

6) Conclusion and Discussion

A lot of empirical case studies on modularization and vertical disintegration have investigated and described the process as one that has incrementally evolved bottom-up over time [2,3,30]. In the given case, strategies of modular and global sourcing have been implemented top-down by one dominating actor. Changes, frictions and conflicts resulting from the modularization and related outsourcing processes became immediately visible. Therefore, the case is particularly suitable to investigate related phenomena of embedding and disembedding. Against the oversimplified assumption that modular products lead to modular organizations (i.e. vertical disintegration), it has been shown that industries do not only disintegrate, but simultaneously reintegrate on different levels given the new opportunities and challenges they are facing [31,32,30]. This has been already shown for the automotive industry by Brusoni et al. [32] and it can be found in the case of the newly formed system provider for aircraft cabins in the Hamburg Aviation cluster around Airbus. This actor has to integrate a diverse range of sub-suppliers that have or have not been in a direct buyer-supplier relationship with Airbus before.

Moreover, processes of structural embedding and disembedding caused by top-down implemented modular and global sourcing strategies do not only occur on different levels of the production network (i.e. architectural integrator and system supplier, system suppliers and sub-suppliers etc.) but also within different dimensions, i.e. cognitive, network and geographical, that can be captured and described using the heuristics of proximity and distance. It has been shown that the different dimensions are interrelated with one another and that they affect inter-organizational knowledge transfer, communication, coordination and the diffusion of knowledge within the whole production system.

Creating a geographical and network proximity to globally dispersed system suppliers comes along with a cognitive distance that has to be bridged. Additionally, creating proximities to hitherto distant actors, in the given case, simultaneously created a high level of network distance to the actual geographical and cognitive close former supply base. Distances in one dimension can certainly be bridged by proximities in another one, since there is no optimal degree of proximity and distance. It has to be balanced out according to the specific context and economic environment that is constantly changing. However, firms have to be aware that the top-down implementation of modularization is accompanied by frictions that can evolve on very different levels and that unexpected transformation costs are very likely to occur.

According to Baldwin [11] modularizations create new module boundaries with "(relatively) low transaction costs" that make transactions "feasible where they were previously impossible or very costly." The results from this case study have, however, pointed out that conflicts, frictions and uncertainty are very likely to occur at the new inter-firm module boundaries due to processes of disembedding and that this implies huge efforts for specification, certification and documentation. This also implies that cost savings from outsourcing or moving an activity out of hierarchy are probably less than expected [32, 33].

Especially, in the theoretical literature on modular systems, the codification of knowledge, the evolution of standards and the definition and design of interfaces have already evolved thus fostering industry modularization. If this development has not taken place, communication between the actors and governance of the production system are profoundly challenged.
Compared to the vast amount of literature on modularity, its impact on communication and governance is until now rather unexplored [33]. Future research on organizational modularity should focus more on the frictions caused by relational disembedding that may occur at the new module boundaries.

7) Outlook

Through the analysis of the dyadic relations of the major actors within the production system we were able to get a more complete picture of how modular and global sourcing strategies affect inter-organizational collaboration and the relations between the actors on different tiers of the network. However, a further validation of the results is necessary. We are currently setting up a data base containing information on all the firms located within the boundaries of the regional cluster and their structural embedding and knowledge bases in order to further test and validate some of the hypotheses that have been generated within this exploratory approach. Moreover, the dimension of network proximity needs to be elaborated, for example, through viewing the network from an input-output relationship perspective and conducting measures of the network structure.

Whereas the focus of this paper has been on producing distances rather than strategies of bridging distances, recent studies on production networks drawing on data from Thales and Liebherr Aerospace in the aviation cluster around Airbus in Toulouse, have shown that there are actors such as key-turn suppliers and subcontractors that play an important role in "bridging" geographical and organizational (i.e. cognitive) distances by functioning as "connective nodes" in supply networks [17,34,35]. Thus, they are able to bridge network distances and foster cognitive proximity through the harmonization of interfaces within their unit of the value chain. Whereas cognitive distances can be bridged by common standards and norms and an efficient codification infrastructure, spatial distances can be overcome by I&C technologies.

Yet, disembedding (i.e creating distances) and embedding (creating proximities or, in other words, bridging distances) are interrelated phenomena and future studies should take this into account.

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