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THE CONFIGURATION OF MANUFACTURING IN MULTINATIONAL ENTERPRISES: EXPLORING THE ALIGNMENT BETWEEN PLANTS AND NETWORKS

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EXECUTIVE SUMMARY

The globalization process has caused major implications for manufacturing firms over the past decades. Production activities in multinational companies are now conducted within networks of factories dispersed worldwide, identified by the literature as *International Manufacturing Networks* (IMNs). Likewise, commercial, sales, engineering, and R&D activities are also carried out in globally distributed functional networks through the relocation of subsidiaries and factories with clearly assigned roles. Although the literature is rich in insights on how to organize single plants and how to manage a network of plants that is aligned with the production strategy, so far, scholars have poorly investigated the relationship between individual plants and the overall manufacturing network, as well as the intermediate level between the two, i.e., groups of intra-firm plants with similar characteristics. Moreover, the literature has neglected the relationships between the configuration of the manufacturing network and other functional networks. Thus, the overall objective of this thesis is to *enhance the understanding of multinational companies, offering a perspective that connects the role of the individual plant, the entire production network, and the related functional networks within the global value chain.* Based on this objective, four papers have been developed. The first paper explores manufacturing and R&D specialization, i.e., whether manufacturing and R&D activities are performed in isolated units within the network or are co-located in a tight plant cross-functional integration. A fuzzy-set Qualitative Comparative Analysis is conducted to examine the configurational effects of six conditions. The results show various combinations of factors that affect the level of integration of R&D and Manufacturing units. The second paper provides a structured definition of the concept of *manufacturing subnetwork*, recently introduced by the literature as a group of plants having similar characteristics and following a coherent manufacturing mission. The conceptual contribution of the work explains the way the subnetwork represents the intermediate level of analysis between the single plant and the network. Besides, the work highlights the differences with other concepts usually utilized by the literature and discusses the practical and managerial implications that the introduction of the subnetwork might have on the IMN domain. The third paper proposes a tool that can facilitate the identification, mapping, and evaluation of subnetworks within a multinational enterprise. In particular, an operationalization of the product and process

characteristics of the subnetworks is proposed. In order to design the tool, a design science approach has been adopted as the methodological foundation, with an interplay between case studies and the design science principles; the outcome of this research should be intended as a prototype for subnetworks description and evaluation. Lastly, a case study research strategy was followed to examine how a plant producing strongly differentiated product groups operates within an IMN. The results show the practices adopted by plants in managing their functions or departments (production, R&D, planning, warehouse and logistics, sales), in a perspective of intra-plant integration. Besides, the paper offers an interpretation of the multiple roles of the plant when examined through a subnetwork perspective. Overall, this dissertation sheds light on some poorly investigated aspects of the configuration and coordination of manufacturing networks in multinational companies while supporting practitioners who actually manage global operations in making more conscious decisions within a highly complex environment.

1. INTRODUCTION AND SCIENTIFIC BACKGROUND

This chapter introduces the research context of the dissertation and provides an overview of the scientific background. Section 1.1 motivates for this research by explaining the underlying research problems, together with the motivations and the purpose of the work. Section 1.2 is meant to provide a general overview of the literature on the topics covered, aimed at a further deepening in the following chapters.

1.1 Purpose and motivation to the research area

The importance of globalization in manufacturing is undeniable. In recent decades, international trade has increased exponentially, determining the globalization of markets, and leading to a global spread of productive networks. Large companies can no longer operate in a single domestic market, and they are forced to operate on an international or global scale. ***Multinational Enterprises*** (**MNEs**) are under tremendous pressure to reduce their production costs, choose the right place where to position their activities, and find the right ways to manage them.

The 2019 World Investment Report by UNCTAD shows a clear picture of the volumes of international business. To give an idea of the phenomenon, the global value chains that are run and coordinated by MNEs account for more than 80% of global trade and almost one-third of global GDP. In terms of research and development, the top 100 MNEs account for more than one-third of business-funded R&D worldwide (UNCTAD, 2019), where the three primary industries are automotive, technology, and pharmaceutical. Data by UNCTAD (2010) show the rapid growth of the number of MNEs worldwide in the last decades: global estimates indicate about 7,000 parent MNEs in 1970, 38,000 in 2000, while in 2008 the estimate had jumped to 82,000 (UNCTAD, 2010).

The rise of international trade resulted in a widespread restructuring of manufacturing systems. In order to survive in the rapidly evolving global economy, it became imperative for manufacturing companies to disperse their plants globally (Canel and Khumawala, 2001). The strategy of manufacturing companies has changed accordingly, passing from domestic supply and export to relying on supplying international markets through local production. This shift resulted in significant implications for manufacturing companies. Today's manufacturing is carried out within intra-organizational networks of globally dispersed factories. These coordinated networks of plants have been recognized by the literature as ***International Manufacturing Networks*** (**IMNs**) (Cheng et al., 2015; Rudberg and Olhager, 2003) where the matrix connections among plants are both via flows of information and physical goods (Rudberg and West, 2008). The design and the configuration of global production networks have become critical tasks for MNEs (Brennan et al., 2015) due to the need to integrate the benefits of distributed plant localization (to gain access to cheap labor, specialized resources, or emerging markets) into their operations.

The internationalization of sourcing and then of production was in many cases a starting point that created a snowball effect and led to the internationalization of other value chain activities (e.g., services, engineering, and R&D activities) (Cheng et al., 2019). The increase of the global presence of MNEs leads to the development of coordinated aggregations of facilities with different tasks (service, sales, engineering, R&D, etc.) owned by one company but located in different places, also called ***functional networks*** (Demeter, 2017; Johansen et al., 2014). This is combined with the presence of global markets, with suppliers and distributors spread across various regions. As a result, companies are required to manage a complicated set of relationships within a *global supply chain* (Caniato et al., 2013; Golini et al., 2016; Prasad and Babbar, 2000). Companies need to diversify their subsidiaries by consciously assigning roles or value-added activities and address the complexity of the geographical dispersion of these functional networks. Factories can specialize in only one of these tasks, or they can present a co-location of several tasks, creating tightly integrated functional networks. For example, one of the leading corporations in the production of sugar and sugar-related products has more than 130 facilities in all regions. These facilities do not only handle the production side of the business but are also co-located with other functional centers; out of the 7 R&D centers, five are located within production facilities, two are stand-alone centers and, in general, most of the production facilities are co-located with engineering centers, warehouses, sales offices, administrative offices, etc. Co-location and intra-firm interactions among factories and subsidiaries serving different roles have been analyzed in several contributions (Kahn and Mentzer, 1994; Maltz and Kohli, 2000), theorizing advantages and disadvantages of having a network with more or less integrated units.

However, there is not much research exploring the reasons why companies decide to adopt specific configurations in allocating their activities. While the literature has typically focused on the localization and distribution of unites (Cantwell, 2009), there are few frameworks for managing multi-functional networks in global companies (e.g., Wang et al., 2008).

A better understanding of the integration between the manufacturing network and other functional networks in MNEs becomes relevant for aligning the configuration of manufacturing with the business strategy, in particular for R&D and production, where employees' capabilities are less easy to be deployed on distributed units (Morschett et al., 2015). Subsidiaries in MNEs often control critical resources, acquiring autonomy and bargaining power in relation to their Headquarters (Vahlne and Johanson, 2014). Thus, a certain allocation of roles in globally dispersed subsidiaries implies the need for precise distribution of resources and capabilities (of plant and network) (Feldmann and Olhager, 2013), which is a key topic in the literature on IMNs and MNEs (e.g., Shi and Gregory, 1998a): for example, a purely productive plant needs different resources, knowledge, and capabilities than an integrated unit with production, research and development, and commercial objectives. Furthermore, the comprehension of the factors leading to integrated functional networks would support managers when modifying their networks. Knowing which drivers influence the level of integration facilitates the distribution of resources and the mix of capabilities to be developed, resulting in a better fit between configuration, coordination and strategy of the global network (Friedli et al., 2014). Despite the considerable research on international companies, the interaction between global production networks and other functional networks within the whole value chain has been indicated as an under-investigated topic (Cheng et al., 2015). There is still a need for contributions to fill this gap, especially in the field of operations management.

The management of ***production networks*** is also undergoing a significant transformation. While in the past most network changes were motivated by the pursuit of low production costs in foreign countries (Schmenner, 1979), today companies review their global networks based on a multitude of organizational and technological factors (Ketokivi et al., 2017).

Ferdows (2014) highlights three main reasons why studying global production networks is a challenge today: the first is the fact that production networks are susceptible to a *detail complexity*, prompted by a number of factors, sometimes contrasting, and decisions that affect them. Detail complexity refers to the need to include a large number of independent variables when evaluating an element or an issue (Senge, 1995). In the case of manufacturing networks, the variables that come into play are those typical of the analysis of most business decisions (for example, variables related to the demand, production processes, products, supply chains), but also variables connected to the geographical localization of production sites and their coordination, with a number of aspects regarding the specific countries where the plants are located (for example, local laws, tax regulations, political risk, currency fluctuations, national cultures) (Ferdows, 2018). The second reason is the *inherent hysteresis*, i.e., the delayed response to stimuli. Considering that it takes months or years to open a foreign plant and change the sites' configuration, network-level decisions only respond late to the inputs they receive. The third reason is that analytical modeling in this area offers only a partial answer: little is still known on the relationship between changes in global production and the variables that influence them; therefore, the *modeling* does not offer a credible alternative to empirical research like in other OM areas (for example, inventory management, quality management, scheduling, etc.).

To manage these challenges, the literature on IMNs has mainly focused on two levels of analysis: a plant perspective, directed to the management of the individual factory, and a network perspective, oriented to the connections among the whole set of plants (Cheng et al., 2015). While on the one hand scholars have usually considered all plants to be under full financial control (Rudberg and Olhager, 2003), on the other hand, they also recognize the need for more fine-grained studies on the relationship between the role of the plant and the network (Blomqvist and Turkulainen, 2019). In fact, the literature has generally neglected how the two perspectives - plant and network - can relate to provide additional insights to managers (Cheng et al., 2011). Likewise, very few studies dwelt on the intermediate level between these two perspectives, i.e., on the analysis of sub-groups of plants that share common characteristics or work for common product groups. A recent contribution by Ferdows et al. (2016) goes in this direction, delayering the network into ***manufacturing subnetworks***, i.e., sets of plants producing similar products and grouped together based on complexity and proprietary information of products and processes. The purpose of decomposing the network is to formulate multiple network scenarios for optimizing the structure and simplifying the company's management. To provide an example, a manufacturing company with globally distributed plants produces various families of products with significant differences: agricultural machines, construction machines, engines. It is possible to disambiguate which plants are working on product group 1, which on product group 2, which on product group 3. For these groups of plants, we can analyze their characteristics, understand how they work and, eventually, define subnetworks. Eventually, the typology of these subnetworks could also be analyzed. With this regard, two main typologies of subnetwork have been discussed by Ferdows et al. (2016), the *rooted subnetwork* - characterized by a high complexity of processes and products made - and the *footloose subnetwork* - characterized by simpler or standard products made with relatively simple processes. A handful of contributions further supports the initial work of Ferdows (Feldmann and Olhager, 2019; Golini et al., 2017), but there is still a lack of full-bodied literature.

Research on manufacturing subnetworks can significantly enrich the literature on global production management, and it might be of keen interest to the practitioners running global operations: the concept of manufacturing subnetwork is a way to disaggregate the network according to criteria of similarity and homogeneity (of products and processes), where the product-group network has typically much lower complexity than the manufacturing network for the entire company (Feldmann and Olhager, 2019); thus, the subnetwork allows to reduce the number of independent variables affecting the network into smaller sets and aimed at structures easier to be handled (Ferdows, 2018).

Being a concept introduced in recent times, the contributions about the basics of the subnetwork are still weak and the theoretical and practical insights that its introduction can offer are still unexplored (its conceptualization, the management of operations within the plant, the overlap between different subnetworks, etc.). As a result, the subnetwork can represent a relevant conceptual framework to reduce the distance between the plant and the network, one of the most prominent gaps in the literature on IMNs (Cheng et al., 2015), and to link high-level strategic management and operations research.

The study of the global production network is a fertile ground for future research, especially in the relationship between a firm's manufacturing strategy, the configuration of its global network, and the plant roles (Cheng et al., 2011). Managers should be aware that the pace of change in today's global economy will continue to accelerate (Johansen et al., 2014). As a result, it is difficult for global companies to think of network strategy as an intellectual effort to be conducted once every ten or fifteen years. In order to foster the alignment between strategy and configuration of IMNs, it is evident the importance of connecting the design of the productive network to the other functional networks within the value-chain (Cheng et al., 2015). Likewise, a well-managed IMN configuration is a formidable source of competitive advantage, while a poorly managed manufacturing network limits the firm's strategic options and can turn into a tremendous cost for the company (Ferdows, 2014); the analysis of the intermediate level between plant and network perspectives can represent a valid solution for managers to investigate new approaches and formulate adequate strategies for their IMNs.

Therefore, this dissertation leverages both primary and secondary data to build on previous knowledge while generating new insights on aspects not adequately addressed by former research. The scope of this thesis is limited to intra-company manufacturing networks. It explores the alignment between different perspectives of analysis - those looking at the single plant, the production networks, and network of facilities of the entire multinational – to better design and structure the configuration of production networks in global companies. This thesis aims to improve comprehension of the mechanisms driving the manufacturing of multinational enterprises, using an approach that combines individual plant and the entire production network (via subnetworks), and related functional networks within the global value chain. The four papers presented in this dissertation aim to provide theoretical and practical evidence on IMNs and MNEs, thereby expanding the body of knowledge on production management.

1.2 Literature background

This paragraph aims to position the research presented in the thesis to existing literature. The thesis is grounded in the operations management literature and is based on two streams of studies: multinational enterprises and international manufacturing networks. The following section reports relevant concepts of both streams. This paragraph is not expected to give an inclusive and detailed literature review but rather to provide the readers with definitions of the main concepts and tools to understand the theoretical framework within which the dissertation works. Main databases were used to search for related articles, for instance, those provided by leading publishers, Elsevier, Emerald, Wiley, or library services (e.g., Ebsco, Jstor). Section 1.2.1 focuses on Multinational Companies. Section 1.2.2 introduces the extensive literature on IMN, deepening the contributions on the network perspective. Section 1.2.3 offers a glimpse of the literature that has adopted a plant perspective. Finally, Section 1.2.4 provides the main limitations of these streams of research.

1.2.1 Multinational Enterprises

A *Multinational Enterprise* (MNE) is defined as "*an enterprise that controls and manages production establishments – plants – located in at least two countries*" (Caves, 2007, page 1). The term has been used in a similar way to *Multinational Company* (MNC) or *Multinational Corporation*, with nuances of meaning not always clear, but still indicating the set of subsidiaries and other assets dispersed in more than one region (Chang and Taylor, 1999). Morschett et al. (2015) characterize multinational corporations as any company having routine cross-border activities. Again, Bartlett and Beamish (2018) see an MNE as an enterprise that comprises entities in at least two countries, regardless of the field of activities, and where there is a strong link or ownership among these entities resulting in a common strategy through one or more decision-making centers. In general, despite some authors require some quantitative thresholds to be respected for MNEs (e.g., a minimum number of countries occupied by foreign entities, a minimum number of employees abroad, etc.), most of the literature consider these thresholds as arbitrary and judgmental (Morschett et al., 2015).

Sometimes, the literature uses the term multinational organization to indicate a particular type of global company, according to the widely accepted framework of

Bartlett and Ghoshal (1989) which identifies *International*, *Global*, *Multinational*, and *Transnational organization*, based on forces for global integration and global responsiveness (for further details, see also Bartlett and Beamish, 2018; Harzing, 2000; Morschett et al., 2015). In this thesis, the terms MNE or MNC will be indifferently used to indicate multi-facility companies, with a strong presence on international markets and with at least one production plant outside the country of origin.

The first academic contributions on MNEs date back to 1960's when the term "globalization" started to be used frequently by economists and social scientists. Research on MNEs covered localizing factors, the importance of going abroad and drivers for industry globalization (e.g., Kogut, 1990; Yip, 1989). Over the last decades, MNEs have assumed a predominant role in the economic development, given the growing integration of economies around the world and the dramatic rise of cross-border activities of companies. Considering the complexity of today's large enterprises, MNEs can be seen as both differentiated networks (Ghoshal and Nohria, 1989), where factories and subsidiaries play different and specific roles, and integrated networks (Bartlett and Beamish, 2018) due to the need of collaborations among the dispersed activities. As such, the literature covered both the configuration aspects, i.e., the locations and countries where the different activities are performed, and the coordination aspects, i.e., activities integration, the allocation of resources, the communication in an intra and inter-site networks perspective (Morschett et al., 2015). Several relevant models have been provided for explaining the international or global presence of multi-plant companies. For example, Caves (1996) divides them into three main groups: a) a first type of MNE that produces the same line of goods in each country where it is operating; b) a second type of vertically related MNE that produces an output that serves as inputs for its other activities; c) a third type of diversified MNE that produces an output in plants that are neither vertically nor horizontally related to one another.

Some of the topics most frequently addressed by the literature on MNEs are: the motives for internationalization (e.g., Dunning, 1988); the headquarters-subsidiary relations (e.g., Dellestrand and Kappen, 2012); the location of activities and offshoring and reshoring issues (Fratocchi et al., 2014); the formal and informal coordination mechanism (Martinez and Jarillo, 1989); the role typologies of foreign subsidiaries (Schmid, 2004; White and Poynter, 1984). It must be noted that the concept of role in

MNEs, i.e., the functional value-added activities (for example, manufacturing, sales, R&D, etc.) differs from the concept of *role of the plants* in IMN literature, which instead consists of the way in which the manufacturing objective is achieved (for further details, see paragraph 2.3, 5.2, 6.2).

Likewise, in MNEs literature there has been a lot of attention to spatial choices, as well as co-location of activities (see Chapter 3.2 for in-depth information). In particular, the relationships between the role of HQs, production plants and R&D sites were thoroughly analyzed (e.g., Castellani and Lavoratori, 2020; Dunning, 2009). Other influential contributions concerned the tension between forces that push towards a global subsidiary network optimization ("global integration") and those that push towards an adaptation of the company according to the countries where it is established. (“local responsiveness”) (Bartlett and Beamish, 2018; Doz, 1980).

Overall, the study of international issues has evolved over time with a growing focus on the network rather than the individual establishment. In particular, contributions have evolved from global sales and marketing into problems related to global manufacturing (Rudberg and Olhager, 2003). Concerning companies’ operations, numerous key theories have been applied to the internationalization process mainly to explain the global production operations of MNEs (Cheng et al., 2015). For example, the transaction cost theory (Williamson, 1971), the eclectic theory (Dunning, 1988), the industrial organization theory (Hymer, 1976), the internationalization process model (Johanson and Vahlne, 1977), and the resource-based view (Barney, 1991) have been used. These contributions paved the way for an extensive IMN literature.

More generally, as clearly summarized by Tallman and Pedersen (2011) "much of business and the environment of business have become global in the last decade or two". The production network is only one part of the complicated web of relationships that is established in multinational companies. Nowadays, there is a massive effort to coordinate the supply chain (SC) of companies (Cagliano et al., 2006) and a growing academic interest has been dedicated to *global supply chain management* (Golini et al., 2016; Prasad and Babbar, 2000).

MNEs consist of various networks, including those formed by non-productive facilities, suppliers, subcontractors, distributors, customers. The literature suggests that global supply chain management is the combination of three different but mutually interrelated operational processes, namely global sourcing, global manufacturing and global distribution, intended as the management of global sales and distribution channels (Bello et al., 2004; Caniato et al., 2013).

Despite the globalization of supply chains has been an enormous opportunity for companies, it has also represented a source of new challenges, for example, longer lead times, higher risks and an increased complexity in managing networks (Caniato et al., 2013; Dornier et al., 2008; Minner, 2003). This raises the question of how companies can organize their global supply chains to compete efficiently and effectively (Ibrahim et al., 2015). For a well-rounded comprehension of IMNs, it is therefore useful to emphasize the importance of understanding supply chain dynamics (Connelly et al., 2013). For example, Ketokivi et al. (2017) emphasize that understanding interdependencies in the supply chain is a fundamental step to implement correct localization decisions on production plants.

However, the analysis of supply chain aspects is only partially within the scope of this thesis. Most of the IMN literature focuses mainly on manufacturing aspects and there are few studies that do not merely analyze intra-firm multi-plant manufacturing networks (Cheng et al., 2015). Rudberg and Olhager (2003) underline that little attention has been put on the physical distribution to and from the manufacturing facilities in IMN literature. Thus, the thesis will only marginally address issues related to supply and sales channels. It will focus on production plants (Chapter 4-5-6), or owned plants (Chapter 1), limiting the aspects related to global supply chain management.

1.2.2 The International Manufacturing Network level

Differently from the literature on MNEs, IMN research focuses on production plants. An International Manufacturing Network is defined as a "*coordinated aggregation (network) of intra-firm plants/factories located in different places*" (Cheng et al., 2015, page 393). IMNs are also referred to as Global Production Networks (GPNs) by the literature, even if less frequently (Norouzilame et al., 2014). Sometimes, albeit rarely, scholars have considered an extended view of the manufacturing network by also incorporating relevant suppliers (Cheng et al., 2011).

One of the main concepts underlined by several contributions studying global networks (e.g., Shi, 2003; Shi et al., 1997; Shi and Gregory, 1998a) is the view of a matrix connection among plants where "*each node (i.e. factory) affects the other nodes and hence cannot be managed in isolation*" (Rudberg and Olhager, 2003, page 30). Moreover, the trend of shifting from stand-alone factories toward more globalized production has been accelerated by the continuous growth of developing economies worldwide (Norouzilame et al., 2014).

Research on IMN has its roots in the literature on international strategy, which tackles the topic with a broader perspective (Feldmann and Olhager, 2019). While research on supply chain/network usually takes a logistical perspective (physical distribution, materials management, planning and control) considering facilities as entities owned by different organizations, the manufacturing network operations adopt an internal perspective, considering plants as key components. The literature began to deal with the migratory phenomena of companies, particularly at the end of the 1980s, describing the triggering factors (drivers) of company globalization, such as market, cost, government, and competition (Yip, 1989) and the advantages brought by this type of activity. The initial contributions on international manufacturing ignored network issues (Schmenner, 1982), but scholars early recognized the need to manage not only the single factory, but also multi-plant organizations. In fact, in the last two decades, research on Operations Management (OM) has seen a growing consensus towards the concepts of manufacturing network, a key element to understand the complexity of the global companies (Coe et al., 2008). Managing Global networks has become increasingly important for manufacturing companies, given the considerable impact that manufacturing networks can have on performance and profitability (Bartlett and Ghoshal, 1989; Ferdows, 1997; Hayter, 1997). Thus, the literature on IMN became one of the research foci of this understanding.

Without any doubt, the presence of a plurality of plants in a global context makes the organization and management of the network more complex. Given the definition of IMN, i.e., a coordinated aggregation (network) of plants owned by a single company but located in different locations, it is implicit that two main levels of analysis arise within the IMN research: a plant perspective and a network perspective. In a recent systematic literature review, Cheng *et al*. (2015) explained that one of the aims of their work is to "*distinguish between the two separate levels (Plant and Network) as basic building blocks* *of IMN*". Most of the literature over IMNs has been dedicated to these two levels, and coherently, the literature review of Cheng *et al.* (2015) includes 40 articles at the plant-level analysis and 67 articles at the IMN-level analysis, with a growing trend that moves from plant analysis to network analysis.

These aspects emphasize the need for dealing with both geographical dispersion of plants and interdependent coordination among plants for an effective network management. At the network level, scholars agree that the configuration of plant's network and the means of coordination are the two critical determinants of the competitiveness of a manufacturing network (Rudberg and West, 2008; Szwejczewski et al., 2016). While network *configuration* concerns the "where", i.e., the location of plants and the allocation of resources typically involved in the value chain (Meijboom and Vos, 1997), the *coordination* concerns the connections between nodes, i.e., the relational aspects through which the plants collaborate each other (Colotla et al., 2003). Traditionally, research has provided more contributions to IMN configurations, while less attention has been dedicated to coordination (Cheng et al., 2015).

Over the decades, the literature at the network level has evolved through different streams, each characterized by a specific focus: for example, the production knowledge transfer (e.g., Deflorin et al., 2012; Ferdows, 2006), the development of multi-plant operations strategies (e.g., Prasad and Babbar, 2000; Schmenner, 1979), and the analysis of multi-plant configuration and coordination (Rudberg and Olhager, 2003). At the network level, companies operating a set of dispersed manufacturing plants can manage a complex system by considering both the plants' structure and locations and their mutual relationships. Companies can potentially benefit from the individual capacities of each plant, and at the same time, exploit the distinct advantages or capacities deriving from the network itself (Colotla et al., 2003). Particular importance was played by the theme of *strategic capabilities* derived from the system configurations – resource accessibility, thriftiness ability, manufacturing mobility, learning ability – (Shi and Gregory, 1998), where the ability of a company consists in being able to renew, increase and adapt its basic skills over time.

1.2.3 The plant level

Always within the IMN literature but keeping a plant perspective, scholars mainly focused on plant locations, plant roles, and site competencies, with a relatively stable publication rate over the years (Cheng et al., 2015). Early research focused on plant location decisions and location factors, where the pivotal objective was to select the least expensive production site in a cost-minimization perspective (Meijboom and Voordijk, 2003; Schmenner, 1979). Over time, there has been an increasing need to consider other factors in the localization choices, such as intangible and qualitative features: much research has been developed on the identification of the drivers to allocate the plants abroad (e.g., Bolisani and Scarso, 1996; Demeter and Golini, 2014; DuBois et al., 1993; Vos, 1991), finding a multitude of factors (e.g., proximity to market and suppliers; access to specific skills, knowledge, infrastructure; availability of labor; availability of emerging economies; access to complementary services, etc.).

The research on the strategic *role of the plant* has also represented an important fraction of contributions over manufacturing plants. The basic assumption of this stream of literature in IMN is the recognition that production plants can play a different role within the network than simply providing low-cost manufacturing. Understanding the specific role of the units composing the network defines a correct structure and facilitates an appropriate allocation of resources, people, and skills. The first contributions to the plant's role belong to Ferdows (1989, 1997), which divided the production plants according to the site competencies and the strategic reasons for locating sites. These studies were the first to suggest a kind of hierarchy among plants in terms of competencies and consequently in the roles within the network. Afterward, several contributions have validated the Ferdows's model, provided new frameworks, and further widened the discussion (see paragraphs 3.2.1 and 5.2.1 for additional details). Connected to this theme, literature has also tackled the areas of site competence that individual units develop to accomplish their manufacturing goals and the knowledge flows among plants (Vereecke et al., 2006). In particular, the role of the plant has often been studied in conjunction with site competence level (e.g., Feldmann et al., 2013, 2009; Golini et al., 2014).

1.2.4 Limitations of research

Section 1.2.1, 1.2.2, and 1.2.3 have highlighted concepts and definitions of the main literature streams which are relevant for this dissertation. Three different perspectives with which looking at globally dispersed enterprises have been introduced:

1. a first perspective that considers MNEs, i.e., the whole set of factories including both manufacturing activities and the other value-added activities carried out in the globally dispersed factories.
2. a second perspective that analyzes IMN, i.e., that focuses on the set of manufacturing plants and facilities.
3. a third perspective that studies the individual plant.

Concerning these different levels of analysis, Cheng et al. (2015) identified some under-investigated topics, two of which are particularly relevant for this dissertation.

The first gap concerns the inadequate research about the relationship between MNEs and IMNs, or rather the lack of attention in the relationship between the manufacturing network and the other functional networks (R&D, sales, commercial, engineering, etc.). Scholars have often differentiated the contributions of IMNs and MNEs, despite the two being strongly correlated. In today's fast-changing world, the linkages between production, R&D, and other functions are fundamental. This means that network configuration decisions can no longer be based on traditional geographical advantages and production cost minimization, but they also need to consider the location of other value-added activities, the knowledge transfer, and the interrelations among networks. However, the intercorrelation among IMNs and other functional networks is still little analyzed (Cheng et al., 2015), with articles providing insights about a specific snippet of the overall value chain. Few theoretical and practical frameworks for managing multi-functional networks in global companies exist (e.g., Wang et al., 2008), and further studies are recommended.

The second gap lies in the fact that there is still little evidence of the relationship between plants and networks and even less of the intermediate level between the plant and the network. The perspective with which studying international companies has been subject to debate, in particular with the growing *microfoundation literature* (Felin and Foss, 2005) where the global strategy has been considered as "*inherently multilevel in nature, involving intricate relations between what goes on at different levels*" (Contractor *et al.*, 2019, page 4). However, different levels of analysis lead to different results. There are some contributions that seek to combine the two perspectives of plant and network, for example, studying the impacts at the network level that occur as a result of changes at the plant level (Cheng et al., 2011; Feldmann et al., 2013; Miltenburg, 2015; Scherrer and Deflorin, 2017), or studying the relationships between plants and network capabilities (Colotla et al., 2003). Although the attempts to connect the two levels of analysis, little has been said about the intermediate level, i.e., taking a perspective that considers sub-groups of plants according to their characteristics. Some studies divide plants according to specific dimensions, for example, based on the "*multiplant strategies*" (Schmenner, 1979) (see paragraph 4.4.1). Other scholars (Feldmann et al., 2013) showed different manufacturing networks for two products that belong to the same business unit. But most of this research lacks an empirical analysis of how the subdivision of plants can help network management. Undoubtedly, the contributions of Ferdows (2009, 2016) on subnetworks gave a strong boost and brought a new light to this stream of research. Golini et al. (2017b) gave further insights on the theme, while Feldmann and Olhager (2019) applied the concept of subnetwork to product-groups networks, studying their characteristics and functioning. However, a substantial effort can still be made to deepen the intermediate level between plant and network and bring new emphasis to the IMN research.

2. RESEARCH OBJECTIVES AND METHODOLOGY

In this chapter, section 2.1 introduces the research objectives and questions this dissertation deals with. Section 2.2 describes the resulting design and the structure adopted for the four papers to address the research questions formulated. Finally, section 2.3 illustrates the research methodology followed.

2.1 Research objectives and research questions

The gaps identified after reviewing the literature on MNEs and IMNs were the basis for defining the overall goal and the research objectives of this dissertation. The **overall goal** of this thesis is *to enhance the understanding of multinational companies, offering a perspective that connects the role of the individual plant, the entire production network, and the related functional networks within the global value chain.* In particular, the dissertation sets three main research objectives for which specific research questions are formulated.

First, literature has shown that in today's markets, MNEs have to manage the development of coordinated aggregations (networks) of facilities of service, sales, engineering, and R&D owned by one company but located in different places. The literature on MNEs has often analyzed individual subsidiary in terms of value-added functions developed (e.g., Birkinshaw and Hood, 2000; Ghoshal and Bartlett, 1986; Schmid, 2004), but there are still few frameworks for managing multi-functional networks of geographically dispersed activities and for understanding the interactions between manufacturing and other functions. In addition, the presence of subsidiaries that play multiple roles (for example, they are characterized by a productive role, commercial, and research and development role) is still little analyzed, and value chain elements are usually tackled separately from manufacturing in the literature (Demeter, 2014; Roth, 1992).

Therefore, a typical aspect that characterizes networks is the level of *specialization*, intended as the level of co-location and integration between the various functions (production, R&D, commercial, engineering, etc.) within the factories worldwide. In order to connect the production network with other functional networks within the multinational company, the **first research objective** is to understand *what drives an MNE to a higher or lower level of specialization (i.e., lack of inter-functional integration) of the individual globally dispersed units*.

Literature studied manifold factors influencing the co-location of functions and specialization of the units, for example, the size of the company, the number of plants, the R&D expenditure, the distance between points, the complexity of products and production processes (e.g., Alcácer, 2006; Alcácer and Delgado, 2016; Castellani and Lavoratori, 2020; Ketokivi and Ali-Yrkkö, 2007). However, the research has neglected a) the co-location between more than two types of networks and b) the analysis of sets (aggregation) of factors combined with each other (studying only the effect of individual factors). Concerning the production network, few contributions (e.g., Wang et al., 2008) study the interactions between manufacturing and other functions in a multi-functional network of geographically dispersed activities. In this perspective, network configuration decisions based on traditional geographical advantages or cost minimization may no longer ensure sufficient competitiveness (Meijboom and Voordijk, 2003). Instead, it becomes relevant to incorporate every activity along the value chain, coordinate the different functions and align them with the location of global operations, especially for some of these capabilities, like R&D and production, that are not easily redeployed (Morschett et al., 2015). For these reasons, with reference to the first objective of the thesis, the focus will be oriented to production and R&D networks. The relative research question is the following:

> ***RQ1****: What is the combined effect of different factors on higher or lower levels of manufacturing and R&D specialization in globally dispersed subsidiaries?*

Despite recognizing the presence of different types of networks, and collecting data on them, the research will mainly focus on two key activities, Manufacturing and R&D. Understanding the reasons why MNEs realize networks of facilities with highly (or poorly) integrated activities and roles allows better control over the possible evolution of the company, with positive impacts on the entire value chain management.

While the literature on MNEs has divided the networks according to the typology of value-added activities, the literature on IMNs has explored management models that divide production activities (the production network) according to the characteristics of the plants (e.g., Hayes and Schmenner, 1978; Schmenner, 1982; Hayes et al., 2005; Friedli et al., 2014). Concerning the manufacturing network, numerous management models have been introduced to disambiguate the role of production plants and better explore how to manage them (see paragraphs 4.4.1, 6.2.1, and 6.2.2 for more information). One of these modes is the recent introduction of the already discussed concept of manufacturing subnetwork (Ferdows et al., 2016): the network is divided into sub-groups of plants with similar characteristics according to the complexity and proprietary information of products and processes. Using Simon's (1973a) terminology, the subnetwork is still a relatively ill-structured concept and very few contributions have deepened the theme (Feldmann and Olhager, 2019; Golini, Vanpoucke, et al., 2017). For these reasons, the **second research objective** is *to understand better the meaning and usefulness of the intermediate level between plant and network - the subnetwork - within IMNs, studying its characteristics and functioning.*

As indicated in section 1.1, the two main levels of IMN research, i.e., plant level and network level, are usually discussed independently. The subnetwork can be considered as a new unit of analysis whose primary objective is to reduce the complexity of the network (Ferdows, 2016), identifying ad-hoc mechanisms for smaller and easier to manage structures. The lack of theoretical and empirical contributions to support Ferdows' initial work requires the creation of an unambiguous definition and tools to handle it effectively. Two research questions have been formulated starting from the above-mentioned considerations:

RQ2*: What is a manufacturing subnetwork?*

This exploratory research question is motivated by the need to provide a definition and a clear conceptualization of the manufacturing subnetwork and well-defined boundaries within the OM literature. The following step turned to a more operational dimension and answered the question:

RQ3*: How can subnetworks be identified within a multinational company and how to describe them in a systematic way?*

The objective here is to offer a tool for identifying subnetworks of plants and describing them in a systematic way through the operationalization of their characteristics.

The subnetwork perspective undoubtedly introduces a different paradigm than traditional methods of subdividing activities. In this sense, the concept of subnetwork still lacks a clear link with the behavior of the single manufacturing plant. The analysis of the plant in the IMN context was carried out from multiple perspectives and analyzing different elements (the role of the plant, its capabilities, skills and knowledge, the information sharing process, etc.). Also the concept of "role of the plant" (see paragraphs 4.2.1 and 6.2.1) has attracted many studies (e.g., Ferdows, 1997, 1989; Vereecke et al., 2006) proposing theoretical and empirical models. However, after the contributions on the focused factory about Skinner (1974) and other scholars more recently (Brumme et al., 2015; Wang et al., 2015), the plant has been very often seen as an element with a single manufacturing mission. The concept of manufacturing mission denotes the production objective and function that a specific plant, network or company should accomplish (see Chapter 6 for more details). To simplify, the mission of a plant is the products it manufactures (Paquet et al., 2004).

What has been less emphasized is the behavior of the single plant when involved in multiple manufacturing missions, i.e., strongly different productions. Companies are increasingly producing product groups that are also very different from each other, with a view to widening and diversifying their offer (Feldmann and Olhager, 2019); multi-production sites acquire a critical role. Therefore, the third objective aims *to understand how the plant behaves when involved in more manufacturing objectives.* The research question formulated is as follows:

RQ4*: How is a plant having multiple manufacturing missions managed?*

This research question answers the need to understand how individual plants whose design is made complicated by a wide range of strategic mandates are managed. The question is split into two further specific questions which aim, respectively, to: a) understand whether the functions and departments within plants producing several distinct product groups are managed in a shared way or there is a physical/logical separation (leading to the product groups being managed rather separately); b) understand how the plant's role can be within plants of this type.

Figure 2.1 shows the research structure with the four research questions and the perspective that each research question considers. The four papers use different units of analysis, contributing to a multi-perspective analysis. All three research objectives aim to analyze the production side of multi-plant international companies through different lenses:

- RO1) relation of the productive part with other functional networks.
- RO2) subnetwork and decomposition of the network.
- RO3) management of the manufacturing plants in case of multi-production.

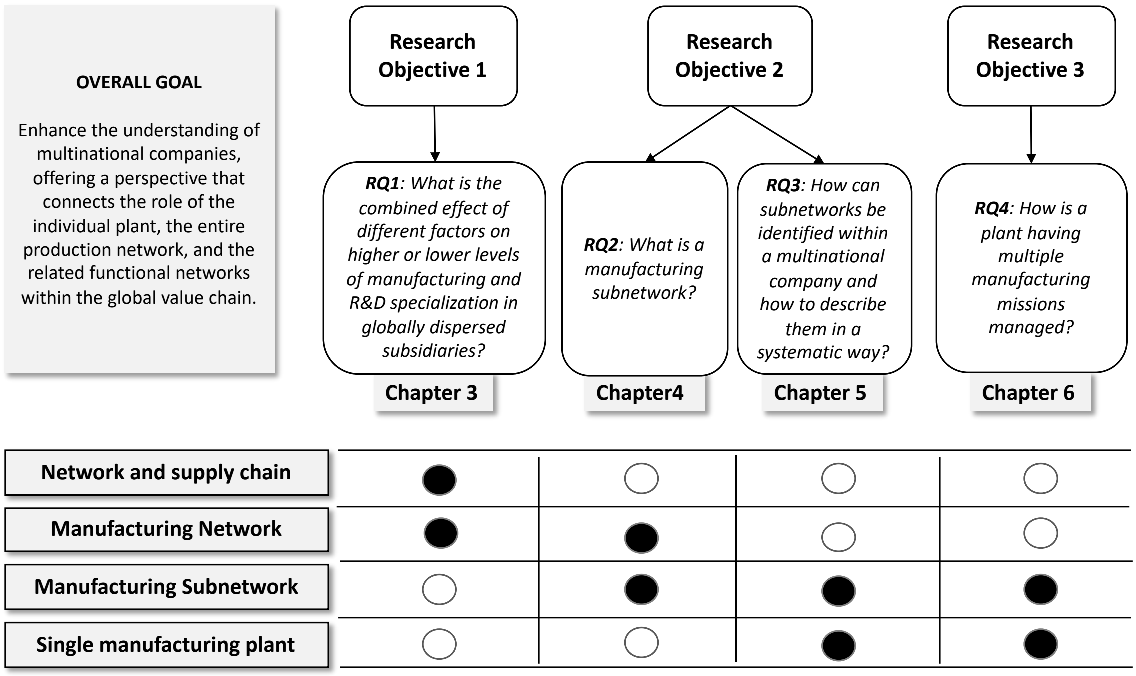

Figure 2.1: Research Structure

2.2 Research design and structure

This dissertation includes seven chapters, as visualized in Figure 2.2. The purpose of each chapter and their main contributions to the research objectives and questions are summarized in the following. Chapter 3, Chapter 4, Chapter 5, and Chapter 6 represent the four papers that have been developed to answer the RQs formulated.

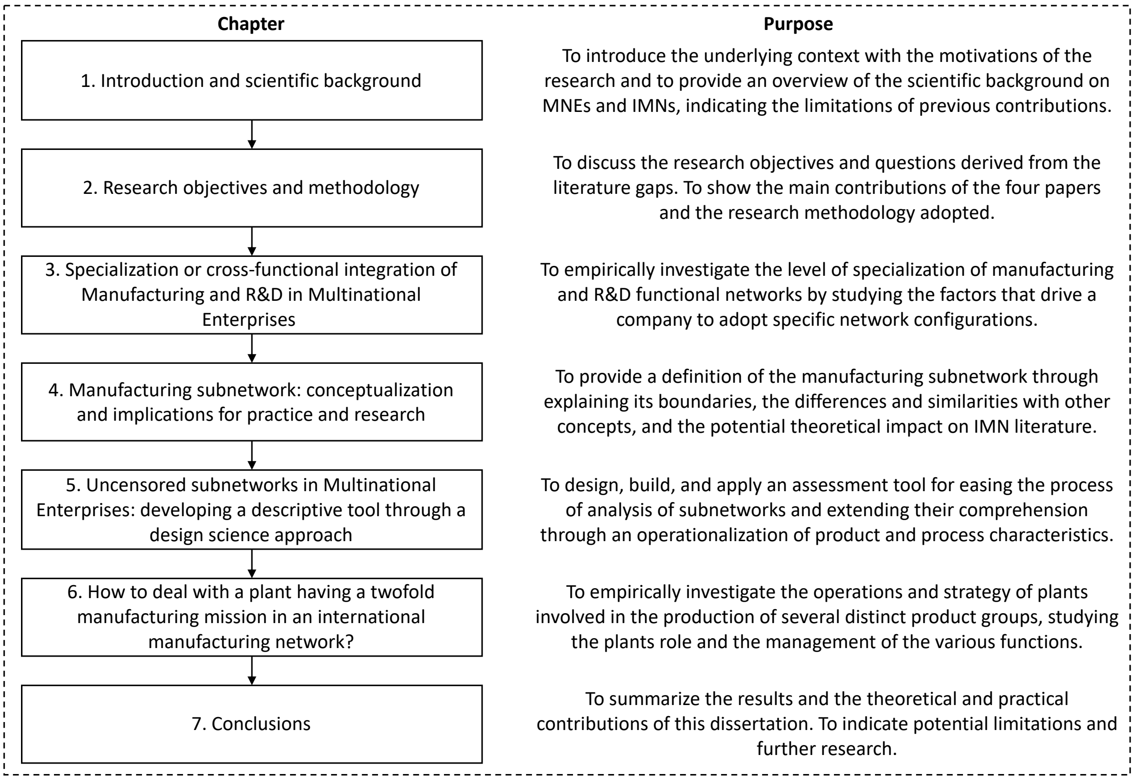

Figure 2.2: Structure of the dissertation

Chapter 3 addresses RQ1 with a study on the specialization or integration of functional networks in global companies. The chapter starts with the analysis of secondary data to find the main roles that branches can undertake (production, R&D, commercial, administrative) and studies the relationships of globally dispersed functional networks. In particular, the paper focuses on manufacturing and R&D specialization, i.e., whether manufacturing and R&D activities are performed in isolated and specialized units within the network, or they are co-located with other functions through a tight plant cross-functional integration. The paper mainly answers the "Why?" questions, i.e., it deals with the factors (or drivers) that induce a company to adopt specific configurations for their functional networks.

Chapter 4 delves into the subnetwork analysis and aims to address RQ2. The essay presented is structured around three main elements of analysis: the first is the definition of what a subnetwork is, with the analysis of its theoretical boundaries. The second is the comparison of the concept of subnetwork with other concepts already used in the literature (business units, networks) to highlight their differences and similarities. The third is to show the practical implications that the introduction of subnetwork might have in relation to some well-known IMN's topics: the plants role, the capabilities, and the manufacturing strategy.

Chapter 5 addresses RQ3 and, starting from the contributions of Chapter 4, further deepens the understanding of subnetwork within global enterprises. The paper designs and builds a descriptive tool that can be used in the evaluation of subnetworks. In particular, the tool aims to help managers in identifying how many and which are the subnetworks in an IMN, mapping the activities, and hierarchically decomposing the network into different subnetworks. Besides, the tool proposes an operationalization of the product and process characteristics of subnetworks.

Chapter 6 addresses RQ4 by adopting both a subnetwork and a plant perspective and studying how plants involved in multiple manufacturing missions are managed. The contribution of this chapter is to get into the operations of how different product groups networks (Feldmann and Olhager, 2019) are managed. The paper compares the practices adopted by plants in managing their functions or departments (production, R&D, planning, warehouse and logistics, sales), in a perspective of intra-plant integration. A subnetwork-level analysis is applied to the two product-group networks being manufactured into the plant under analysis, where the first product group includes standard and low-tech products, the second includes personalized and high-tech products.

Finally, *Chapter 7* provides a conclusive discussion about the dissertation. In particular, the chapter debates the main research findings, linking the results to the proposed research questions. Besides, the theoretical and practical implications are explored; the section concludes with the limitations of this dissertation, pointing out opportunities and areas for further research.

2.3 Research strategy and methodology

This dissertation is aimed at generating scientific knowledge on the management of MNEs and IMNs. To provide solid constructs and assure evidence of credibility (Lee and Lings, 2008) to the results, an adequate selection and application of research strategies and methodologies is essential (Bell et al., 2018; Easterby-Smith et al., 2012).

In Chapter 3, secondary data were collected on more than 2200 subsidiaries in 34 MNCs. Methodologically, cross-tabulations helps to identify potentially relevant factors, then a fuzzy-set Qualitative Comparative Analysis (QCA) (Ragin, 2000) is conducted to examine the configurational effects of six conditions impacting on specialization. The practical goal of QCA is to explore evidence descriptively and configurationally (Ragin, 2000), rather than to test the theory. QCA interprets the data qualitatively whilst also looking at causality between the variables. This method is based on two assumptions: first, that an output is often the result of different combinations of factors; second, that different combinations of factors can produce similar output (Ragin, 1984). These two conditions make QCA particularly suitable as complementary lenses to understand better causal patterns of the phenomena under observation (Fainshmidt et al., 2020). The "why" question of RQ1 and the search for set (aggregation) of drivers or conditions for manufacturing and R&D specialization make this methodology particularly suitable for the research purpose.

Chapter 4 presents mainly a conceptual contribution. The analysis does not show a real empirical analysis but paves the way for further research over subnetworks. It leveraged on a literature review on the use and meaning of specific concepts- network, subnetwork, business unit - as well as different well-known IMN's topic (role of the plants, factory and network capabilities, manufacturing strategy). Furthermore, practical examples from four real cases have been used to give additional evidence on the conceptualization developed and its managerial implications.

In chapter 5, a design science approach (Hevner et al., 2004) is used as methodological foundation, with an interplay between case studies and the design science principles (Kaipia et al., 2017; Wagire et al., 2020). The *Design Science Research* (DSR)-based process is modeled on the first three of the four phases described in Holmström et al. (2009), namely solution incubation, solution refinement, and explanation phase (Middle-Range theory). In particular, the research develops five exploratory case studies in international or multinational enterprises to build the descriptive tool, main output of the research. Then, the tool is applied in the European network of one of the business units of a company with more than 30 globally dispersed manufacturing plants.

In Chapter 6, an exploratory multiple case study approach (Eisenhardt, 1989; Yin, 2009) is adopted to address the research question, where the unit of analysis is the single plant involved in two (or more) product-group networks. Case study research is highly recommended for theoretical and descriptive understanding of complex phenomena (Yin, 1994) and particularly suitable in operations management (Voss, 2002). Twelve plants in international networks were analyzed, mainly adopting an inductive approach. Data were coded and analyzed by considering individual functional activities and the roles of the plants within the networks. In order to assure reliability, construct validity, internal and external validity of the case studies, the methodological suggestions provided by numerous scholars (Eisenhardt, 1989; Karlsson, 2016; Miles and Huberman, 1994; Saunders et al., 2009; Voss, 2002) were followed. Table 2.1 summarizes the methodology choices of the research.

Table 2.1: Research Methodology

	Chapter 3	**Chapter 4**	**Chapter 5**	**Chapter 6**
Research questions	RQ1	RQ2	RQ3	RQ4
Research strategy	Qualitative and quantitative	Conceptual	Qualitative	Qualitative
Research design	Fuzzy set QCA	Literature review	DSR-based approach	Multiple case studies
Purpose	Theory exploration and description	Theory extension	Theory extension	Theory exploration

3. SPECIALIZATION OR CROSS-FUNCTIONAL INTEGRATION OF MANUFACTURING AND R&D IN MULTINATIONAL ENTERPRISES

***Acknowledgement**: This chapter is derived from the article "Carminati, P., Kalchschmidt, M. (2020). Factory Specialization or Aggregation in Global Networks: Relationship between Manufacturing and R&D location" presented at the DSI (Decision Sciences Institute) 51st Annual Conference in November 2020. I am personally responsible for any changes made from the last version. I extremely appreciated the work with my co-author Matteo Kalchschmidt, who has always been available to provide guidance and share ideas.*

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Abstract

Spatial organization and location choices for Multinational Enterprises (MNEs) have long been two predominant themes in literature. In contrast, less has been said about the co-location of different value-added activities (e.g., production, R&D, sales, etc.). This paper collects secondary data at a network- and plant-level to explore how MNEs configure their networks from a geographical point of view. It focuses on manufacturing and R&D *specialization*, i.e., whether manufacturing and R&D activities are performed in isolated and specialized units within the network, or they are co-located with other functions through a tight plant cross-functional integration. Data from 2267 units in 34 MNEs were collected; a fuzzy-set Qualitative Comparative Analysis (QCA) is conducted to examine the configurational effects of six conditions impacting on the specialization of manufacturing and R&D functions: company size, average units' size, dispersion of manufacturing and R&D networks, average distance among all the network's units, average distance among manufacturing and R&D units. Our results show that different configurations are linked to high manufacturing specialization and high R&D specialization, as well as to the absence of these outcomes. The article concludes by providing a categorization of companies based on their manufacturing and R&D specialization levels and discussing it based on previous contributions to MNEs.

Keywords: Multinational Enterprises, fsQCA, Manufacturing, R&D, location, cross-functional integration.

3.1 Introduction

MNEs develop their networks by carefully allocating activities, resources, and competencies based on different factors, such as strategic goals, market characteristics, and competitive scenarios. In international management literature, these value-added activities (e.g., production, R&D, sales, etc.) have been studied in relation to the "subsidiary role", i.e., the specific tasks the foreign unit has within the network (Andersson and Forsgren, 1996; Birkinshaw, 2016). Each unit can have a very specific task (i.e., perform a specific function – production duties, sales or commercial duties, Research and development, etc.) or a diversified task (i.e., the same unit performing different value-added activities). To provide a practical example, an R&D lab may be positioned in a site together with production, commercial, or distribution activities, or the company may have opted for an extreme specialization in which the unit has only a research and development objective. Similarly, a manufacturing plant may be complemented by (and co-located with) different functions, or it may only fulfill production duties.

This intra-firm interaction among value-added functions has been analyzed in several contributions (Kahn and Mentzer, 1994; Maltz and Kohli, 2000) under the generic name of *cross-functional integration*, theorizing advantages and disadvantages of having a network with more or less integrated units. Besides, also co-location of different functions has a long tradition in International Business studies, especially for manufacturing and R&D (Castellani and Lavoratori, 2020; Ivarsson and Alvstam, 2017; Ketokivi and Ali-Yrkkö, 2007). Based on different factors, companies decide the geographical distribution of manufacturing plants and R&D sites according to the objectives and duties of the networks' units. For example, this strand of literature has emphasized that the propensity to co-localize manufacturing and R&D can vary substantially according to firm characteristics (Ketokivi et al., 2017). The allocation of roles and tasks is a key aspect of today's manufacturing companies. It influences the configuration and coordination of the network (Morschett et al., 2015), in particular for some of these capabilities, like R&D and production, that are not easily redeployed.

However, there is not much research exploring the reasons why companies decide to adopt specific configurations ("where to do what") in the allocation of their activities. The notion that all the factories must be capable of multiple value-adding activities negates the advantage of efficient development and sharing of resources within the MNE (White and Poynter, 1984). Thus, specific attention should be devoted not only to understanding how companies distribute manufacturing and R&D sites geographically, but also to comprehend how they integrate different functions among units. While the literature has typically focused on the first problem (i.e., the localization and distribution of units) (Cheng et al., 2015), cross-functional integration has been less analyzed.

This paper aims to investigate the co-location of R&D and manufacturing with other value-added activities in MNE, analyzing the higher or lower level of *specialization* within the same unit. The analysis explores the moderating circumstances that may affect the specialization of these two value-added functions in comparison to the other company's functions. More precisely, the interest is oriented to the sets of conditions (the configurations) leading to a specific spatial organization. The objective is to analyze the combinations of factors leading to the same company configuration.

The study uses qualitative and quantitative data of 2267 units on 34 multinational companies, collected through a plant-level and network-level analysis. Data about economic, dimensional, and geographical aspects were collected for all the plants in the network. The location data allowed us to calculate metrics of intra-network distances and dispersions to be used as potential factors affecting manufacturing and R&D specialization. Information was collected at the plant level to find the main goals that each site plays within the network, categorizing four types of value-added functions or "tasks": Headquarters, Production, R&D, Other (commercial, sales, service center, etc.). Each of the 2267 units has been labeled according to the type(s) of value-added task(s) it performs, considering that each site can have more than one task.

Methodologically, a *fuzzy set Qualitative Comparative Analysis* (QCA) (Ragin, 2000) was used, supported by a cross-tabulation analysis to initially explores the factors of interest. QCA enables the study of conjunctural causation, i.e., if and how various causal attributes combined into different configurations lead to an identified outcome, and equifinality, i.e., if multiple cause conditions are responsible for the outcome (Ragin, 2000; Fiss, 2011) (Rihoux and Ragin, 2008). It was designed for small samples (15-40 cases), even if it has also been used for larger models (Kraus et al., 2018). This methodological approach seems to be suitable for the purpose of the research since it complies with the objective of exploring multiple configurations leading to high or low values of manufacturing and R&D specialization.

Companies are categorized in a matrix according to the level of specialization in manufacturing and R&D activities, and then the presence of cases in each quadrant of the matrix is discussed based on theoretical and empirical findings. The results show that different sets of conditions can lead to the same levels of specialization. This paper helps managers by offering them meaningful insights for designing their networks based on manufacturing and R&D units and by showing alternatives when exploring ways to modify their networks.

3.2 Literature and research questions

3.2.1 Subsidiary roles and Value-added activities within MNEs

An MNE is characterized by a set of subsidiaries and other assets dispersed in more than one region (Chang and Taylor, 1999). Rapid changes in the global competition have obliged international managers and management scholars to explore new ways of handle MNEs effectively (Van Dut, 2018; O'Donnell, 2000). Nowadays, MNE literature can be broadly divided into aspects related to coordination and configuration (Morschett et al., 2015), where configuration regards the geographic locations of each value chain activity and their organizational processes, and coordination regards the process of integrating and connecting the different units.

From the configurational point of view, one of the perspectives that can be adopted to analyze MNEs configuration is focused on the typology of tasks (or value-added activities) undertaken by the single units (Birkinshaw and Hood, 2000). A large number of typologies have been suggested in the MNEs literature (Schmid, 2004), sometimes called "subsidiary roles" (Ghoshal and Bartlett, 1986; Jarillo and Martíanez, 1990; Roth and Morrison, 1992). The subsidiary roles (i.e., the tasks performed by the site) should not be confused with the concept of "manufacturing role" (e.g., Cheng et al., 2011; Ferdows, 1997, 1989; Vereecke et al., 2006), i.e., the fact that manufacturing plants can have different roles and responsibilities according to the strategic goals they have to accomplish. The manufacturing role of plants is a key theme developed over the years within the IMNs literature (see Chapter 1.2.3).

The assumption characterizing the strand of literature dealing with factories' role is that MNEs continually reconfigure their widely dispersed activities by specializing units and integrating them towards the best configuration as a whole (Vahlne and Ivarsson, 2014), based on the acknowledgment that international factories and subsidiaries should be heterogeneous (Nohria and Ghoshal, 1997; Morschett et al., 2015).

Attention has been given in the literature to the R&D and Manufacturing functions. Concerning the production plants, the set of globally dispersed manufacturing plants of MNEs is usually referred to as *International Manufacturing Network* (IMN) (Cheng et al., 2015; Rudberg and Olhager, 2003) or *Global Production Networks* by the literature, even if less frequently (Norouzilame et al., 2014). A general trend of today's large organizations is to adopt increasingly fragmented production processes (Morschett et al., 2015), where plants are focus on tiny and specific production stages, which are often located in many countries. Grünig and Morschett (2017) contribute to this theme, providing a set of configurations based on the "international splitting of production processes" and the number of locations of manufacturing plants. Besides, most of MNEs are nowadays multi-product companies developing flexible manufacturing systems that reduce the need for specific investments but preserving the differentiation of final products.

A specific focus has also been dedicated to the R&D function. Global competitive markets push companies to invest in their core competencies and to develop new knowledge by means of research to outperform competitors. R&D is one of the most strategic, and therefore sensitive, activities of firms (Gugler and Michel, 2010). For most large companies, managing global R&D is still a challenge of macroscopic proportions and a very risky endeavor due to the physical distance among R&D units, and between R&D units and corporate headquarters (von Zedtwitz and Gassmann, 2002). While until the 1980s, the primary role of R&D abroad was to adapt companies' products to market conditions (Hegde and Hicks, 2008), from the 90s onwards, R&D facilities in foreign countries have become essential for access to superior knowledge and know-how (Gugler and Michel, 2010). It must be noted that a difference exists between research and development: while research is the process of discovering new scientific knowledge and has the potential to enable subsequent development of products and manufacturing processes (hence there is no expectation of immediate commercial success), the development aims to exploit currently available platforms or scientific knowledge for the commercialization of new products and processes. Most of the research has considered R&D as a whole (Cheng and Johansen, 2015), and most of the (few) contributions that differentiate between research and development management ignore the international dimension (e.g., Eldred and Mcgrath, 1997). For these reasons, we will consider R&D as a single entity.

The trend is towards more R&D sites abroad, and companies are investing in a wide range of innovations in multiple countries to strengthen their R&D departments (Ferraris et al., 2019). For a recent review of the literature on R&D internationalization in MNEs, see Papanastassiou et al. (2020).

Literature within the MNEs domain has been directed to analyze how to manage such a complex and geographically dispersed knowledge in an effective manner. The two most typically followed approaches are the *Integrated Network* of R&D units, where a coherent, centralized and tightly integrated R&D strategy is developed, and limited degrees of freedom is allowed to global R&D units, and a *Loosely-Coupled Network*, where individual R&D units are given specialized tasks and considerable freedom (Birkinshaw, 2002). The specialization of R&D originates from the leading forces in international R&D - access to local markets and customers, and access to local knowledge and technology – and guides the distribution logic of the development function of today's MNEs. The next paragraphs explain the studies about integration or separation of the manufacturing and R&D units from different factory roles.

3.2.2 R&D and manufacturing localization

The categorization of multinational companies into factories that perform different tasks has also been emphasized from a localization point of view. More generally, the concept of "distance" among factories has been given much attention as one of the key determinants of international strategic management and companies' internationalization (Alcácer, 2006). Attention has been devoted to analyzing the geographical aspects of MNEs companies, taking into account the specificity and dispersion of the various functions (production, R&D, commercial, etc.), and the intrafirm cross-functional distance, for example, the distance between production and R&D plants.

Many contributions have been directed to the localization research, trying to explain the reasons and the dynamics of factory localization (Lane, 1998; Morschett et al., 2015; Nachum et al., 2008; Pananond, 2013). Studies on MNEs subsidiaries suggest that geographical and cultural distance between local and host countries positively influence decision-making autonomy; in particular, when geographic distance increases, it becomes more complex and expensive to control subsidiaries, leading to a higher degree of factories' autonomy (Van Dut, 2018).

Concerning the production plants, companies are under pressure for correctly choosing where to position manufacturing plants to maximize the potential rate of return on facility investment: the literature on facility locations has aroused much interest, developing a wide variety of approaches and methods (to learn more, see some of the comprehensive reviews in facility location: Farahani et al., 2010; Melo et al., 2009; Orfi et al., 2011; Revelle et al., 2008). Literature on global facility location mainly described the plant location decisions quantitatively, based on a number of factors: market access and proximity, costs, regulations, taxes, trade barriers (e.g., Canel and Khumawala, 1996, 1997; Dogan, 2012; Kouvelis et al., 2004; MacCarthy and Atthirawong, 2003). Differently, the IMNs literature provides mostly qualitative contributions from the strategic and economic perspectives. For example, Ketokivi et al. (2017) focus on localization decisions over international assembly plants and their key linkages with the supply chain. Their results suggest that location decisions on establishments are tightly connected to three "*dimensions of interdependence with suppliers, markets and development activities*" (Ketokivi et al., 2017, page 21), emphasizing that an understanding of interdependencies in the supply chain is a key step to implement correct localization decisions of production plants.

The location of R&D plants is also a subject of interest (for example, Chen, 2008; Florida and Kenney, 1994; Gugler and Michel, 2010). A natural dilemma in multinational companies is whether to opt for an international R&D, or whether to centralize the R&D function in the headquarters home country. In MNEs companies, overseas R&D can help develop products for particular markets or areas (Pearce, 1994). Literature has widely studied the reasons to internationalize R&D (*centrifugal forces)* and the reasons for a regional concentration of R&D (*centripetal forces)* (Fisch, 2001). For example, literature in global innovation assumes that MNEs distribute their innovation activities hierarchically, with advanced and high-tech innovation centers being circumscribed to the developed industrialized countries, while more low-end innovation centers being distributed in developing countries (Chen, 2008). Furthermore, recent studies have analyzed the distance of R&D centers from HQs as well as the distance between production and R&D facilities, emphasizing the managerial, economic and innovation implications that distance plays in this type of relationship (Carboni, 2013; Castellani et al., 2013; Lehto et al., 2011), and more generally, the importance of geographical proximity and network tie for firm innovation (Lin and Wang, 2019).

3.2.3 Cross-functional integration and spatial organization

Localizing different activities worldwide is not enough. MNEs are increasingly aware that a proper selection and location of skills provide a great competitive advantage, particularly in multi-product contexts of globally dispersed sites. To this end, this paragraph connects the previous two paragraphs by depicting the intra-firm interactions among different functions, such as marketing, logistics, R&D, finance, and manufacturing (Kahn and Mentzer, 1994; Maltz and Kohli, 2000).

Intra-firm interactions have long been debated since Thompson (1967) introduced the sequential or reciprocal interdependence among R&D and production. In line with him, White and Poynter (1984) investigate typology roles based on three criteria, where one of these is the value-added scope, i.e., whether the unit carries out a single function (for example, manufacturing, or R&D, or marketing) or whether it provides a wider spectrum of functions. More recent contributions show the importance of cross-functional integration among companies functions for specific objectives, for example, for new product performance (e.g., Ernst et al., 2010; Harryson, 1997) and, in general, functional integration has been analyzed mainly through well-known theories and perspectives, such as the resource dependency theory (Pfeffer & Salancik, 1978) and contingency theory (Miller, 1988).

There are several cross-functional relationships between different parts of the supply chain, driving companies to co-locates functions to benefit from internal agglomeration (Ivarsson and Alvstam, 2017). This stream of literature is part of the wide global supply chain management literature introduced in Chapter 1.2.1. A number of studies examine the spatial organization of firms through the value chain, exploring location choices of

R&D, manufacturing, and sales activities: for example, Alcácer (2006) finds that production and sales subsidiaries are more geographically dispersed, while R&D labs are more concentrated. Alcácer and Delgado (2016) observe that what helps companies to be geographically dispersed is related to their ability and management skills to disperse value chain activities to distant locations, thus reducing the need for co-location.

Converging on our research, the cross-functional integration of production and R&D, that is, the presence of factories with the dual function of producers and developers, has attracted a certain interest (Ivarsson and Alvstam, 2017). Ketokivi et al. (2017) use the concept of coupling in the Production-Development dyad in terms of interdependencies in the production-development functional interface. A tight coupling of manufacturing and R&D activities arises in the case of mutual functional interdependencies requiring cross-cutting and heavy efforts, and a joint problem-solving approach within the organization. Recently, Castellani and Lavoratori (2020) showed that the strength of co-location between R&D and production activities is highly heterogeneous across firms and depends on geographical dispersion, intangible assets, and codified knowledge.

To summarize, the literature has approached MNEs both as networks characterized by a high specialization of activities, where plants are isolated self-referential units, and as multi-target plants characterized by a tight plant cross-functional integration.

3.2.4 Research questions

Although it is widely acknowledged that MNEs activities are becoming more internationally dispersed, contributions on the specialization or aggregation of roles in globally dispersed plants are still scarce. Literature about plant typology has scarcely considered cross-functional integration with the coexistence of more than one value-added function in an individual unit. Previous paragraphs have shown that there is even less concern on why manufacturing and R&D are configured in isolated factories or integrated into multi-task units. Furthermore, no papers analyze the combinations of these factors: literature has usually analyzed the topic adopting specific but partial lenses (Morschett et al., 2015).

This research explores the patterns adopted by international companies in distributing their manufacturing and R&D activities worldwide. Unlike previous studies (Castellani and Lavoratori, 2020; Ivarsson and Alvstam, 2017; Lica et al., 2020), this research does not only analyze the co-location between R&D and manufacturing, but it elucidates whether, and under what conditions R&D and manufacturing plants within a MNE are co-located with other functions or, vice versa, they are specialized networks located in independent units. Thus, our research begs the following question:

What is the combined effect of different factors on higher or lower levels of manufacturing and R&D specialization in globally dispersed subsidiaries? ***(RQ1)***

The study focuses on the empirical investigation of the possible *combinations* of predictors leading to the same output through the use of QCA methodology. As far as we know, this approach has rarely been taken into consideration.

3.2.5 Theoretical framework

In order to set the theoretical framework for the analysis, some macro factors concerning MNEs' structure and configuration have been taken into account. These macro-factors, which serve as a theoretical foundation, have been identified within the MNE and IMN literature as relevant in the choices of localization and cross-functional integration, in particular in contributions aimed at the analysis of the co-location between R&D and manufacturing.

Castellani and Lavoratori (2020) summarize some of these past studies (in particular, Alcácer and Delgado, 2016; Mariani, 2002), noting that "*the propensity of MNEs to co-locate offshore R&D labs with their production plants can vary substantially according to firm and industry characteristics*" (Castellani et al., 2020, page 121). From these contributions, the macro variables that have been considered in this work are: A) the plant distance and geographical dispersion, B) the industry, and (C) the size variables of the company.

Regarding the spatial distance among plants (A), Pisano and Shih (2012a) analyze the factors that allow a separation between R&D and manufacturing and, therefore, geographically distant networks. Castellani and Lavoratori (2020) find that the intensity of co-location between R&D and manufacturing is higher in companies with less geographical dispersion, supporting the hypothesis that co-location is a substitute for the company's ability to coordinate globally dispersed sites. Likewise, Alcácer and Delgado (2016) add that co-location is higher for companies operating in a few locations, including a component related to *geographical dispersion* (in addition to distance). Second, the industry (B) has been recognized as another potentially critical factor. Ivarsson and Alvstam (2017) and Ketokivi et al. (2017) state that the need to co-locate R&D and manufacturing is mainly an industry-specific phenomenon. Ketokivi et al. (2017) add that R&D-manufacturing interdependencies may be stronger in one industry than another due to the different roles of manufacturing and R&D in different industries. Finally, the *size* (C) of the company might play an important role in the need for co-location (Castellani and Lavoratori, 2019). Larger companies may have structured capabilities, both organizational and managerial, and therefore be also capable of coordinating remote operations and managing knowledge transfer between geographically dispersed units. Conversely, smaller companies may need co-location in order to coordinate activities due to the lack of structured organizational processes (Gray et al., 2015). The size has been analyzed both at a single factory level and at the whole company level. It has been tested in studies very close to our interest (e.g., Castellani and Lavoratori, 2020; Ketokivi et al., 2017).

For these reasons, the preliminary theoretical framework is represented in Figure 3.1. The methodological chapter will explain what measures and metrics were used to represent these three elements and clarify the approach.

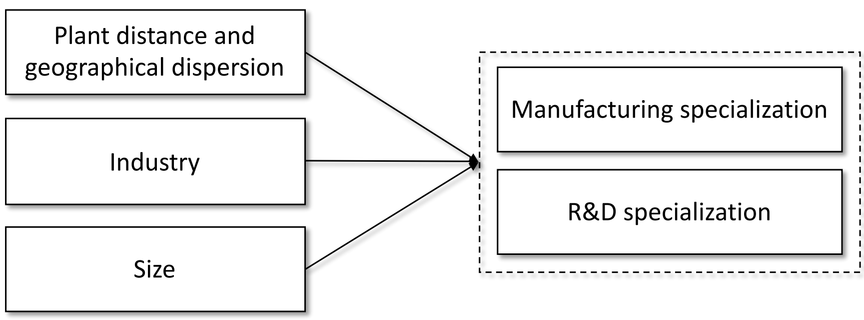

Figure 3.1: Preliminary theoretical framework

3.3 Research method and data

3.3.1 Data collection and sampling

Data collection focused on configuration- and coordination-related information within MNEs. Data are derived from a detailed analysis of secondary data sources (websites, annual reports, company brochures, marketing data, etc.), starting from a large population of enterprises from the Orbis Database. This type of analysis has represented the major contribution to the data collection. Furthermore, additional data have been obtained by international databases (AIDA, Orbis) to provide financial and operative performances, to complete the lacking information, and finally to triangulate data (Jick, 1979).

The data collection was carried out through a detailed analysis of individual MNEs, at two different levels of analysis: network- and plant-level. At the network level, the collected information concerns: the size, the annual revenues, the industry, the number of units, the main economic items. At a plant level, information was collected on the name, the address (or geographical coordinates where available) and the characteristics of the individual unit, together with its role and the function/s performed.

A first strict requirement was the need to understand the typology (role) of the individual plant. To codify this information, the individual unit's role details were used as provided by the available sources. The study of secondary data showed that information was not always presented in the same way. Sometimes, websites reported foreign commercial offices with different names and meanings (branches, commercial offices, spare parts offices, leadership offices, etc.).

Therefore, we chose to categorize the roles or value-added functions of the plants into four labels in order to be able to encode the information logically. The information was codified in this way:

- Label "H" [HQ role]: Units acting as global or regional headquarters.
- Label "M" [Manufacturing role]: production facilities and manufacturing plants or activities close to production (e.g., logistic warehouses).
- Label "R" [R&D role]: units carrying out R&D activities.
- Label "O [Other roles]: units that perform roles other than the previous ones, such as sales offices, organizational offices, or service locations (after-sales, service, spare parts).

Our choice was therefore motivated by uniformity of classification. It was decided to lump multiple roles under the umbrella of "others" into a single block. Otherwise, we would have had a multiplicity of functions difficult to analyze. We found it hard to discern precisely what the role was, also due to the multiple ways in which they are identified. Thus, the procedural simplification in choosing four labels is to avoid too much subjectivity. A higher level of detail would have generated ambiguity and inaccuracy in the classification of the data.

To avoid misunderstandings, we will refer to the physical site as *unit* and to the function or value-added activity as *task* (also to distinguish from Ferdows' "role of the plant", widely used in this thesis). A single unit may have more than one of the above tasks and therefore be targeted with more than one label. For example, a central unit that acts as HQ and that carries out production and R&D activities is labeled with an "H-M-R" label. This information, which is relevant to our study, strongly limited the potential sample of companies. It is noteworthy that isolated production facilities were often indicated as operating only on a specific product group or a specific Business Unit. On the other hand, plants in which the productive task is combined with others tend to be less specialized also from a productive point of view but are often multi-production plants.

In addition, in order to analyze the location choices and distances, the address of each plant was gathered. This has further reduced the companies that could potentially be analyzed. The information collected at the plant- and network level is summarized in Table 3.1.

Table 3.1: Information collected on companies

	Attribute	**Description**
Network level	Company name	/
	Industry	NACE classification
	HQ country	Country of Headquarters or Main Registered Office
	Company size	Number of employees
	Revenue	Billion €
	Number of plants	Total number of factories
	B2B vs B2C	Focus towards a B2B or a B2C model

Plant level	Plant name	(if any)
	Country	/
	Address	Coordinates were collected when available
	Typology	H, M, R, O

Information was collected on 50 companies for a total of 3036 units. Starting from the Orbis Database, the criteria followed for the selection of companies are the following: a) multinational or transnational companies; b) multi-plant companies (>=10 units); c) companies with more than 500 employees; d) manufacturing companies. In particular, the chemical, automotive, and food sectors were analyzed (NACE classification). The reason for analyzing the following industries is that they are the sectors whose companies provide the most extensive data for reasons of transparency; in particular, they are more inclined to represent the location of their activities, and the strategic tasks that individual plants have within the network, which are the two essential information for this research. Furthermore, these three industries offer sufficiently different features regarding products and processes to well represent the possible implications caused by industry characteristics in co-locating different functional networks (Alcácer and Delgado, 2016; Castellani and Lavoratori, 2020; Mariani, 2002).

Companies with less than two units per typology and companies for which relevant information was missing have been eliminated. The final dataset includes 2267 units from 34 MNEs. Considering that each unit can have more than one task, the total number of tasks analyzed is 2928 (on average, 1.29 per unit).

For each unit, the geographical coordinates (Latitude and Longitude) were obtained through Google API and using Python and Stata statistical software for data organization. In case the exact address was not present, the address of the city of the plant was kept as a reference (177 out of 2267 plants, 7,80% of the cases). Table 3.2 summarizes the aggregate information of the final sample and shows that both the number of employees and the number of plants undergo a large standard deviation. Table 3.3 points out the geographical dispersion of the tasks. The detail of the analyzed cases is in Appendix 3.A.

Table 3.2: Summary information at the network and plant level

	Total			
No. of companies	34			
No. of units	2267			
	Min.	**Max.**	**Avg.**	**St. Dev.**
No. of employees	500	185.000	3057	45.959
No. of Plants	10	268	37	64

Table 3.3: Geographic distribution of unit based on their tasks

Area	Headquarter [H]	Manufact. [M]	R&D [R]	Other [O]	Total No. of tasks	%
Africa	3	42	4	30	79	2,70%
Asia	45	406	130	268	849	29,00%
Central America	7	53	6	19	85	2,90%
Europe	86	654	180	314	1234	42,14%
Middle East	4	3	4	18	29	0,99%
Northern America	18	250	90	130	488	16,67%
Oceania	2	9	1	10	22	0,75%
South America	12	73	16	41	142	4,85%
Total	**177**	**1490**	**431**	**830**	**2928**	**100,00%**

3.3.2 Measurement of variables

Some metrics have been used to analyze the collected data:

Manufacturing specialization and R&D specialization: to quantify the level of integration of manufacturing and R&D facilities, a proxy of the concept to be measured is built. For each company, the metric of manufacturing specialization (*MANUFspecializ*) has been calculated as Number of specialized manufacturing units (i.e., the number of units having only the manufacturing function) divided by the number of total manufacturing plants (i.e., the number of units having also the manufacturing function). Similarly for the metrics of R&D specialization (*RDspecializ*). This metric is used to have an estimate of how much companies individually work on plants that perform only one role and how much they work on plants that have multiple functions.

$$MANUFspecializ_i = \frac{(No. of\ units\ specialized\ in\ manufacturing)}{(No. of\ units\ with\ any\ manufacturing\ role)}$$

$$MANUFspecializ_i = \frac{M_i}{(HM_i + MR_i + MO_i + HMR_i + HMO_i + MRO_i + HMRO_i)}$$

$$RDspecializ_i = \frac{(No. of\ units\ specialized\ in\ R\&D)}{(No. of\ units\ with\ any\ R\&D\ role)}$$

$$RDspecializ_i = \frac{R_i}{(HR_i + MR_i + RO_i + HMR_i + HRO_i + MRO_i + HMRO_i)}$$

The metric used suits the data collected, with large companies a high number of plants (see Table 3.2). The average number of units having a manufacturing task (among others) per plant is over 43, while the average number of factories having an R&D task (among others) is over 12. Therefore, we believe that we have an internally consistent metric that measures how well a company specializes in its plants. For simplicity of use, the words *manufacturing specialization* will be used in place of "specialization of the units having a production task" and the words *R&D specialization* will be used in place of "specialization of the units having a research and development task".

Distance metrics: there are several metrics used in the literature for calculating geographical distance. In this research, similarly to other works (Berry et al., 2010; Chen, 2004; Choi and Yeniyurt, 2015) the average distances between plants in the network were calculated using the great-circle distance in kilometers (Anderson, 1979; Berry et al., 2010; Fitzpatric and Modlin, 1986; Fratianni and Oh, 2009; Phalippou and Gottschalg, 2009). The distance was calculated using the geographic coordinates (latitude and longitude) of the units. Table 3.4 summarizes the measures used. For example, DistALL is obtained from the average distance between all the company's units, regardless of the units' typology.

Dispersion metrics: these metrics were inspired by the study of Alcácer and Delgado (2016), which introduced the importance of dispersion (in addition to distance) in co-location between different functional networks. The set of metrics used in this research aims to study the geographic dispersion, i.e., the extent to which the company's units are located across a wide range of geographic regions. We relied on the literature to build a metric that takes into account the dispersion of plants in macro-areas. The basic formulation of the metric was inspired by the research of Stock et al. (2000): a company with a high level of geographic dispersion would present a low proportion of units within each individual region; vice versa, a low level of geographic dispersion implies a high proportion of units within one region and low proportions in others. Similar to Lorentz et al. (2012) and Lorentz et al. (2016), this research makes use of the geographic dispersion metric developed by Stock et al. (2000), but modified for eight regions. This metric ranges from 0 to 1, with 1 meaning maximum dispersion and 0 meaning minimum dispersion. For example, a 100% concentration of plants in one of the suggested areas results in a dispersion value of 0, while equal plant dispersion in all the areas results in a dispersion of 1. As suggested by Lorentz et al. (2016), also here the researchers decided to use 8 zones. The regional configuration adopted is based on the most common scenarios found on companies' websites, where the plants were often divided geographically according to this classification for commercial and production reasons. The classification into 8 zones does not assume a homogeneous distribution by default but serves to understand the intensity with which the company has geographically dispersed plants, regardless of the regions in which it is located. The current network dispersion is analyzed in the following areas: Europe (EU); Africa (AF); Central America and the Caribbean (CA); North America (NA); South America (SA); the Middle East and Central Asia (MECA); Asia (AS) and Oceania (OC). Configurations that consider similar geographical areas have been used by works in literature (Castellani et al., 2013; Lorentz et al., 2016; Stock et al., 2000). The metric is calculated using the formula below:

$$DispersX = 1 - \frac{\begin{bmatrix} \left[EU\% - \left(\frac{100}{8}\right)\right] + \left[AF\% - \left(\frac{100}{8}\right)\right] + \left[CA\% - \left(\frac{100}{8}\right)\right] + \left[NA\% - \left(\frac{100}{8}\right)\right] + \\ \left[SA - \left(\frac{100}{8}\right)\right] + \left[MECA\% - \left(\frac{100}{8}\right)\right] + \left[AS\% - \left(\frac{100}{8}\right)\right] + \left[OC\% - \left(\frac{100}{8}\right)\right] \end{bmatrix}}{\left(100 - \left(\frac{100}{8}\right)\right) + (8-1) * \left(\frac{100}{8}\right)}$$

In the dataset, the company's geographical dispersion ranges from a minimum value of 0.06 (meaning a very concentrated network) to a maximum value of 0,52 (strongly dispersed network). In Table 3.4, DispersM only considers the location of the units having a manufacturing task, regardless of the fact that the unit performs only a manufacturing task or also other tasks. Similarly, for DispersR with R&D tasks. Instead, DispersALL considers all the company's factories.

Table 3.4: Distance-related and dispersion-related metrics

	Distance	Description
Distance	DistALL	Average distance among all the units of the company
	DistM	Average distance among the manufacturing plants
	DistR	Average distance among the R&D factories
	DistMtoR	Average distance between manufacturing plants and R&D units
Dispersion	DispersALL	Dispersion of all the units of the company
	DispersM	Dispersion of manufacturing plants
	DispersR	Dispersion of R&D facilities

Other metrics: in addition to the metrics explained above, the study takes into account three indicators of the *size* that have been widely used in the literature regarding multinational companies, and, more specifically, in the literature about units localization and cross-functional integration: the *size of the company* (e.g., Alcácer and Delgado, 2016; Castellani and Lavoratori, 2019), the *number of units* (e.g., Lehto et al., 2011), and the subsidiary size, i.e., the average number of employees per plant (e.g., de Jong et al., 2015; Johnston and Menguc, 2007). The average number of employees per plant is a proxy for measuring the *average size of plants* (Chiao et al., 2008; O'Donnell, 2000).

3.3.3 Research design

The empirical analysis uses two methodologies carried out in sequence. First, an analysis is carried out through cross-tabulations (contingency tables). Contingency tables use categorical variables to show the frequency of co-occurrence of the mutually exclusive characteristics of each variable (White, 2004). In the context of our research, cross-tabulations help us in two ways: they explore the existence of individual variables (or *conditions*, in QCA terms, i.e., factors that are thought to cause a phenomenon) that affect manufacturing and R&D specialization. Second, they facilitate the emergence of asymmetric relationships among variables: for example, when X is positively associated with Y, there is a possibility to have both cases of high X and low Y as well as cases of low X and high Y. This is what is typically recognized as *contrarian case analysis* (Russo et al., 2019; Russo and Confente, 2019): this type of analysis provides support where the literature, through the methodologies used, has often ignored contrarian cases, considering only the main effect (Woodside, 2014). The contrarian case analysis is adopted to show the existence of cases where the relationship among variables is not symmetric.

This analysis facilitates the understanding of the complexity of a phenomenon as it shows the existence of cases where the relationship among variables is not symmetric. For example, when X associates positively with Y with high correlation, the same data set may include cases of high X and low Y as well as cases of low X and high Y. However, most of the time, scholars ignore these contrarian cases in their research, considering only the main effect (Woodside, 2014).

Afterwards, a **fsQCA** (Ragin, 2000, 2008) is developed. While cross-tabulations allow us to understand which factors can be potentially relevant, the QCA enables the understanding of the coexistence of factors, i.e., a *set* of conditions that have an effect on R&D and manufacturing specialization. QCA is a method that empirically investigates the relationships between the outcome of interest and possible combinations of its predictors (Fiss, 2007; Ragin, 2000; Woodside, 2015). Therefore, QCA takes as input only some of the factors that have been studied with cross-tabulations (further information is available in paragraph 3.4.1). In order not to make the analysis section too extensive, the full description of cross-tabulations is presented in Appendix 3.B, with the first part of Chapter 3.4.1 showing only the key results. Instead, the next paragraphs will focus on the second part of the analysis, i.e., the QCA approach, as an extension of the previous results. Figure 3.2 shows the theoretical framework of the research, with the two sequential methodological steps.

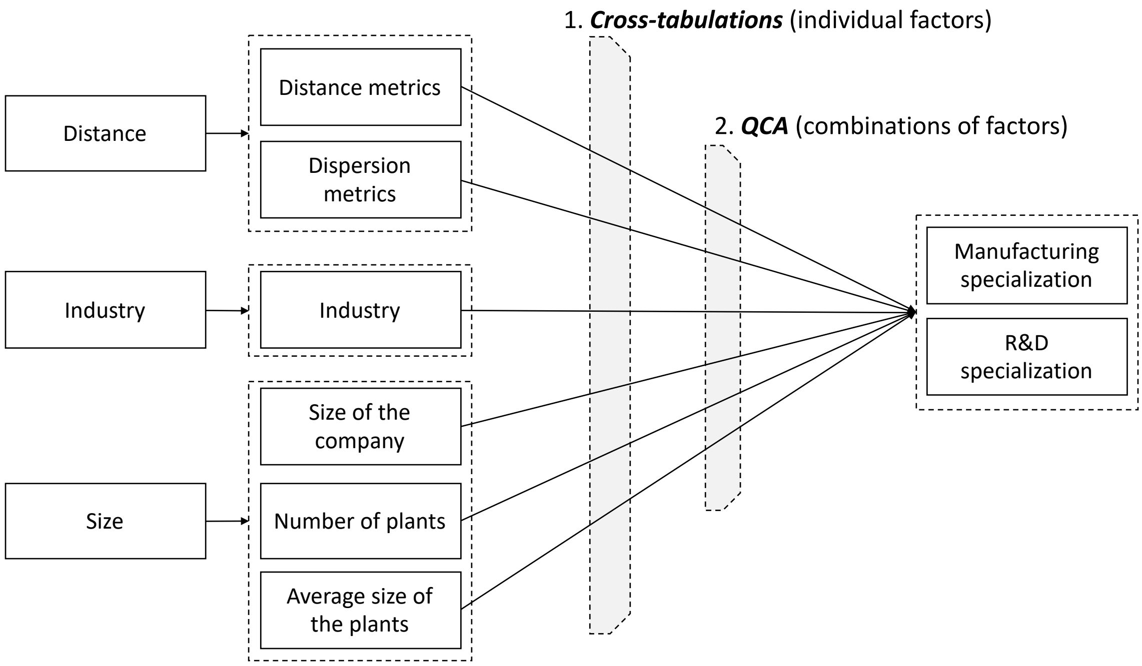

Figure 3.2: Theoretical and methodological framework

3.4 Analysis

The metrics obtained allow us to graphically represent the level of specialization of the manufacturing and R&D facilities. Figure 3.3 represents the degree of specialization of the manufacturing sites on the x-axis, while the degree of specialization of the R&D sites on the y-axis. The size of the square is given by the size of the company (measured by the number of employees).

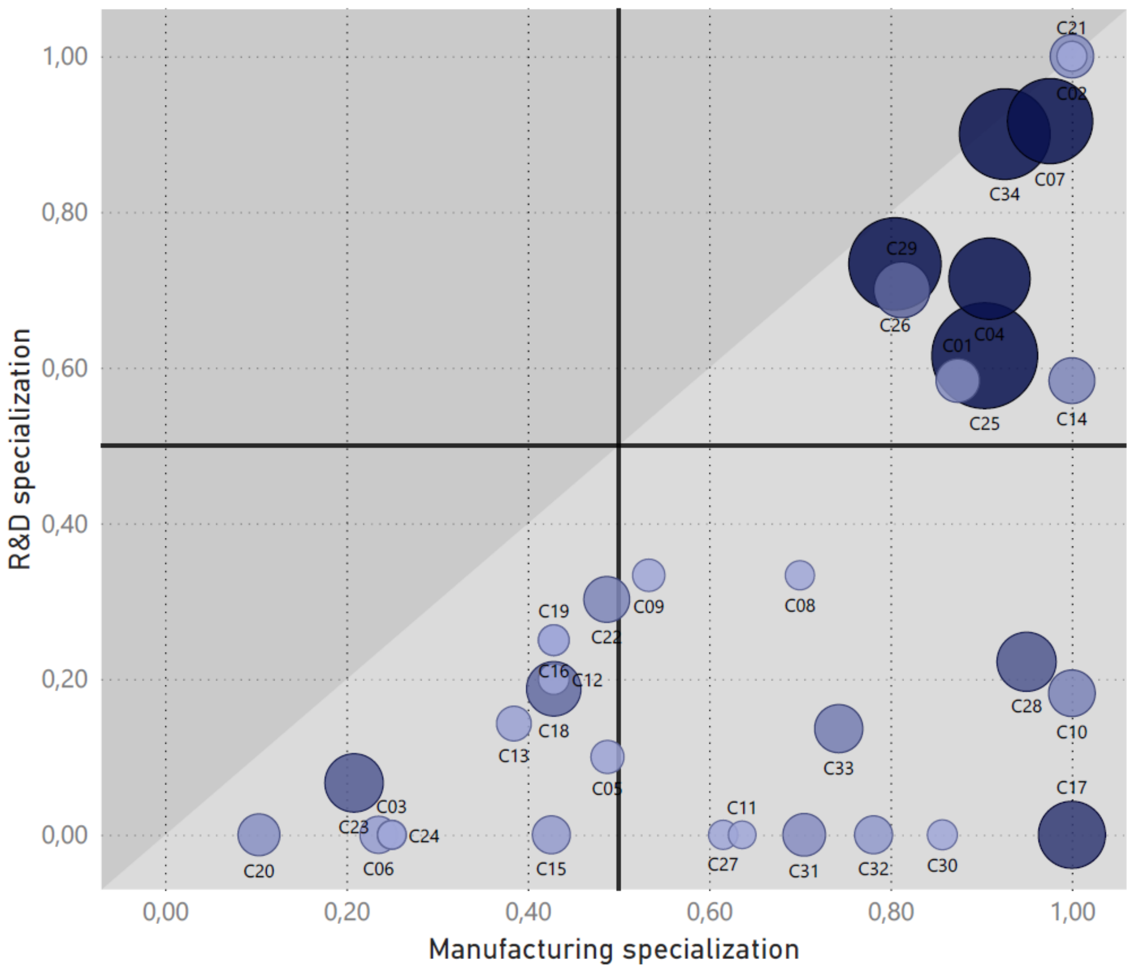

Figure 3.3: Scatterplot of manufacturing and R&D specialization

Based on Figure 3.3 and the data collected, some initial considerations can be drawn. First, it seems that the largest companies are in the upper-right quadrant, suggesting that a high specialization in manufacturing and R&D occurs more likely in larger companies. Second, there are no companies in the upper left quadrant, i.e., low manufacturing specialization and high R&D specialization, meaning that companies that specialize R&D are only those in which also manufacturing is specialized. Third, there are no cases for which the R&D specialization is higher than manufacturing specialization (i.e., all the points are below the diagonal), suggesting that the specialization levels of R&D and manufacturing are somehow connected.

When delving deeper into the data, besides the observation from the above figure, data show that manufacturing is far more specialized than R&D: the average values of the specializations when considering the whole sample are 0.65 for manufacturing and 0.31 for R&D, meaning that manufacturing units are more than twice as specialized as R&D units. By looking at the individual units, it can be noted that, on average, the manufacturing task when not specialized is mainly coupled with the “other” task (382 cases) rather than the R&D task (174 cases). However, the number of total units having “other” roles (830) is almost double that of R&D units (431), thus making the ratios similar. Instead, R&D is mainly coupled with manufacturing activities.

3.4.1 Complex causality and set relations

This paragraph aims to summarize the main results of the analysis through the Cross Tabulations so as to effectively and functionally introduce the QCA. To avoid overly burdening the description, we leave the reader to look at the methodological details and the outcome in Appendix. Appendix 3.B highlights the significant effects of some variables on their positioning within the quadrants, interpreting the results of the cross-tabulations. Chi-square and Fisher’s tests were performed to investigate the potential correlation. The computation was performed using SPSS software.

In particular, the contingency tables were developed on manufacturing and R&D specialization, but also on the four quadrants of the matrix specialization. Table 3.5 and Table 3.6 show the summarized results of the cross-tabulations. Only the significant effects are emphasized here. The three contingency tables show significant effects (not symmetrical for all contingency tables) of the company size, the average number of employees per plant, the DispersR, and the distance metrics. All the detailed results can be found in Appendix 3.B.

Table 3.5: Contingency tables on manufacturing and R&D specialization

	MANUFspecialization			RDspecialization		
Conditions	Signif.	Cramer's V	% of expected values smaller than 5	Signif.	Cramer's V	% of expected values smaller than 5
Size	*	.378	0%	**	.555	25%%
AvgNoEmplUnit	○			*	.426	25%%
DistR	*	.424	0%	○		
DistALL	*	.454	25,00%	○		
DistMtoR	*	.424	0%	○		

Note: o stands for p > 0.05, * for p < 0.05, ** for p < 0.01, *** for p < 0.001, **** for p < 0.0001, - for 'not available'.

Table 3.6: Contingency tables over Matrix Quadrants

Conditions	**Signif.**	**Cramer's V**	**% of expected values < 5**	**Direction**
Size	**	.566	16,66%	High Size: majority of companies in the top-right quadrant. Low Size: majority of companies in the bottom-left quadrant (or bottom-right, less frequently)
AvgNoEmplUnit	*	.429	16,66%	High AvgNoEmplUnit: majority of companies in the top-right quadrant. Low AvgNoEmplUnit: majority of companies in the bottom-left quadrant. In the bottom-right quadrant, prevalence of low AvgNoEmplUnit
DispersR	*	.492	50,00%	High DispersR: majority of companies in top-right and bottom-left quadrants. Low DispersR: majority of companies in the bottom-right quadrant
DistR	*	.435	0%	High DistR: majority of companies in bottom-left quadrant. Low DistR: companies are divided between bottom-right and top-left quadrant
DistALL	*	.470	50,00%	High DistALL: majority of companies in the bottom-left quadrant. Low DistALL: majority of companies in bottom-right or top-right quadrants
DistMtoR	*	.492	0%	High DistRtoM: majority of companies in bottom-left quadrant. Low DistRtoM: majority of companies in bottom-right or top-right quadrants

Note: o stands for p > 0.05, * for p < 0.05, ** for p < 0.01, *** for p < 0.001, **** for p < 0.0001, - for 'not available'.

Starting from these results, this paragraph aims to explore the motivations that characterize the position of companies, also taking into account the contrarian cases. The positioning into the matrix could be linked to a combination of different factors that lead to the same output. Our aim in using the QCA is to explore and support initial results from the cross-tabulations, and underline possible configurations of factors (Fiss, 2007; Ragin, 2000; Woodside, 2015) that can lead to a high or low level of specialization in manufacturing and R&D units. This kind of approach is in line with other research work (e.g., Russo et al., 2019). A *fuzzy set Qualitative Comparative Analysis* (fsQCA) (Ragin, 2000, 2008) that transforms interval or ratio scale variables into a fuzzy set was used. We applied the suggestions of Schneider and Wagemann (2010) to run the analysis.

3.4.1.1 Measures and calibration

fsQCA uses fuzzy set theory and Boolean algebra to investigate the extent to which certain factors or combinations of factors are present or absent when a phenomenon of interest occurs and when it does not occur. Thus, conditions can be causally related to an outcome as necessary or sufficient, alone or in combination among them. In order to provide a solid methodological approach, the analysis performed in this article proceeds follows the four-step procedure suggested by Fiss (2011):

1. <u>Defining the conditions and the property space</u>

The first thing is to figure out what conditions to analyze. Remember that conditions are the factors thought to be the causes of a specific phenomenon. We could have chosen all the variables considered in the cross tabs, but they would have been difficult to be managed, having a limited number of cases: literature suggests that seven causal conditions require a sample of at least 30 elements (Marx, 2006), and that models with more than seven causal conditions can become hard to interpret; thus, they should be avoided (Fainshmidt et al., 2020). Furthermore, we followed Schneider and Wagemann (2010) suggestions to keep the conditions moderate and to adapt the selection of conditions during the research process.

Therefore, the decision was to analyze six variables also based on the results of the contingency tables: Size (the company size), Average number of employees over plant (AvgNoEmplUnit, i.e., the average unit size), DispersM, DispersR, DistALL, and

DistRtoM. DispersM was included to understand the relationships with DispersR (which was significant from all previous analyses), while DistR was not added to avoid having too many distance measurements. In this way, two variables are dispersion-based, two are distance-based. It should be noted that the distance and dispersion metrics use both geographical coordinates (latitude and longitude) but measure two different concepts (Lorentz et al., 2016). Moreover, due to choices of the conditions, the dispersion and distance values are not linked: DispersM and DispersR analyze only the dispersion of specific functional networks, not the network as a whole; DistALL also considers HQ, sales, and service offices. By including a perspective with other functions besides production and product development, the value is often significantly different from the distance between specific typologies. A company could have a low DispersM (for example, if most of the plants are located in low-cost countries of China and Asia-Pacific), a low DispersR (for instance, if most of the R&D centers located in Europe - for reasons of access to skills and competencies), and still have a high DistRtoM (which instead calculates the average distance between manufacturing and R&D tasks).

2. Calibration

The second phase of the analysis is the calibration which consists of setting membership measures for all the attributes used. While the conventional set is dichotomous, meaning that a case can only be present (equal to 1) or absent (equal to 0), the use of a fuzzy-set membership implies specific membership values between 0 and 1 (Russo and Confente, 2019), i.e., "Data that do not naturally take the value of '0' or '1' need calibration" (Fainshmidt et al., 2020, page 456). Given that this research uses a fuzzy set QCA, our variables were transformed into fuzzy set membership scores (Ragin, 2008). The calibration procedure needs the specification of three qualitative anchors: the threshold for full membership (i.e., value 1), full non-membership (i.e., value 0), and the crossover point (i.e., value 0.5). The crossover point is "the point of maximum ambiguity (i.e., fuzziness)" in the evaluation of whether an element is more in or more out of a set (Ragin, 2008). Past studies agree that calibration represents one of the most challenging parts of the QCA procedure and cannot be interpreted as merely a rescaling of quantitative variables (Crilly, 2011; Greckhamer et al., 2018; Misangyi et al., 2017). As the variables are not naturally dichotomous, they were transformed into fuzzy set membership scores, calibrating measures by specifying the three qualitative anchors (Ragin, 2008). For each condition, we set these thresholds based on existing theory and substantive knowledge.

In order to transform the measures into set memberships, the direct method of calibration in the fsQCA software (Fiss, 2011; Ragin, 2008) was used. Given that our variables are not categorical but continuous, we cannot take the highest and the smallest possible scores as anchors (e.g., Ciravegna et al., 2018), but we need to specify the anchor for each of them. Thus, an analysis of the existing literature was needed to provide the most accurate membership measures. To summarize, Table 3.7 shows the calibrations that have been elaborated. A detailed description of the calibrations for the outcomes and conditions is provided in Appendix 3.C.

Table 3.7: Break-even points for Calibrating Fuzzy Sets

	Fuzzy set calibration			***Descriptive Measures***			
Condition	**Lower limit**	**Cross-over point**	**Upper limit**	**Mean**	**SD**	**Max**	**Min**
Size	2000	20000	100000	3056.97	45959.10	185000	500
AvgNoEmplUnit	80	250	2500	738.63	1206.45	5776.94	20.83
DispersM	0.15	0.30	0.45	0.32	0.11	0.53	0
DispersR	0.10	0.25	0.40	0.25	0.13	0.53	0
DistALL	2500	6000	7500	6310	1279	8283	3568
DistRtoM	2500	6000	7500	5816	1777	8451	683
MANUFspecialization	10^{th}	50^{th}	90^{th}	0.65	0.27	1	0.10
R&Dspecialization	10^{th}	50^{th}	90^{th}	0.30	0.32	1	0

<u>3. Logical minimization and consistency in set relations</u>

The truth table analysis (i.e., the table that serves to recognize the causal combination of conditions that are sufficient for the outcome) produces three different solutions: a) a complex solution, b) a parsimonious solution, and c) an intermediate solution. These solutions differ in the approaches to simplifying assumptions but never contain contradictory information (Legewie, 2013). For a detailed discussion of how fuzzy sets are displayed in truth tables, see, among others, Rihoux and Ragin (2008) and Schneider and Wagemann (2010). The calibration is the input for the fuzzy-set analysis using the truth table algorithm.

As a matter of fact, after the calibration was performed (i.e., after having defined the degree of "membership" of the computed conditions), the necessity analysis of all attributes was implemented, applying a recommended consistency benchmark of ≥ 0.9 and taking coverage as a measure of a necessary condition (Ragin, 2000; Schneider and Wagemann, 2010). As suggested by the literature, we considered only those configurations with a minimum number of empirical representations equal to one, which is the recommended threshold for the frequency of medium-sized samples (10–50 cases) (Ragin, 2008).

The following step is to consider only consistent combinations. In order to clarify this passage, it is important to emphasize what is meant for consistency and coverage, which are two key measures in the analysis of necessary condition: consistency expresses the degree to which a given condition is a subset of the outcome, while coverage provides a numeric expression for the empirical importance of a given condition (or a combination of them) for producing an outcome (Schneider and Wagemann, 2010). Consistency ranges from "0" (indicating no consistency) to "1" (indicating perfect consistency). Once it is determined that a condition is consistent, coverage provides a measure of empirical relevance, ranging between "0" and "1".

In doing this, remember that a condition is sufficient if, whenever the condition is present, the outcome is also present, while a condition is necessary if, whenever the outcome is present, the condition is also present (Schneider and Wagemann, 2010). Thus, the analysis tests whether any factor qualifies for necessary conditions for the high specialization of manufacturing and R&D factories and its negation (low specialization). None of the individual conditions exceed the threshold of 0.90 in both tests (Greckhamer, 2011), as in other contributions (e.g., Chen et al., 2018) (see Appendix 3.D).

4. Logical reduction and analysis of configuration

A consistency benchmark to conduct sufficiency analyses using Ragin's (2008) algorithm was applied. A frequency cutoff of 1 is usually advised for small samples (Ragin, 2008), while a minimum of 0.75 is generally required for the consistency score. We applied a consistency benchmark of ≥ 0.8 for sufficient analysis (Greckhamer et al., 2018) and 1 as the frequency cutoff. All the analyses were conducted with the software fsQCA 3.0. The following analysis reports a combination of intermediate and parsimonious solutions, as it is more suitable for theoretical interpretation (Fiss, 2011; Ragin and Fiss, 2008). The intermediate solution represents a subset of the parsimonious solutions (i.e., the solution that reduces to the smallest number of conditions possible), and a superset of the most complex solutions. As explained in Ragin and Fiss (2008), the elements included in the parsimonious solutions are those that must be included in any representation of the results since they are "the decisive ingredients that distinguish combinations of conditions that are consistent subsets of the outcome from those that are not" (Ragin and Fiss; 2008, page 204). That's why these terms are considered as the "core" causal conditions. Instead, the terms added in the intermediate solutions are complementary or contributing conditions, i.e., they continue displaying the outcome but require difficult counterfactuals to be removed. The difference between intermediate and parsimonious solutions relates to the concept of "easy" and "difficult" counterfactuals, where "easy" counterfactuals relates to situations where a redundant causal condition is added to a set of causal conditions that by themselves already lead to the intended outcome (Fiss, 2011). In other words, an easy counterfactual refers to the presence of substantive empirical or theoretical knowledge which provides a clear indication of how a condition contributes to an outcome. Core conditions remain part of the solution even when assuming a state of the world in which difficult counterfactuals (consistent with empirical evidence but not with theoretical knowledge) occur (Soda and Furnari, 2012). However, considering the exploratory purpose of our research and given that there is not much guidance in the literature as to how each condition should affect results, we followed the suggestion of Judge et al. (2014), and we abstained from specifying easy counterfactuals.

To simplify, core conditions are part of both parsimonious and intermediate solutions, while peripheral conditions are deleted from the parsimonious solution and only appear in the intermediate solution (Fiss, 2011).

3.4.1.2 Main findings from the QCA

Tables 3.8 and 3.9 present the results of our analyses. The fsQCA configural solutions are presented using the notation of Ragin and Fiss (2008): black circles (●) indicate the presence of a condition (or factor), and circled crosses (○) indicate its absence. Blank spaces mark attributes that may be present or absent. Also, core conditions that occur in parsimonious and intermediate solutions are indicated with large circles, while complementary conditions that occur in intermediate but not parsimonious solutions are indicated with small circles. Furthermore, following the guidelines of Greckhamer (2016), configurations were sorted by unique coverage, then we grouped those sharing core conditions (neutral permutations) together. They were numbered as S1a, S1b, etc. The accepted threshold for coverage is 0.01 (Ragin, 2008; Russo et al., 2019). The consistency cutoff values chosen are 0.8313 for high manufacturing specialization, 0.847 for low manufacturing specialization, 0.843 for high R&D specialization, and 0.860 for low R&D specialization. These values are larger than the recommended rule of the cutoff value.

The configurations of relatively high manufacturing specialization and low manufacturing specialization show high levels of overall solution consistency (0.83 and 0.84, respectively) and solution coverage (0.63). Similarly, the configurations for high and low R&D specialization show even higher values for overall solution consistency (0.86 and 0.93 respectively) and acceptable levels of overall solution coverage (0.37 and 0.61 respectively). The level of coverage shows the empirical importance of the solution as a whole (Chen et al., 2018; Crilly, 2011), and these relatively robust results show that the obtained configurations play a relevant role in explaining factories' specialization. Furthermore, previous studies (e.g., Campbell et al., 2016) suggest an acceptable consistency (≥ 0.80) when measuring how well a solution corresponds with data. Our consistency score for each configuration is often higher than 0.90, pointing out the equifinality of causal combinations (i.e., the presence of multiple sufficient configurations that lead to the same outcome), as suggested by fuzzy set logic (Fiss, 2011; Ragin, 2000). Our exploratory approach is similar to previous studies in addressing both the presence and the absence of multiple outcomes (Greckhamer, 2016; Judge et al., 2014), and also the performance levels are in line with their contributions.

In the next paragraph, first, an interpretation of the presence and absence of high specialization of manufacturing plants is suggested, followed by a comparison between these findings; then, an interpretation of the presence and absence of high specialization of R&D units is suggested, supported by a comparison of the results.

Table 3.8: Configurational solutions for Manufacturing specialization

	High MANUFspecialized			**Absence of high MANUFspecialized**		
Configurations	S1	S2a	S2b	S3a	S3b	S4
Size	◦	⬤	⬤	◯	◯	◯
AvgNoEmplUnit	◦	•	•	◦		⬤
DispersM		⬤	⬤	•	◦	◯
DispersR	◦	•	•	•	◦	◦
DistALL	◯	•	◦	⬤	⬤	•
DistRtoM	◦	•	◦	⬤	⬤	
Consistency	0,84	0,83	0,93	0,85	0,89	0,89
Raw coverage	0,30	0,37	0,22	0,44	0,30	0,35
Unique coverage	0,19	0,18	0,04	0,23	0,01	0,07
Solution coverage	0,63			0,63		
solution consistency	0,83			0,84		

Note: ⬤ core condition present; ◯ core condition absent; • peripheral condition present; ◦ peripheral condition absent. Blank space: the condition may be either present or absent. N=34

Table 3.9: Configurational solutions for R&D specialization

	High RDspecialized		**Absence of high RDspecialized**		
Configurations	S5a	S5b	S6	S7	S8
Size	⬤	⬤	◯	◦	◯
AvgNoEmplUnit	•	•	◦	◦	⬤
DispersM	•	◦	•		◦
DispersR	•	•	•	◯	◦
DistALL	◯	◯	•	◯	•
DistRtoM	◦	•	⬤	◦	
Consistency	0,84	0,93	0,99	0,88	0,93
Raw coverage	0,32	0,25	0,35	0,26	0,25
Unique coverage	0,12	0,05	0,15	0,11	0,03
Solution coverage	0,37		0,61		
solution consistency	0,86		0,93		

Note: ⬤ core condition present; ◯ core condition absent; • peripheral condition present; ◦ peripheral condition absent. Blank space: the condition may be either present or absent. N=34

3.4.1.3 Interpretation of the results

Specialization of manufacturing units

- *High specialization of Manufacturing units (Table 3.8, Left side)*: based on core conditions (Fiss, 2011; Meuer, 2014), two configurations were consistently linked to membership in the set of companies with the presence of high specialization of manufacturing plants. To provide an example of how to interpret the table, the first configuration (S1) combines (irrespective of the level of development) a low level of DistALL as core conditions, along with the absence of some complementary conditions: the size, the average number of employees per plant, dispersion of R&D networks, and distance between manufacturing and R&D plants. Solutions S2a and S2b are identical in core conditions, i.e., the presence of large size and a high level of dispersion in the manufacturing network. Yet, they differ in some peripheral conditions (DistALL and DistRtoM). The common conditions in S2a and S2b underline how a high degree of specialization can be achieved with large companies with medium-large plants and where the dispersion of R&D and manufacturing networks is high.
- *Absence of high specialization of Manufacturing plants (Table 3.8, Right side)*: a relatively dominant path (S3a, raw/unique coverage = 0.44/0.23) combines high levels of distances, and small size as core conditions. Here, the core conditions over distance emphasize the difficulty to specialize manufacturing when far away from other functions. S4 combines a high AvgNoEmplUnit with relatively small companies and low dispersion as core conditions, and low DispersR and high DistALL as peripheral conditions; this seems to suggest they are small multinational companies (not transnational companies) with limited R&D and manufacturing dispersion, but high distance: in this case, D labeled units are geographically distributed (increasing the DistALL), or manufacturing and R&D networks are on far each other.
- *Comparing configurations*: the comparison between the presence and absence of high specialization configurations (left and right side of Table 3.8, respectively) allows us to make some observations. Apart from S1, the results support the fact that size is an important condition in manufacturing specialization. This might be interpreted in relations to different perspectives; for example, a large size of the company might be correlated with a higher subsidiary's decision making autonomy (Van Dut, 2018; Hedlund, 1981; Katrin et al., 2005) or to higher decentralization (Johnston and Menguc,

2007). Comparing S2a/b with S3a/b and S4, it can be noted that the core conditions on Size and DispersM are opposite. Regarding distance, the core conditions are opposite between S1 and S3a/b, while interpreting peripheral conditions is more challenging. It is noteworthy that the absence of high manufacturing specialization is always supported by the presence of high distances between all plants and between R&D and production networks.

Specialization of R&D units

- *High specialization of R&D facilities (Table 3.9, Left side)*: high R&D specialization is obtained with a unique configuration (S5), which shows slight differences in peripheral conditions (S5a and S5b): the core conditions indicate the need for large size and a limited distance between all the plants. Both solutions have medium to large plants (presence of peripheral condition on AvgNoEmplUnit).
- *Absence of high specialization of R&D facilities (Table 3.9, Right side)*: the configurations that support a low specialization of R&D are three: the first (S6) presents companies with small size, and high distance between manufacturing and R&D factories as core conditions, combined with high distance and dispersion conditions and a reduced AvgNoEmplUnit per plant as peripheral conditions. These are small companies with relatively small factories but are characterized by high dispersion and distance. The second configuration (S7) has a low dispersion of the R&D network and a low distance between all plants as core conditions. All peripheral conditions are absent (empty bullet), thus resulting in small companies, not very dispersed and geographically close to each other. The third configuration (S8) has a small size, but high AvgNoEmplUnit as core conditions, and limited dispersion as peripheral conditions; this case seems to suggest that the limited number of factories in the network leads to the inclusion of R&D within large but not specialized units.
- *Comparing configurations:* when comparing the left and the right part of Table 3.9, the size is core condition in all configurations (except one where it is peripheral) and is present in S5a/b (presence of high R&D specialization), absent in S6, S7, S8 (absence of high R&D specialization). The DistALL instead is present as a core condition in S5a/b and in S7, but in both cases, it is absent. Moreover, the S6, S7, S8 configurations emphasize once again the equifinality (Fiss, 2011) with the achievement of the same

output (absence of high R&D specialization) with very different configurations. For example, the dispersions and distances of S6, S7, S8 are contrasting, in some cases supporting high R&D specialization in others supporting low specialization.

3.5 Contributions

Previous analyses tried to understand to what extent manufacturing and R&D functions are specialized or integrated with other typologies and to explore what are the factors and configurations that lead to more integrated or more specialized networks in terms of aggregation of functions. Regarding the first object, it is noticeable that companies specialize much more in manufacturing and that they tend not to occupy the top-left quadrant of the matrix in Figure 3.3. In other words, companies do not specialize R&D activities in dedicated units unless the company also specializes the manufacturing network (thus resulting in the top-right quadrant). Despite the limited number of cases, this can be considered an important first indication of the paper, also in the light of the previous literature on R&D, in particular regarding the concepts of coupling and specificity (Ketokivi et al., 2017).

In this section, a managerial interpretation to the main objective of the paper is offered, i.e., which are the configurations – the sets of factors - that drive towards more specialized or towards more integrated manufacturing and R&D networks. Contingency tables have highlighted significant effects of size, average size of the plants, dispersions, and distances. These individual conditions may suggest that managers might influence configurations according to purposeful decisions they might take on (some of) the variables studied above. For example, the size of the company might drive the decision about specialization, for both manufacturing and R&D sites. Alternatively, an increase in R&D specialization seems to be linked to a limited dispersion of the R&D network, which may be due to very different reasons, for example, to the objectives (applied research related or not to current market needs) pursued by overseas R&D sites (Pearce, 1994).

However, the QCA has emphasized that there are also configurations – i.e., bundles of factors – that can lead to the same output. The analyses allow us to make some considerations by analyzing the quadrants of the initial matrix (Figure 3.3), in particular, comparing the solutions of Table 3.8 and Table 3.9.

Top-right quadrant

In order to evaluate the top-right quadrant of Figure 3.3, a comparison between the configurations leading to high manufacturing specialization (S1, S2a/b) and those leading to high R&D specialization (S5a/b) has to be done. S2a/b and S5a/b, are similar in the presence of Size (core condition), and in AvgNoEmplUnit and DispersR (peripheral conditions). The single case analysis shows that only one of the cases in the top-right quadrant has less than 20,000 employees, and only two have a low R&D specialization. To these conditions, when comparing S1 and S5, we notice that DistALL is the absent core condition in all three configurations (S1, S5a, S5b). It seems that a limited distance between points of the network fosters specialization; as discussed above, there has been much debate about the geographical distance of units in the network, in particular, related to the independence versus cross-functional integration of units (e.g., Ketokivi et al., 2017). Our configurations emphasize the importance of physical and information proximity for manufacturing plants to be specialized. This is probably a result of the increase of uncertainty and information costs due to distance (Castellani et al., 2013); thus, the core conditions on distance (all absent) can be interpreted as an indication that units are easier to specialize when they are close to other functions and skills.

Bottom-left quadrant

A comparison between the configurations leading to low manufacturing specialization (S3a/b, S4) and low R&D specialization (S6, S7, S8) must be performed. Size is absent as a core condition in all the configurations, showing that it must be low to experience low levels of specialization. As discussed above, this result further supports the strand of literature suggesting a direct correlation between size and subsidiaries decision-making autonomy (Van Dut, 2018; Hedlund, 1981; Katrin et al., 2005). Comparing S6 with S3a (which has a dominant effect compared to S3b - 0.23 vs. and 0.01 of unique coverage), almost identical solutions can be identified. This suggests that a relatively small company with small factories and with high dispersions and distances is likely to be positioned in the bottom left quadrant. This result of a high level of distances and dispersion is consistent with Alcácer and Delgado (2016), that found that co-location across activities (low specialization) is higher for companies operating in a few locations. Similarly, S4 and S8 are identical configurations, with DispersM as core condition in S4 and peripheral condition in S8. In both the solutions, AvgNoEmplUnit is a core condition (present); several studies (Gates and Egelhoff, 1986; Johnston and Menguc, 2007) argue that large subsidiaries imply a higher level of decentralization of the decision-making process. It might be due to the overlapping of tasks (low specialization for both manufacturing and R&D). To summarize, many similarities emerge between the proposed configurations that lead to low specialization in both production and R&D.

Bottom-right quadrant

For evaluating the bottom-right quadrant, the comparison is between the configurations leading to high manufacturing specialization (S1, S2a/b) and low R&D specialization (S6, S7, S8). The comparison shows that there are not many similarities between the configurations considered except for S1 and S7: these two configurations are identical, with the absence of all the conditions studied, and DispersM which is indifferent to both. S1 and S7 are comparable in that there are low distances (between manufacturing and R&D networks but also considering all the other plants) and low R&D dispersion; that is, they represent regional rather than globally dispersed networks, in which, even with distributed sales offices, the core of the company is quite concentrated. The fact that DispersM is indifferent and that the low level of DistALL is the only core attribute for both S1 and S2 partially supports Castellani and Lavoratori (2020) in stating that R&D labs are located next to manufacturing plants to compensate for the lack of ability to manage knowledge transfers across geographically dispersed units.

Top-left quadrant

The comparison is between the configurations leading to the absence of high manufacturing specialized (S3a/b, S4) and those leading to high R&D specialized (S5a/b). These configurations have substantial differences in the conditions, often antithetical, i.e., where the core conditions (present) in S3a/b, S4 are paired with the same core conditions (but absent) in S5a/b. It happens both with size (core condition present in S5 and core absent condition in S3a/b and S4) and DistALL (core condition present in

S3a/b and peripheral present in S4 and core absent condition in S5). The lack of similar configurations is consistent with the lack of companies in the top-left quadrant.

Table 3.10 summarizes the results of the latest analysis based on the quadrants of Figure 3.3., emphasizing only the core conditions.

Table 3.10: Analysis of the core conditions based on quadrants

Quadrant	Results
Top-Right Quadrant	• Size: core condition (present) in S2a/S2b and S5 • DistALL: core condition (absent) in S1 and S5
Bottom-Left Quadrant	• Size: core condition (absent) • *DistRtoM:* core condition (present) in S3 and S6 • *AvgNoEmplUnit:* core condition (present) in S4 and S8
Bottom-Right Quadrant	• *DistALL:* core conditions (absent) in S1 and S7

3.6 Conclusions

This paper investigates the combinations of factors leading to different levels of specialization or co-location of manufacturing and R&D in the context of MNEs. Our study links these two value-added activities by analyzing the drivers behind the choice of multinational companies to diversify their units. The methodological approach uses cross tabulations as support for a fuzzy set QCA (Ragin, 2000).

Some noteworthy contributions to the MNEs literature are given. First, the results enrich the literature of cross-functional integration and spatial organization in the context of MNEs. Our study supplements an already established body of research spanning multiple disciplinary fields (Alcácer, 2006), by suggesting drivers of firm location choices. The results of the cross tabulations suggested some drivers (e.g., company size, intra-network distance between plants, dispersion of individual manufacturing and R&D factories) as significant for the level of functional specialization. Besides, the preceding cross-tabulations provided empirical support to the choice of the factors to be considered in the QCA following the framework in Figure 3.2 to ensure greater robustness of the analysis (Schneider and Wagemann, 2010). Interestingly, although the literature has indicated the industry as a relevant factor for the choice of co-location of manufacturing and R&D (Ivarsson and Alvstam, 2017; Ketokivi et al., 2017), the results of the cross-tabulation did not show any significant effect; however, considering the different objectives of R&D in each industry, it is conceivable that the industry affects the specialization (for example, of the R&D network). This evidence should be tested with new empirical research.

Second, the analysis provides configurations (i.e., bundles of factors) that lead a company towards high and low specialization in manufacturing and high and low specialization in R&D. Past studies have focused mainly on the net effects of factors antecedents over the cross-functional integration; thus, they seldom capture the complexity of the relationships through an integrated perspective. QCA allowed exploring causal asymmetry (Fiss, 2011), assessing conjunctural causation and equifinality (Rihoux and Ragin, 2008) in the collected data. In fact, apart from the case of high R&D specialization where only one configuration emerged, different combinations were found to lead to the same outcome. These findings emphasize the complexity of the relationships among factors that impact specialization in MNEs.

Third, QCA results have been used to offer an interpretation to levels of manufacturing and R&D specialization, i.e., to the quadrants of Figure 3.3, cross-referencing the configurations from S1 to S8 and showing the similarities between configurations. QCA is considered a methodology for exploring and learning, rather than for testing; by exploring several paths leading to the same destination, our analysis supports managers to allocate their limited resources better and configure their companies, offering alternatives for intervening on their dyadic production-development networks.

Although the network configuration has long been seen as a medium-to-long-term process, the time frame is shortening. Companies are being called upon to review their strategies faster and faster and free themselves from their conventional inflexibility (Johansen et al., 2014). Through the QCA and the study of the configurations that lead to greater or lower specialization, the objective of this work is to support managers by offering them alternatives when exploring ways to modify their networks.

3.6.1 Limitations and further research

Recognizing the exploratory purpose of this research, the limitations of this study lead to potential future research directions. *First*, conscious that any theoretical research is limited in the number of attributes it can include (Fiss, 2011; Marx and Dusa, 2011), the first limitation of this study is that the analysis was performed on the impact of a limited number of antecedents (six) on factories specialization. The limited number of factors has been constrained by the QCA requirements to keep the number of conditions moderate (Fainshmidt et al., 2020; Marx, 2006; Schneider and Wagemann, 2010). However, in the future, even more holistic studies, including different stimuli for cross-functional integration or functional specialization should be taken into consideration. Additionally, further contributions might replicate this approach to other value-added activities besides manufacturing and development, such as sales and marketing, service, or finance.

A second limitation is that the metric used as a proxy to calculate manufacturing and R&D specialization is conceptually simple, albeit new. There is not much literature to support it, considering that there are no works that have used a specific metric. Thus, the theoretical justification for using our metrics is limited. A possible further development could be to estimate manufacturing and R&D specialization differently and gather data related to specialization variables based on multi-item scales to explore the validity of our results further.

Expanding the research towards an economic geography perspective, it would be interesting for future studies to see what could be the effects of the "country" factor in the choices to co-locate or specialize manufacturing and R&D networks. For example, some countries attract foreign investments through tax relief and specific economic strategies. It may be helpful to understand if and how the factors and configurations found in this research change according to the countries studied.

Furthermore, this paper develops tentative propositions about the causal relationship investigated, but other researchers might develop additional fuzzy-set analysis to explore uncovered boundaries. In particular, the logic and empirical depth of our qualitative analysis could be applied to a broad set of cases, considering that QCA has been extended its application to larger samples (e.g., Leischnig et al., 2018). Set-theoretic methods are particularly suited to grasp the complexity of a phenomenon, and potentially the implementation of QCA-based research opens up relevant possibilities for OM scholars.

Lastly, the proposed cross-quadrant analysis is only "qualitative" in order to provide evidence that the quadrant view is interesting and can bring further insights. However, future developments of the article could perform the QCA by considering manufacturing and R&D specialization together. It should be noted that we could not have used both variables (MANUFspecialized and RDspecialized) as dependent variables. An alternative would have been to enter MANUFspecialized and RDspecialized as independent variables one at a time, while studying the other as the dependent variable. Given the limited number of cases, adding more causal conditions would have strained the limit suggested in the literature about the number of conditions that could be used in QCA (Fainshmidt et al., 2020; Marx, 2006; Schneider and Wagemann, 2010). Therefore, we did not perform it in this study. We see this as a relevant opportunity for future research.

Appendix 3.A: Summary data

Appendix 3.A.1: Case studies analyzed

Code	Industry	Country	Size	B2B vs B2C	No. of units
C.01	Chemical	France	20.000	B2B	226
C.02	Chemical	South Korea	20.000	B2B	59
C.03	Chemical	UK	1.800	B2B	14
C.04	Automotive	Sweden	103.985	B2C	18
C.05	Automotive	Italy	6.818	B2B	51
C.06	Automotive	Italy	10.800	B2B	24
C.07	Automotive	France	115.496	B2B	268
C.08	Automotive	Italy	2.200	B2B	12
C.09	Chemical	Italy	5.108	B2B	43
C.10	Automotive	USA	25.000	B2B	66
C.11	Chemical	Italy	500	B2C	24
C.12	Automotive	Italy	3.266	B2B	10
C.13	Automotive	USA	8.100	B2B	40
C.14	Chemical	USA	24.000	B2C	26
C.15	Food	Switzerland	12.000	B2C	85
C.16	Chemical	Italy	3.729	B2C	26
C.17	Chemical	France	67.000	B2B	25
C.18	Chemical	Japan	39.283	B2B	71
C.19	Chemical	Italy	3.420	B2C	77
C.20	Chemical	Japan	17.743	B2B	70
C.21	Chemical	France	3.200	B2B	32
C.22	Chemical	Belgium	24.100	B2B	242
C.23	Chemical	Japan	48.320	B2B	108
C.24	Chemical	Switzerland	1.019	B2B	11
C.25	Automotive	France	185.000	B2C	61
C.26	Automotive	Japan	138.893	B2C	70
C.27	Automotive	USA	2.000	B2B	26
C.28	Automotive	USA	50.000	B2B	111
C.29	Chemical	Denmark	42.218	B2C	24
C.30	Food	Italy	3.029	B2C	22
C.31	Food	Germany	19.271	B2C	140
C.32	Food	France	12.600	B2C	57
C.33	Automotive	Germany	28.578	B2B	82
C.34	Automotive	Germany	133.778	B2C	46

Appendix 3.B: Understanding the conditions of interest through cross-tabulations

In order to investigate whether any of the variables collected significantly affect the R&D and manufacturing specialization, the data were first explored through cross-tabulations, grouping data into discrete and mutually exclusive categories, and then analyzed through the QCA methodology, in line with other research work (e.g., Russo et al., 2019). This Appendix describes the procedures and the results of the cross-tabulations.

Unlike Russo et al. (2019), who built contingency tables through quintiles, all the continuous or discrete variables of interest for this work were categorized using 2x2 or 2x3 matrices due to the limited sample size (Kroonenberg and Verbeek, 2018). The tested variables are: Industry, Size, NoPlants (Number of Plants), AvgNoEmplUnit (Average Number of Employees per Unit, obtained as Size/NoPlants), DispersM, DispersR, DispersALL, DistM, DistR, DistALL, DistMtoR.

In order to transform discrete or continuous variables into categorical variables, we decided to adopt unbiased thresholds; for example, the mean value and the median were used to divide the values into *high/low levels*, wherever possible. Seldom, criteria decided by the researchers and different than the mean value or the median were used to divide the values into *high/low levels*. These thresholds (the mean or the median value) were also raised or lowered to verify the robustness of the results, comparing them with the ones obtained when using the mean or the median values. The results showed slight deviations, not impacting the results. We examined the frequency of occurrence for each category. Chi-square and Fisher's tests were performed to investigate the possible correlation with manufacturing and R&D specialization. This computation was performed using SPSS software.

The first step was to evaluate the attributes extrapolated from the dataset on the single axes of the matrix, i.e., to build contingency tables where the considered variable is associated with manufacturing specialization, then to R&D specialization. As a practical example (Appendix 3.B.2), a two-way contingency table was built to evaluate whether DistR is associated with manufacturing specialization. The two conditions have two levels (low or high) each. The chi-square test of independence between DistR and MANUFspecialization showed a statistically significant association with $\chi2(1, n=34) =$

6.103, p=.016, Phi=.424. In this case, the association is strong (Cohen, 2013). The results of the cross-tabulations on manufacturing and R&D specialization are reported in Appendix 3.B.3.

Appendix 3.B.2: DistR and MANUFspecialization – Cross Tabulation

			MANUFspecialization		Total
			High	Low	
DistR	High	Counts	7	10	17
		% in DistR	41,2%	58,8%	100,0%
		% of total	20,6%	29,4%	50,0%
	Low	Counts	14	3	17
		% in DistR	82,4%	17,6%	100,0%
		% of total	41,2%	8,8%	50,0%
Total		Counts	Counts	13	34
		% in DistR	% in DistR	38,2%	100,0%
		% of total	% of total	38,2%	100,0%

Appendix 3.B.3: Contingency tables on manufacturing and R&D specialization

	MANUFspecialization			**RDspecialization**		
Conditions	Signif.	Cramer’s V	% of expected values smaller than 5	Signif.	Cramer’s V	% of expected values smaller than 5
Industry	o			o		
Size	*	.378	0%	**	.555	25%%
NoPlants	o			o		
AvgNoEmplUnit	o			*	.426	25%%
DispersM	o			o		
DispersR	o			o		
DispersALL	o			o		
DistM	o			o		
DistR	*	.424	0%	o		
DistALL	*	.454	25,00%	o		
DistMtoR	*	.424	0%	o		

Note: o stands for p > 0.05, * for p < 0.05, ** for p < 0.01, *** for p < 0.001, **** for p < 0.0001, - for ‘not available’.

Significant effects of some variables can be observed: size, average number of employees per plant, DispersR, some conditions of distances. Some variables have 25% of the cell (i.e., one cell out of four in a 2x2 matrix) with expected values smaller than 5, which is close to the limit of 20-25% that is commonly adopted (Moore et al., 1999; Yates, 1984). The high percentage of expected values less than five are explained by the limited number of observations (Kroonenberg and Verbeek, 2018). 2x2 matrices were used for purposes of homogeneity and ease of analysis. However, robustness tests were carried out, changing the thresholds (for example, increasing or decreasing the threshold that justifies the passage from "large size" to "small size", placing it at 20.000 employees, then 30.000, then 40.000). 3x2 matrices have also been tested (for example, with "small", "medium", and "large" Size). In both situations, the results were consistent with those of the matrices presented.

Then, in order to better understand the effects of individual factors, we explored what happens by using the quadrants in the matrix as factors in one of the dimensions of the contingency tables. Since companies only cover three quadrants, 2x3 contingency tables were drawn. Results are in Appendix 3.B.4.

Appendix 3.B.4: Contingency tables over Matrix Quadrants

Conditions	Signif.	Cramer's V	% of expected values < 5	Direction
Industry	○	/	/	/
Size	**	.566	16,66%	High Size: majority of companies in the top-right quadrant. Low Size: majority of companies in the bottom-left quadrant (or bottom-right, less frequently)
NoPlants	○	/	/	/
AvgNoEmplUnit	*	.429	16,66%	High AvgNoEmplUnit: majority of companies in the top-right quadrant. Low AvgNoEmplUnit: majority of companies in the bottom-left quadrant. In the bottom-right quadrant, prevalence of low AvgNoEmplUnit
B2B vs B2C	○	/	/	/
DispersM	○	/	/	/
DispersR	*	.492	50,00%	High DispersR: majority of companies in top-right and bottom-left quadrants. Low DispersR: majority of companies in the bottom-right quadrant
DispersD	○	/	/	/
DispersALL	○	/	/	/

DistM	○	/	/	/
DistR	*	.435	0%	High DistR: majority of companies in bottom-left quadrant. Low DistR: companies are divided between bottom-right and top-left quadrant
DistD	○	/	/	/
DistALL	*	.470	50,00%	High DistALL: majority of companies in the bottom-left quadrant. Low DistALL: majority of companies in bottom-right or top-right quadrants
DistMtoR	*	.492	0%	High DistRtoM: majority of companies in bottom-left quadrant. Low DistRtoM: majority of companies in bottom-right or top-right quadrants

Note: o stands for $p > 0.05$, * for $p < 0.05$, ** for $p < 0.01$, *** for $p < 0.001$, **** for $p < 0.0001$, - for 'not available'.

The size, the average number of employees per plant, the distance between R&D plants, and the average distances between R&D and manufacturing plants have significant effects on the distribution over quadrants. DispersR and the average distance between all plants are significant but have expected too many cells with values smaller than five. Also here, higher-order matrices (2x4, 2x5, 3x3, 3x4) were analyzed to give even robustness to the analysis, obtaining equally significant results but at the same time exceeding the limits of the literature on minimum expected values (Kroonenberg and Verbeek, 2018).

In the last column, the directions of the significant relationships are shown. Looking back at the example, the interpretation of the cross-tabulations suggests that companies with a high DistR (average distance between R&D plants) are prone to fall into the Bottom-Left quadrant (low R&D and low manufacturing specialization). Factories with a lower DistR are mainly in the Bottom-Right and Top-Right quadrants. However, some negative contrarian and positive contrarian cases are present within this relationship. For example, there are cases in the Bottom-Left quadrant with a low DistR value. These contrarian cases impact the remainders, which constitute the main effect of the relationship.

Appendix 3.C: Calibration measures

This paragraph provides a detailed discussion on how the calibration measures have been obtained. Most of the analysis is based on a detailed analysis of the literature.

Calibration of outcomes: lacking established knowledge of what constitutes high specialization of manufacturing plants and high specialization of R&D factories, the decision was to apply the approach of Greckhamer (2011) and Greckhamer et al. (2018), choosing the 90th percentile as the breakpoint for full membership, the 10th percentile for full non-membership, and the 50th as cross-over point. Similar approaches have been used by Woodside, (2013) and Moreno et al. (2016)

Calibration of conditions

- *Size*: several studies within the international business or MNEs literature have analyzed global companies with very heterogeneous sizes. For example, Feldmann and Olhager (2019) analyze networks between 11.000 and 18.000 employees, with an average of 14.100. Cheng et al. (2011) study manufacturing network evolution through three case studies with 1.400, 4.000, and 16.457 employees, respectively. Other studies work on multinationals with much larger dimensions: Faccio and FitzGerald (2018) analyze an international group with about 100.000 employees, Secchi and Camuffo (2016) have case studies on MNE from 12.000 to 105.000 employees, Crilly (2011) works on companies with 8.000 to more than 100.000 employees in a paper with a QCA-based approach. Considering that the sample in this research is representative of very large companies (from a minimum of 500 to a maximum of 185.000 employees), we set the fully out threshold at 2.000, and the fully-in threshold at 100.000. The crossover point was set at 20.000 employees. This is in line with the average dimensions of previously cited papers.
- *AvgNoEmplUnit*: similarly to the size, also for the average size of single units, we relied on examples from the literature in IB or MNEs. Among others, Lewis (2000) built three case studies in companies with 150-500 employees on a single unit, Corti et al. (2014), from 80 to 4.500 employees per unit. Our sample is in line with previous works (the average is 738 employees per plant). Thus, these thresholds were adopted: fully in equal to 2.500, fully out equal to 80 and the cross over point at 250.
- *DispersM and DispersR*: the metrics were built using the contributions of Lorentz et al. (2012, 2016) (see paragraph 3.3.2). For the sample of Lorentz et al. (2016), the

average dispersion of production capacity was 0.049, indicating on average an inclination towards domestic supply among the analyzed companies. Instead, Lorentz et al. (2012) show that their mean levels for the three metrics they have used are 0.34, 0.18, and 29 respectively. In our sample, the dispersions range between 0 and 0.53 (in line with Lorentz et al., 2012). Considering our values, we based our threshold values on their contribution, and the thresholds used are 0.15, 0.30, 0.45, and 0.10, 0.25, 0.40 for DispersM and DispersR, respectively.

- *DistALL and DistRtoM:* Given that the sample consists of very extensive networks, even the average distance is understandably high (mean of DistALL=6.310 kilometers, mean of DistRtoM=5.816 kilometers). In literature, many studies have used geographical distance measurements for much more limited contexts, for example, to measure short distances within micro-areas (Laajimi et al., 2020; Schmitt and Van Biesebroeck, 2013). There is less evidence on global networks. Arellano et al. (2020) calculate the geographical distance as the distance between the headquarters and plant's location based on latitude and longitude, and they use a range of distance from 100 to 150.000 kilometers. The value of 7.500 kilometers was adopted as fully in threshold, and 2.500 kilometers as fully out threshold, assuming that, for the areas considered, there is a good chance to stay within the boundaries of each geographical area with less than 2.500 kilometers, starting from any point. The cross-over point has been fixed at 6.000 kilometers, also considering that the average in our sample is very high.

Appendix 3.D: Necessary conditions - fsQCA

Appendix 3.D.5: Analysis of necessary conditions

Causal configurational solutions	High manufacturing specialization		Low manufacturing specialization		High R&D specialization		Low R&D specialization	
	Cons.	Cov.	Cons.	Cov.	Cons.	Cov.	Cons.	Cov.
Size	0.62	0.82	0.36	0.38	0.75	0.61	0.37	0.58
AvgNoEmplUnit	0.68	0.73	0.55	0.49	0.82	0.54	0.50	0.65
DispersM	0.68	0.65	0.69	0.53	0.72	0.42	0.64	0.73
DispersR	0.60	0.61	0.63	0.52	0.73	0.45	0.58	0.70
DistALL	0.69	0.56	0.90	0.59	0.74	0.37	0.78	0.76
DistRtoM	0.58	0.56	0.78	0.60	0.68	0.40	0.66	0.75

Cons. = consistency; Cov. = coverage.

4. MANUFACTURING SUBNETWORK: CONCEPTUALIZATION AND IMPLICATIONS FOR PRACTICE AND RESEARCH

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Abstract

A wide literature about International Manufacturing Networks (IMNs) has been developed in the last decades, driven by the globalization of operations. Attention has typically been directed on plant and network levels, while little emphasis was given to subgroups of plants within the same company. Ferdows et al. (2016) introduced the concept of manufacturing subnetwork through the clustering of plants into sub-groups on the basis of products and process characteristics. However, manufacturing subnetworks still lack well-defined boundaries, and initial evidence shows a gap in the comprehension of what a subnetwork really is. This paper aims at providing a definition and a clear conceptualization of the subnetwork. The research highlights the main characteristics of the concept and the difference between subnetworks, networks, and business units. Furthermore, it shows the theoretical and practical implications that the introduction of the subnetwork perspective might have on multi-plant companies. Examples from four real cases are used to provide additional evidence on the conceptualization developed and its managerial implications. The paper can help practitioners and academics in the identification and recognition of subnetworks within companies, bundling global plants into sub-groups based on the product groups characteristics. This research paves the way for further empirical research over subnetworks.

Keywords: subnetworks; conceptualization; plants role; global operation; multi-plant networks; configurations; product groups.

4.1 Introduction

The globalization of companies has forced managers to develop new organizational approaches due to the internationalization of operations and the expansion of production, purchasing, and distribution from a single nation to a global scale (Meijboom and Voordijk, 2003).

In an attempt to analyze the complexity of the phenomena behind the companies' internationalization, a rich literature has developed over the years with a specific focus on Multinational Enterprises (MNEs) and International Manufacturing Networks (IMNs). Concerning the manufacturing dimensions, the configuration and management of manufacturing networks still represent very complex and critical activities for companies from the perspective of gaining a sustainable competitive performance. Global companies need to adopt a broader vision compared to single plant-based organizations, considering the two main characteristics of the network, i.e., the geographical dispersion of plants and the interdependent coordination among plants (Mauri, 2009; Shi and Gregory, 1998).

IMNs can be studied from different perspectives depending on the level of specificity of the analysis: by considering the individual plants, groups of plants, or the entire network. Literature attention has gradually shifted from the individual plant within the supply chain to a network of plants mutually connected and mutually dependent (Rudberg and Olhager, 2003) and Operations Management extended its focus to multi-plant management and network management. Although the borderline between the analysis of a single plant and the analysis of the entire network has gradually narrowed, the literature has mainly considered only these two levels of detail (Cheng et al., 2015), and little attention has been given to the analysis of sub-groups of plants. However, plant-related problems are difficult to be understood if the network is analyzed as a whole, and vice versa, network-related issues are hardly detectable due to a too narrow perspective, focused only on single plants: nowadays, large corporations operate through different businesses and tend to serve so many markets that insights or conclusions bounded to a too aggregate level risk to be misleading, so a change in the unit of analysis is needed (Feldmann and Olhager 2019).

This work will focus on the concept of "subnetwork", as first elaborated by Ferdows et al. (2016). The authors were the first to introduce manufacturing subnetworks as a different way to cluster plants within a network, proposing to divide a complex business system into smaller and more congruent parts in their manufacturing mission. They defined a subnetwork as a set of plants grouped "on the basis of complexity and proprietary information in the products they produce and production processes they use to produce them" (Ferdows et al., 2016, page 63). In their paper, which represents the first contribution over subnetworks, the exploratory conceptualization is supported by evidence from real case examples.

One of these cases (Case B, which produces consumer plastic products) shows how the treated company has been divided into four subnetworks, based on the products manufactured and the processes used. The four subnetworks represented reveal different levels of competence, higher or lower levels of outsourcing, and membership in different quadrants within the matrix he designed. Examples of subnetwork can be found in many international companies: one of the leading global companies in braking systems is active with 14 global production plants, which are divided according to the products manufactured (brakes for cars, bikes, vans, or dedicated to the racing world). Although there are no real business units, the separation of products, processes, and flows is evident. However, in these networks characterized by high complexity, the boundaries between plants producing different product groups are not always well defined, both for physical and logical flows.

To this end, the final aim of the approach is "to simplify the complexity of a production network", as the subdivision of an extensive manufacturing network into sub-groups of activities, if properly constructed, helps in mapping the network itself and should facilitate the management of the complex system upstream.

The paper of Ferdows et al. (2016) has been remarkable in introducing the new approach and in setting a starting point in the topic. However, the understanding of subnetworks in international companies is far from being completed. Literature still lacks at least three main dimensions:

- i) offering a clear and unified definition of the concept: the subnetwork is an entity that still lacks well-defined boundaries; a structured conceptualization would give formal clarity to academics, practitioners, and managers.
- ii) giving support to the claim of its relevance in the management of international companies: the initial contributions have pointed out the importance of

understanding a subnetwork-based model, but the managerial implications have not been stressed yet.

- iii) providing a clear distinction between this concept and other related ones: subnetwork could be misinterpreted and used in place to other concepts, like network or business unit.

More generally, we found a shortage of literature about subnetworks. Apart from the seminal contributions of Ferdows et al. (2016), Feldmann and Olhager (2019), and Golini et al. (2017), no further contribution to subnetworks can be found. This paper is a conceptual contribution that enriches previous studies trying to fill the above gaps by addressing the overall research question:

What is a manufacturing subnetwork? **(RQ2)**

4.1.1 Methodological Approach

This paper represents a conceptual and theoretical contribution. Conceptual thinking has the objective to understand a situation or a problem abstractly by the identification of its key underlying characteristics and patterns with similar concepts. In particular, this research aims at offering a contribution to the "explicating" and "relating" goals of the framework of MacInnis (2011), which offers a widely used framework for conceptualization and definition contributions. Emphasis is given to generalities and abstractions rather than exceptions. The objectives are delineating what a subnetwork is, what it might involve, what relationships might exist in the Operations Management domain, and summarizing key elements taking a holistic perspective.

The first research objective of this essay is to *define* what a subnetwork is: we aim at providing a definition of the concept by means of defining attributes. Second, the paper wants to *understand* how the concept of subnetwork can help in the analysis and comprehension of manufacturing networks, showing some practical and managerial contributions. The third objective is to *underline* the similarities and differences between subnetworks and other two widely known concepts in OM: networks, and business units.

With respect to what is proposed in this paper, there is a close correspondence with three of the eight specific conceptual goals in the MacInnis framework (delineating, summarizing, differentiating). Therefore, Table 4.1. presents details about the three specific objectives, offering a more robust methodological approach.

Table 4.1: Conceptual goals (adapted from MacInnis, 2011)

General conceptual objective	**Explicating**		**Relating**
Meaning	Articulating, explaining, or drawing out ideas and relationships from subnetworks. Emphasis on generalities and abstractions as opposed to details, on rules rather than on the exception.		Emphasizing differences, exploring new facets, Emphasis on comparison.
Objective	**Defining** [Delineation]	**Understanding** [Summarization]	**Underlining** [Differentiation]
Meaning	To delineate, articulate, describe, or depict the concept of manufacturing subnetwork.	To stock, summarize, and reduce the subnetwork to a set of key elements and guidelines.	To differentiate, see the differences between subnetworks and other well-known concepts.
Specific objectives	Describe what the concept of subnetwork represents, why it is important to study it, and how it works. Connect the concept to the Operations Management domain. Provide a roadmap for future research.	Simplify through reduction. Offer some key managerial takeaways to help towards future development. Adopt empirical evidence to derive conclusions about what is known.	Evoke the steps of distinguishing, parsing, classifying entities. Provide a holistic perspective of subnetwork within other well-known constructs in Operations Management literature such as networks or Business Units.
Required skills	Deductive reasoning skills	Inductive reasoning skills	Comparative reasoning skills

4.2 International Manufacturing Networks

Subnetwork analysis can be included in the broader theme of IMNs, in which an IMN is defined as "*a factory network with matrix connections, where each node affects the other nodes and hence cannot be managed in isolation*" (Shi and Gregory, 1998). Although the need to consider a multi-plant context (multi-plant organization) and not to focus on a single plant was recognized almost at the end of the 80's, the first studies about international manufacturing management were largely directed to localization choices, treating the plants as separated facilities and ignoring the concept of network (Schmenner, 1982). This was facilitated by the fact that the companies still had a relatively centralized production instead of global markets (Rudberg and Olhager, 2003). With time passing, the need to consider multi-plant organizations grew. Starting from Shi and Gregory (1998a), it emerged a definite necessity to analyze networks by both covering geographical dispersion and interdependent coordination among plants (Colotla et al., 2003; Feldmann and Olhager, 2019). In one of the most influential and recent reviews on IMNs, Cheng et al. (2015) distinguished these two separate levels of analysis - plant and Network – emphasizing that they occupy most of the contributions over the topic. The analysis of the literature in the next paragraph follows the distinction between these two perspectives.

4.2.1 The plant within the network

Relevant research on plant-level analysis has been mainly published on single plant locations and plant roles. Most of the initial contributions focus on decisions about plant locations (Meijboom and Voordijk, 2003), where the leading factor for deciding where to locate plants was cost minimization (Schmenner, 1979, 1982). Later, research has been focused on other drivers for allocating manufacturing activities abroad, such as tariff barriers, currency fluctuations, proximity to markets or suppliers, and access to specific resources, skills, or infrastructures (Bolisani and Scarso, 1996; Ferdows, 1989; Meijboom and Vos, 1997).

A broad interest was dedicated to the specific role of plants in international companies (Demeter, 2017). Skinner (1974) and Hayes and Schmenner (1978) can be said to be the precursors in this strand of literature. As for the plant role analysis, several models have been proposed for assigning a specific range of plant expectations to a global production network. Some major models have been proposed for categorizing plants role in an IMN: Ferdows (1997) classified plants into six well-known types according to their role, defining "offshore", "outpost", "source", "server", "contributor" and "lead" plants. More recent contributions tested and validated Ferdows' model (Vereecke and Van Dierdonck, 2002) and further strengthened the literature about the role of the plants within IMNs

(Vereecke et al., 2006; Cheng et al., 2011; Cheng and Farooq, 2018; Demeter et al., 2017; Feldmann and Olhager, 2019, 2013; Szász et al., 2019; Szwejczewski et al., 2016).

4.2.2 Designing global networks

Within the literature related to global manufacturing, a clear distinction can be made between the analysis of network configurations and the analysis of network coordination, which have widely been used as the two key dimensions of IMNs (Meijboom and Vos, 1997; Porter, 1985, 1986; Rudberg and West, 2008; Shi and Gregory, 1998). These two strands occupy much of the global network literature (Feldmann et al., 2009).

The IMN configuration concerns the location of plants and the allocation of resources typically involved in the value chain, i.e., concerns the structure (nodes) of the network (Meijboom and Vos, 1997). Different typologies of classification about IMN configurations have been proposed (Prasad and Babbar, 2000; Meijboom and Voordijk, 2003; Miltenburg, 2009; Pashaei and Olhager, 2017).

The IMN coordination deals with the infrastructure, that is the relational aspects and organizational processes between different plants (connections between nodes) (Colotla et al., 2003). Coordination is related to the links and the relationships among the company's facilities and between production and distribution facilities. Cheng et al. (2015) summarize three main streams of studies about coordination in IMNs: the introduction of practices related to IMN coordination, the transfer of technologies and knowledge, and the optimization of physical distribution.

Configuration and coordination are strongly related, despite usually presented separately. To this twofold perspective, Friedli et al. (2014) introduce a third macro area of *IMN strategy*. This third and final area completes with a slightly different perspective the dynamics observable in an IMN, giving space to the study of objectives and enabling factors in an international company and to the necessary skills within the network.

4.2.3 Reconciling plant-level and network-level analyses

Although most of the analysis has been conducted either at a plant-level or at a network-level, a number of works try to connect the two levels, for example, investigating how the changes in the plant roles, products manufactured, or processes impact on the other plants on the whole network (Cheng et al., 2015; Feldmann et al., 2013; Miltenburg, 2015;

Scherrer and Deflorin, 2017), or considering the whole supply chain (inter-firm manufacturing network) (Golini, Caniato, et al., 2017; Jaehne et al., 2009). Again, other researchers explore the interdependencies between plants and network capabilities (Colotla et al., 2003). Apart from the abovementioned literature, which connects the plant with the network perspective, we found very few works that disassemble the networks in groups of plants. For example, Hayes and Schmenner (1978) introduced the concept of "multiplant strategy" and suggested to divide the plants based on products, markets, or process. There are studies about the business unit, where most of the research is related to performance (Tsai, 2011).

When looking at the closest domain to subnetworks, the literature analyzing the product-group level (considering plants producing homogeneous product groups) is scarcely developed. A structured literature review was conducted according to the guidelines of Burgess et al. (2006) to investigate what had already been said about product-group networks and subnetworks. Journal articles were sourced from the most relevant academic databases (Scopus, Web of Science, ScienceDirect, etc.). An initial search for articles containing the term "subnetwork" (limited to titles and abstracts of journals) revealed that almost all the articles containing the term "subnetwork" were related to fields other than management. When limiting the search to Operations Management research, about a hundred articles were identified, a handful of which were relevant to the topics of our interest. This initial research, also done to understand in which other contexts the term subnetwork was used, was accompanied by a parallel research using crossed keywords to indicate the concepts of manufacturing plant ("facility", "site", "node", etc.), subnetwork ("group of", "sub-set", "sub-group", "cluster", "bundle", "collection"), and disaggregation ("disassemble", "disaggregate", "disjoint") in the IMN and operations management domains. After having identified the research terms, the irrelevant references were filtered out (Matthews and Marzec, 2012).

We found a few references about how the manufacturing strategy can be related to just a bunch or a group of sites (Chang and Harrington, 2002; Wathen, 1995). In a recent article, Feldmann and Olhager (2019) provide an exploratory study on how to divide plants into "multi-plant networks", categorizing factories within five global manufacturing firms according to 20 product group networks. In their research, their use of the term “network” is similar to the subnetwork in Ferdows et al. (2016), despite they mainly focus on product groups, not on processes. Feldmann and Olhager (2019) also emphasize the lack of empirical research at a more detailed level of analysis than the network.

In general, we noticed a gap of research regarding the intermediate level of analysis between plant level and network level, i.e., whether and how companies divide their plants by aggregating them into sub-groups with common characteristics: it is clear that the “group of plants” is not considered as a unit of analysis within the IMN domain. In the following paragraphs, we will analyze the most relevant articles from the literature review about the subnetwork topic in detail.

4.3 Networks and subnetworks

4.3.1 Rooted and footloose models

The research about subnetworks has its origins in a series of works by Ferdows (2009, 1997, 1989), through which, in line with what was anticipated by Skinner (1974), the need to simplify an international production network is brought to the forefront. Ferdows (2009), in particular, proposed a framework to guide companies’ strategic choice, identifying two opposite models of international firms management: a "footloose" network, i.e., a network that frequently moves manufacturing activities to find the best location according to cost-related drivers; a "rooted" networks, in which plants are stable in space and time and, although they do not benefit from low-cost countries advantages, can maintain high-quality standards by means of the higher level of competences and know-how. The study suggested a matrix with products manufactured on the x-axis and processes used on the y-axis. This is a relevant contribution because it offered a categorization of manufacturing plants according to the product and process characteristics. The choice of using similar production processes in different countries for the production of similar products has been subject of debate (West and Bengtsson, 2007).

In addition, the contribution of Ferdows (2009) maximizes the importance of the product as a qualifying attribute for designing the manufacturing footprint. When we use the term "products" to refer to the product family or product group, we have relied on the definition of Simpson et al. (2012), which defines a product group as "*a group of related* *products that are derived from a common set of components, modules, and/or subsystems to satisfy a variety of market applications*" (Simpson et al., 2012, page 141). In this thesis, we will often refer to similar products, product groups, and product families as synonyms. Although the product is a pivotal element to fully comprehend a manufacturing network strategy, apart from Ferdows' model, there are no many frameworks in the literature that consider the product when studying global networks (Sweeney, 1994; Rudberg and West, 2008; Feldmann and Olhager, 2019). Nowadays, international companies offer a plurality of diversified products and product groups in a multitude of countries and with differentiated supply chains, but few theoretical models can describe and support these choices.

4.3.2 Moving from networks to subnetworks

In line with a previous article (Ferdows, 2009), Ferdows et al. (2016) outlined that a similar logic of rooted and footloose networks can also be applied to homogeneous sub-groups of plants within the same company. The authors identified a set of subnetworks within the same IMN and studied their positioning based on product and process characteristics. The final objective of the new approach was to reduce the complexity of the network by breaking it down into simpler and easier to manage entities. This ambitious goal is supported by the increasing complexity of today's large organization and by internal and external factors that affect IMNs, which makes it complex to verify the effectiveness of the manufacturing mission of the network when considered in its entirety.

The concept of manufacturing mission was first introduced by Skinner (1974) and then tackled by numerous other studies. Manufacturing mission refers to the production goal that a certain plant or manufacturing network has and includes both the final goods to be produced and the ways in which these goods are produced. Ferdows et al. (2016) use this concept to explain that a subnetwork is congruent if it "*has an appropriate manufacturing mission and the competencies that it would need to carry it out*" (Ferdows et al., 2016, page 63). Therefore, the concept of manufacturing subnetwork can be applied not only to a single plant or to an entire network but also to fractions of the network.

Golini et al. (2017), in line with Ferdows' preliminary work, defined subnetworks as "*sets of plants that produce products with similar characteristics*" (Golini et al., 2017, page 1), thus giving more emphasis on the product dimension; they studied the characteristics of rooted and footloose subnetworks and how they are managed, trying to understand the implications for operations strategy. Apart from Golini et al. (2017) and Feldmann and Olhager (2019), to our knowledge, no other research about subnetworks has been published. The next chapter will focus on what a subnetwork is by analyzing both the elements that define subnetworks and the practical and managerial implications.

4.4 What is a subnetwork

4.4.1 Definition of subnetwork

In general, the concept of subnetwork introduces a different way of interpreting the organizational architecture of the network. The subnetwork is not an objectively detectable or easily recognizable entity. In sum, it is the aggregation of several production plants resulting from managerial decisions and from deconstructing the production network based on products manufactured. Often, the subnetwork can be interpreted as a unit of analysis rather than a concept. This paragraph aims to provide a comprehensive definition and a conceptualization of the subnetwork, by mixing evidence from the literature about IMNs, and additional inquiry and considerations from the authors.

We offer a series of *attributes* and explain them singularly. The attributes are not intended to be binding and to force the concept to stay within strict boundaries, but on the contrary, they aim to provide guidelines towards a better understanding of the concept. Examples from four real cases will be provided to help the reader further. The examples are chosen taking into account both large networks and smaller networks (2-3 plants) with a sufficiently clear distinction (at least at the commercial level) between final products were analyzed. Exploratory interviews were conducted to emphasize the specificities and show the differences in a marked way, and to circumscribe what falls within and outside the scope of the subnetwork. This was complemented by secondary data (brochures, company reports, websites, press releases, etc.). An overview of the main characteristics of the cases is reported in Table 4.2.

Table 4.2: Overview of the case-examples used

Company	HQ	Industry	Product Type	Revenues M€ (2017)	No. of manufacturing plants	Total no. of productive and non-productive factories
Company A	Italy	Industrial automation	Linear guides, integrated systems, linear motion systems	66	2	7
Company B	Luxemburg	Energy, gas, water	Steel pipes production	4300	24	69
Company C	Italy	Manufacturing	Microwave instrumentations	41	3	6
Company D	Italy	Industrial automation	Lens cutting machines	74	3	5

Attribute 1: Individual manufacturing orientation

A subnetwork is a decomposition of the manufacturing network, i.e., it represents the operative side of the organization. Subnetworks include the fabrication, assembly, production, and finishing of manufacturing goods. This is consistent with the typical perspective of IMN literature, which is usually concerned with the OM perspective (focusing on the network, the coordination, and configuration of the plants), instead of with the SC management perspective (Rudberg and Olhager, 2003; Friedli et al. 2014).

What is important to note is the connection that a subnetwork establishes with its "manufacturing mission". This concept has been emphasized by Ferdows et al. (2016), which in turn refer to Skinner (1974) and to his "focused factory": Skinner observed that plants within a global company often try to respond to too many manufacturing mission simultaneously, facing troubles in achieving most of their goals. To this end, the subnetwork is a tool to be used when an analysis of the whole network results in ambiguous conclusions. Clustering plants through subnetworks helps in disambiguate objectives: each subnetwork contributes to a specific goal; this does not mean that a plant has only one production goal (as analyzed more specifically in one of the following paragraphs) but that each subnetwork has only one manufacturing mission. As in Ferdows et al. (2016), a congruent subnetwork is obtained when it has a "*coherent manufacturing* *mission and appropriate competencies to carry it out*" (Ferdows et al. 2016, page 64). Thus, the subnetwork represents the unit of analysis to which plants having a single coherent manufacturing mission can be divided.

Attribute 2: Criteria for dividing plants among other multiplant strategies

In general, manufacturing plants can be divided according to different aspects: volume, products, processes, flexibility, the role they play in the network, etc. For example, Hayes and Schmenner (1978) identified two possible "multiplant manufacturing strategies" with which organizing production: the product-oriented strategy, where each plant is responsible for one group of products, and the process strategy where each plant is focused on a particular process. Schmenner (1979, 1982) improved the model, adding two different multiplant strategies, i.e., the market-oriented strategy and the flexibility-oriented strategy (general purpose), together with a mixed product-market approach. Other authors contribute to the debate. Friedli et al. (2014) further expanded research about network specialization providing seven potential configurations by means of which production can be organized. Table 4.3 shows the discussed configurations and the corresponding drivers.

Table 4.3: Contributions on multiplant strategies

	Drivers for multiplant strategy								
Articles	Product	Market	Process	Volume	Region	Complexity	Life cycle	Flexibility	Product-market
Hayes and Schmenner (1978)	X		X						
Schmenner (1979)	X	X	X					X	X
Schmenner (1982)	X	X	X					X	
Hayes et al. (2005)	X		X	X	X				
Erb-Herrman and Gricknik (2008)	X	X	X	X				X	
Friedli et al. (2014)	X	X	X	X		X	X	X	

The subnetwork perspective does not interfere with the multiplant strategy but rather integrates it. The classification using subnetworks is close to the "product-oriented strategy" presented above: plants are divided based on products that belong to the same product group (Ferdows et al., 2016; Golini, Vanpoucke, et al., 2017). However, in addition to what already said by the literature, we add that the subnetwork introduces two elements of novelty.

First, dividing in subnetwork does not exactly mean to divide by product groups manufactured: there may be situations where a single product group has to be further divided according to specific reasons. For example, there may be differences in their supply chains in terms of management or market requirements that justify treating them separately and thus splitting the structure into more subnetworks. Or they might have a different downstream supply chain with diversified channels. It could also happen in companies with only one product group but with local supply chains where it may be useful to divide the structure into multiple subnetworks. This can also happen within the same product-group network, showing that a subnetwork is not equivalent to a "product-oriented" classification.

Second, contrarily to the multiplant strategies identified above, subnetworks imply that products and processes are used jointly to evaluate and categorize the plants. Literature about network categorization and multiplant strategy has usually considered one attribute; an example of twofold evaluation (product-market) is proposed only in Schmenner (1979) and scarcely considered in general. Similarly, business units focus only on one element at a time: products, markets, or geographic areas. Two or more drivers have been used just to categorize plants within the same network, but not jointly; they have been used to offer multi-level decompositions of the same network, for example, to divide plants based on product families and then, in turn, divide these groups of plants at a lower level based on the markets served. On the contrary, the combined product-process evaluation was proposed in Ferdows et al. (2016). In addition, for both the product and the process dimensions, two attributes (complexity and proprietary design) need to be assessed.

Attribute 3: Structure of subnetworks

If a plant works individually on a product group by completing most of the operations and no other plants contribute substantially to the processes, the subnetwork collapses on the concept of plant. For example, Company A produces over 95% of its goods in Italy; its network is composed of two separate but geographically close manufacturing factories that produce two distinct product groups, and by more than ten other factories worldwide (with mainly commercial and service purposes and only relatively small finally assembly procedures); in this case, the two subnetworks almost coincide with the two Italian plants. Feldmann and Olhager (2019b) use the term “subnetwork” to refer to subsets of the product-group networks they have studied, showing that their subnetworks can be referred even to single plants. This type of configuration not only occurs in small-medium size companies but could also happen in large enterprises if a single plant is dedicated to a specific niche product, to product groups that do not require too extended volumes, or if it has specific characteristics within the value chain.

In terms of structure, two main typologies of networks were identified by the literature: vertical networks, where production processes are fragmented and the company deals with only one or a few production stages, and horizontal networks, where a company deals with all or almost all process steps (Egelhoff, 1982; Rudberg and Olhager, 2003). Subnetworks can be found both in horizontal and vertical structures. For example, in company B, which is a large, process-oriented firm (a global company producing steel pipes for the world’s energy industry), it was noted that some subnetworks deal with a large part of the production chain. In other words, a subnetwork can generally include more than one production stage. Similarly, Feldmann and Olhager (2019) found that all the product-group networks they investigate include two tiers of production, component manufacturing, and assembly. Most multinational companies do more than one production step or tier. Having subnetworks that represent more steps of production implies that the processes within a subnetwork may also significantly differ from each other.

Attribute 4: Subnetworks can have fuzzy boundaries and create overlapped sets of plants

In literature, the plant has typically been considered as the minimum unit of analysis. However, there is a clear indication that a single plant can be part of more than one subnetwork (Ferdows et al. 2016; Golini et al. 2017): if a plant includes more than one production line, with different product groups realized and processes used, the same plant can be assigned to more than one subnetwork. This is a typical situation to exploit the economies of scale and scope and avoid duplication in all the indirect or non-manufacturing activities (like gatehouses, commercial offices, legal offices, etc.). Thus, a subnetwork can be identified by a set of minimum two plants that work entirely or partially over a specified group of products and with specific manufacturing processes. The subnetworks decomposition can create clusters partially or completely overlapped. In case of overlapping, different situations can emerge:

a) Shared location: subnetworks within a multi-plant company can share all the locations (nodes) or just part of them but without shared manufacturing processes or activities. For example, this could happen for different reasons: the need to produce more product families (even if divergent) in several plants to reduce the distance from customers or avoid duplication of non-manufacturing resources. For example, in *Company B* there is an overlap of product range among the various production sites almost everywhere; apart from some cases, there are no plants that are dedicated to specific product groups, i.e., no plants that work exclusively for one subnetwork. However, manufacturing processes are clearly distinct within plants.

b) Shared locations and manufacturing processes: partial overlapping could also exist for specific manufacturing processes (or productive lines) that are used jointly by two or more product families (Figure 4.1). In contrast to the previous scenarios, in this case, the two (or more) subnetworks share both the node (physical site), and the production processes (area of processing, machinery, lines, etc.). For example, in *Company C*, three subnetworks can be identified; in particular, two subnetworks share common processes in the beginning part of the manufacturing processes (the preliminary operations of assembly and iron or aluminum carpentry are executed by both the subnetworks). Coherently, these processes are co-located in the same plant. After the first processes, the goods follow distinct paths and are sold through different channels and different segments.

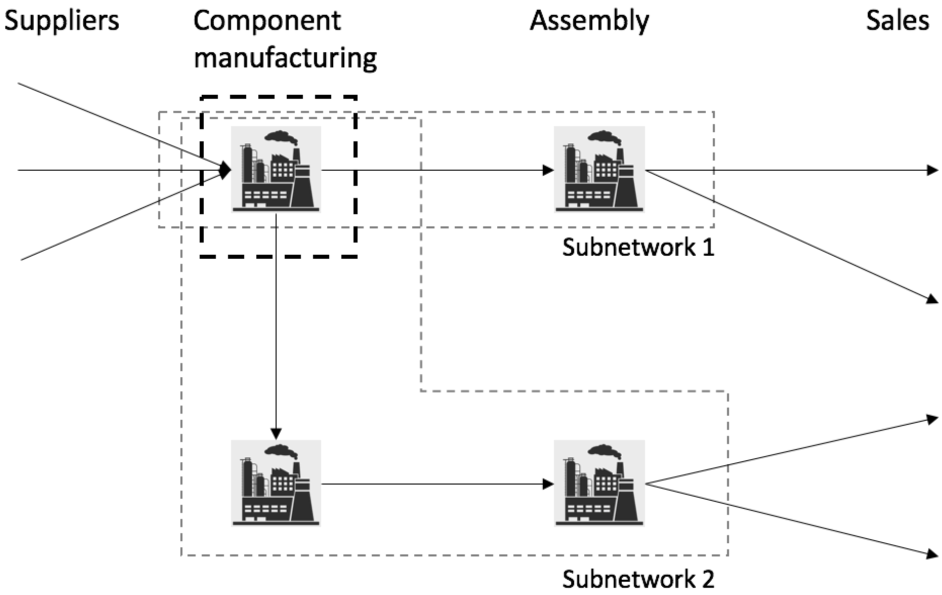

Figure 4.1: Overlapping of subnetworks: shared location and processes

The opposite situation could also occur, i.e., a process of convergence of several subnetworks sharing the final stages or the last sequences of production processes. In paragraph 4.4.2, the different configurations that subnetwork can create will be discussed in detail.

Definition

Grounded on the literature review, on the above consideration, and on the clarification suggested, we propose the following definition of subnetwork:

"A subnetwork is the aggregation of a set of plants that work entirely or partially over a specified group of product missions and with a specific manufacturing." Subnetworks comply with the following attributes:

- *Attribute 1 – Individual manufacturing orientation*: A subnetwork is a decomposition of the manufacturing network, i.e., it represents the operative side of the organization. Subnetworks include the fabrication, assembly, production, and finishing of manufacturing goods. The subnetwork represents the unit of analysis to which plants having a single coherent manufacturing mission can be divided.

- *Attribute 2 - Criteria for dividing plants among other multiplant strategies:* Subnetworks offer an alternative to other multiplant strategies. Subnetworks are divided according to the products realized but are evaluated considering both products and manufacturing processes used. For both these dimensions, the complexity level and the proprietary information level must be evaluated.
- *Attribute 3 – Structures of subnetworks:* If the production of a/some product group/s is carried out in just one plant, the concept of subnetwork collapses on that of plant. Subnetworks can be found both in vertical and horizontal network structures. They can include one or more production steps (e.g., component, assembly).
- *Attribute 4 - Subnetworks can have fuzzy boundaries and create overlapped sets of plants*: A plant can be part of one or more subnetworks. Subnetworks can partially or entirely share the physical location and also processes. Different configurations can occur when plants and subnetworks are combined.

4.4.2 Practical and managerial considerations

Besides the defining characteristics described above, some managerial implications emerge; this paragraph articulates them and provides additional insights that may be considered during the passage from a plant or network perspective to a subnetwork perspective.

Subnetwork perspective over IMNs literature

Being at an intermediate level, most of the principles applied at a network or at a plant level can also be applied at a subnetwork level, depending on the size of the subnetwork. This is an intuitive but not obvious consideration. It is not certain that the discussion and examinations that can be made at the network level (for example, about the structure, specialization, resource allocation, supply chain configuration, etc.) remain valid also at the subnetwork level. The size of the subnetwork plays a fundamental role: we can expect that subnetworks will respond more to the networks' principles or to the plants' principles, depending on their size. In order to study the impact that the subnetwork could have over the IMN literature, this research analyzes three core elements that support the company's strategy: the role of the plants, the theme of capabilities and the manufacturing strategy (Table 4.4). In particular, the analysis first explores the potential usefulness of subnetworks over each specific area: for example, subnetworks might untie the concept of the plant's role (Cheng and Farooq, 2018; Demeter et al., 2017; Ferdows, 1997; Vereecke et al., 2006) from the overall company's production mission, with the possibility to further enrich the already extensive discussion on the role of the plants within multinational networks. The belief suggests that a plant can belong to more subnetworks, and consequently, it hints at the possibility that a plant may play different roles for different subnetworks. The concept will be widely covered also in Chapter 5 and Chapter 6. In general, the understanding that a plant can be part of more than one subnetwork is substantially new in the literature. That concept was mentioned by Ferdows in one of his examples "*Subnetwork B1 consisted of two plants in high-cost regions of Europe and US; these two plants were also a part of the B2 subnetwork, but B2 also had two other plants in lower-cost regions in Southern Europe and Africa...*" (Ferdows et al., 2016, page 68). If a subnetwork is a group of plants that are homogeneous in terms of product and process characteristics, then the manufacturing missions of different subnetworks will be different. Neither Ferdows et al. (2016) nor Golini et al. (2017) have addressed this issue extensively.

Second, the analysis investigates the unsolved challenges that subnetworks may raise; for example, talking about manufacturing strategy, we can ask ourselves whether, how and how often the manufacturing strategies of subnetworks change, or regarding capabilities we might wonder whether subnetwork capabilities differ from factory capabilities and from network capabilities (Shi and Gregory, 1998). Last, the analysis elaborates some possible new interpretations that the introduction of subnetworks brings when dealing with organizations: for example, capabilities typically include trade-offs at network perspective (access to low-cost labor in developing countries versus proximity to specific markets in rich and developed countries, or also the manufacturing flexibility allowing to manufacture products in multiple locations versus the concentration of production activities on a single area to develop economies of scale (Colotla et al. 2003)). Subnetworks might give an interpretation to these trade-offs among different network capabilities, disambiguating objectives, roles, and business needs and considering the network as a set of different and diversified structures. These insights offer a first glimpse of the topic, but additional research is needed.

Table 4.4: Impact of subnetwork approach on plants roles, capabilities, and manufacturing strategy

	Usefulness	Challenges	Possible interpretation (implication, explanation, meaning)
Role of the plant	- Subnetworks separate the plant's role from the overall company's manufacturing mission. - Subnetworks allow a faster and more flexible approach when modifications or adjustments are needed.	- How does the role of the plant change if analyzed at a network or a subnetwork level?	- A single plant can have multiple roles when belongs to more subnetworks. - A single subnetwork can require a plurality of roles. - The type of subnetwork influences the plants' roles required.
Capabilities	- Subnetworks narrow the distance between plant capabilities and network capabilities. - Possibility to have type-related subnetwork capabilities for different types of subnetworks	- How do subnetwork capabilities differ from factory capabilities and from network capabilities? - Are the subnetwork capabilities coherent with the manufacturing mission?	- Thriftiness ability, manufacturing mobility, learning ability, strategic accessibility can also be applied at a subnetwork level. - Subnetworks can shed light on the interdependencies between firm and network capabilities. - Better management of the trade-off relationships among different network capabilities.
Manufact. strategy	- Subnetworks as the real entity to which differentiating factors can be bounded	- How can we integrate the manufacturing mission of a company with the subnetwork's specific objectives? - How and how often do the manufacturing strategies of subnetworks change?	- Coexistence of different manufacturing strategies in the same organization. - More frequent changes in subnetworks' manufacturing strategies

Plants' configurations

From a managerial perspective, the introduction of subnetworks has profound implications. Two or more subnetworks that include the same plant might be divergent in terms of typology (for example, one rooted and the other footloose). This implies that each plant should be managed following different practices and ad-hoc approaches based on the type of products manufactured and processes used. These plants, which are part of two (or more) subnetworks, might behave in an unconventional way. With this regard, Chapter 6 offers a contribution about plants having multiple manufacturing missions.

Furthermore, today's international organizations are both multi-product companies, and multi-stage processes companies, with very fragmented production chains. One of the most adopted frameworks that explain these multi-stage processes is offered by Grünig and Morschett (2017). Similarly, different types of plants' configurations can occur when considering subnetworks. Said that subnetworks can share nodes (physical location) or also processes, Figure 4.2 proposes a simplified framework to categorize them according to two dimensions: first, the presence of overlapped or non-overlapped clusters; second, the fact that each subnetwork includes all the plants of the network (inclusive solution) or just some of them (selective solution). This classification shows four basic structures:

- *Unique structure*: all plants produce the same family of products and work with similar production processes. It means that the subnetwork coincides with the whole network. This configuration usually represents companies with few plants.
- *Homogeneous structure*: all plants work on different product groups and represent different subnetworks. This usually happens in large, process-oriented plants to exploit economies of scale or to avoid duplication of resources.
- *Clustered structure*: the plants can be grouped in non-overlapped clusters, each of which works for a group of products or a family of products. Typically, these subnetworks include multiple stages of production in vertical networks.
- *Mixed structure*: there is a mixed situation in which subnetworks with different responsibilities are partially overlapped, but where at least some subnetworks might be represented by just part of the plants. In other words, not all plants work for all subnetworks.

There might also be an intermediate situation, for example, a subnetwork that includes all the plants and is partially overlapped with other subnetworks that include only specific nodes among the production chain. However, large and diversified companies are expected to be positioned on the right side of the matrix. Understanding the management models of such subnetwork configurations is an intriguing managerial issue.

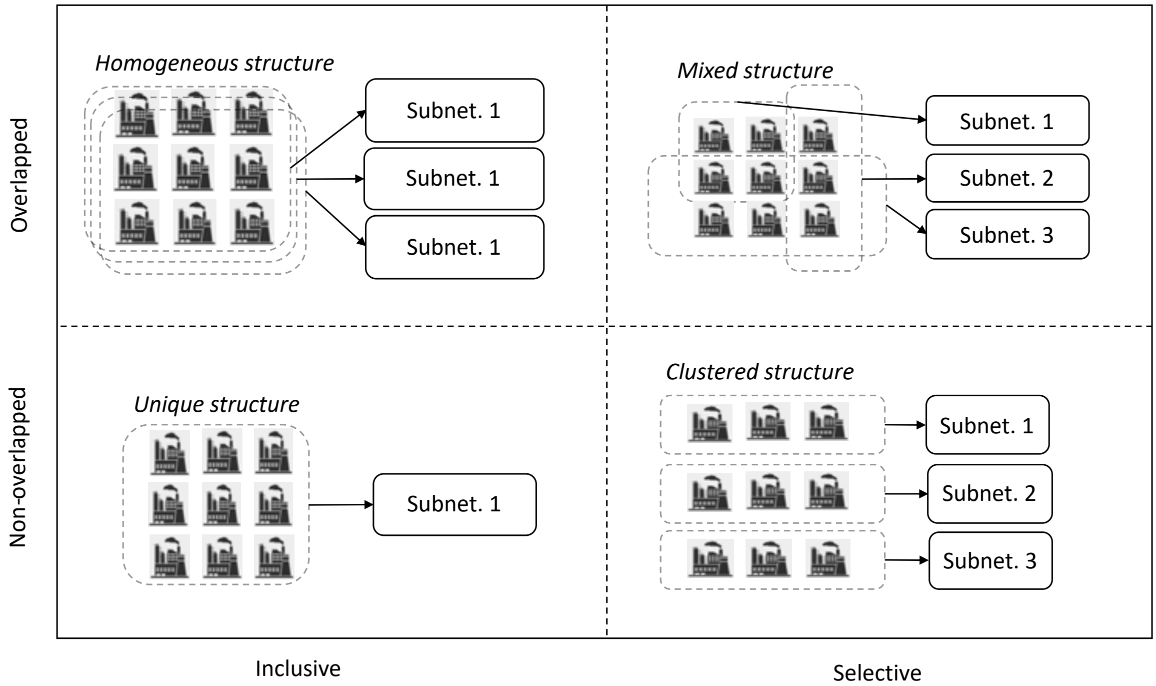

Figure 4.2: Subnetworks configurations

Static vs. dynamic perspective

The subnetwork can be interpreted as a new unit of analysis that frees the company from a whole network-oriented perspective and that provides managerial support in decision-making. Any shifts, relocations, or opening of new production branches can be interpreted based on the existing subnetworks (ex-post analysis) and carried out according to the future needs of subnetworks (ex-ante analysis), through conscious considerations of a strategic, operational and profit-oriented nature. It is the type and objectives of the subnetwork that influence the strategic choices and no longer the network itself. Ferdows *et al*. (2016) suggest the use of subnetworks as a tool for a periodic audit of companies: simplifying the management of companies also means making the control faster and more effective.

It could happen that company's plants remain relatively stable over time from a purely geographical point of view, but that what is produced in each single plant changes and that the role of the plant varies over time. There is no strict relationship between the localization of plants and the internal organization of what to produce in each plant. This aspect risks going unnoticed from a too aggregated perspective and without a clear distinction of where the various product families are produced. Focusing on product groups and manufacturing processes, subnetworks facilitate a more precise and dynamic analysis of manufacturing choices in terms of 'where each PG is produced'.

4.4.3 Subnetwork, Network, and Business unit: Similar or different concepts?

The concept of subnetwork is at least apparently overlapped to other two concepts: the network and the Business Unit (BU). In order to prevent ambiguous or misleading interpretations of the term "subnetwork", it is worth to clearly distinguish the differences among these concepts. This is not only a wording problem to avoid misspelling or misspecification, but it also helps in clarifying the nature and the role of each of these three concepts. Both differences and similarities can be outlined according to specific dimensions summarized in Table 4.5.

Table 4.5: Subnetwork - Network – Business Unit: summary of similarities and differences

Characteristics	Network	Subnetwork	Business Unit
Unit of analysis	It is the aggregation of intra-firm plants spread over different countries. Whole set of plants and activities.	Group of plants within a network. They are responsible just for part of the whole manufacturing mission of the company and usually comprehend some of the plants.	Independent and autonomous entities within the company itself: 'company within the company'. The units at the first level of the organization are created using grouping criteria that are oriented to output (i.e., market, customer, product)
Objectives / strategy	To reach the strategic business objectives: the corporate strategy has a plurality of manufacturing objectives.	To simplify the management of IMNs. Presence of tinier, specific objectives for each subnetwork (e.g., lowest-cost, higher customer services, highest quality products).	To manage independent and autonomous part of the company: independent business strategies.

External recognition	Strong. Companies usually publicize their networks' manufacturing footprint and the geographical location of their plants.	Very limited. Companies do not have incentives and are rather reluctant to share information about the presence of more rooted or more footloose subnetworks or to publicize which product types belong to which subnetworks.	Strong. Business units are entities that are quite easily recognized from an external perspective, i.e., from customers, external stakeholders, competitors, etc.
Identification criteria	No need to identify. The network is represented by the collection of all manufacturing facilities.	Simultaneous and joint evaluation of Product & Process. Subnetworks do not use markets or geographical areas as drivers for dividing plants.	By products OR by processes OR by markets OR by geographic area.
Degree of independence from the central unit	High. Networks represent independent entities, typically managed through a central HQ and eventually through multiple regional HQs.	Medium-to-low. Subnetworks have a strong dependence on the HQ and many links to other subnetworks.	High. A BU replicates internally all the main line-function of the company and is responsible for its own operational strategy, even though within boundaries that are defined by the central unit.
Cost and revenue autonomy	Yes. The network often includes expenditure items from a number of different business units.	No. A subnetwork does not represent an independent profit center.	Yes. A BU can be considered as an independent profit center.

4.5 Conclusions

While the attention of IMNs literature has passed from analyzing the single plants to the network as a whole, the research over the intermediate level is still scarcely developed. In this perspective, the central purpose of this paper is to provide a working conceptualization of the "subnetwork". This research aims at aligning the international community over the meaning of manufacturing subnetworks, which leads to the use of a common language; the research contribution is to clarify its key underlying properties, highlighting the differences with other grouping criteria, in order to avoid misunderstandings and misconceptions. Besides, the study emphasizes the potential impact of subnetworks over companies from a managerial point of view. Inductive, deductive, and logical reasoning has been used. Collectively, the ideas developed in this article are intended to offer a positive step in the advancement of critique and dialogue towards the concept of manufacturing subnetwork to enhance support for the overall comprehension of global networks.

This research provides four basic attributes for defining manufacturing subnetworks: these attributes are presented in an explicit way, and they concur in our working definition. Related to these attributes, some insights and clarifications that could help in practical terms when dealing with subnetworks are shown; examples taken from real cases have been presented; the research also explains some of the managerial implications of subnetworks which do not concur in the definition but offer important insights into how subnetworks are structured in practice within IMNs. Moreover, the analysis presented the impact that subnetworks might imply over companies, by investigating the effects and the challenges over three key topics in the IMN literature: the role of the plants, the capabilities, and the manufacturing strategy. Finally, an insight into the main differences between network, subnetwork, and BU is offered. In particular, subnetworks and BUs have been represented as two separate entities, with clearly identifiable differences and few similarities.

The conceptualization of subnetworks has proved to be complex and multifaceted, but it opens up a series of further possible interpretations. In short, a manufacturing subnetwork is a concept to be used when an analysis of the entire network leads to unclear conclusions. These ambiguous situations can occur, for example, when networks are complex and heterogeneous. The example presented in Chapters 4.1 and Chapter 4.4.2 shows how Ferdows et al. (2016) hint that a plant may be part of multiple subnetworks. In such situations, the multiplicity of products, processes, and flows risks compromising the validity of the network analysis. For example, the same plant may take on different strategic roles depending on the product being studied. The plant would end up assuming an "intermediate role", or the researchers could opt to give the plant a role among those already proposed in the literature (e.g., source, server, etc.), forcing the choice and denying the presence of different roles. Neither scenario, therefore, would accurately describe the actual situation. A disaggregation into subnetworks would reveal the real situation much more accurately. This concept will be largely captured in the next two chapters.

To conclude, our insights about subnetworks invite academics and practitioners to focus on three core aspects: first, the non-uniqueness of the dimensions through which grouping plants and activities, which put subnetworks in contrast with all the other grouping criteria found in the literature. Besides, subnetworks analysis highlights the relationship between product diversification and international diversification (Zúñiga-Vicente et al., 2019). Second, the managerial implications that the subnetwork-level perspective can bring when designing and structuring global corporations. Third, the possibility to have heterogeneous configurations where plants, product families, and process lines are combined on the basis of the specific characteristics of the company.

Future research

There are several issues that call for further research; in particular, empirical research should be conducted to explore the insights offered in this paper. First, we expect that much of the future advantage will be given by a more in-depth analysis of the different typologies of subnetworks, through the operationalization of their characteristics. Second, the research of Golini et al. (2017) paved the way for an analysis of how subnetworks are managed and organized. By becoming aware of the presence of different subnetworks and by assessing their typology, management models that can help practitioners in the evaluation and refinement of networks' organization and configuration could be derived. Exploring the two issues goes in the direction of further stimulate research about subnetworks.

5. UNCENSORED SUBNETWORKS IN MULTINATIONAL ENTERPRISES: DEVELOPING A DESCRIPTIVE TOOL THROUGH A DESIGN SCIENCE APPROACH

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Abstract

Global companies are facing critical structural changes, driven by the increasing complexity and opportunities of the global environment. To simplify the management of production networks, Ferdows et al. (2016) introduced the concept of manufacturing subnetwork, offering a model that clusters and characterizes the groups of plants in multinational companies according to the complexity and proprietary information of products and processes. By taking this perspective, this research designs and applies a descriptive tool that helps identify subnetworks in multinational companies and understand their structure. Besides, it provides an operationalization of the product and process characteristics of subnetworks, integrating previous models and considering additional dimensions and attributes. Our tool is built following the Design Science Research (DSR) principles through a trial-and-error– type iterative process by means of five cases, and it is then applied to an additional global manufacturing company.

Keywords: International Manufacturing Networks, Global Operations, Multinational Enterprises, Multi-plant Strategy, Design Science Research

5.1 Introduction

In recent decades, large multinational companies have undergone major changes in structure, focus, and behaviors. The internationalization of markets and the globalization of production activities have seen the continuous transformation of companies into increasingly complex and differentiated entities.

Multinational companies have followed the globalization wave, developing geographically dispersed plants (Cheng et al., 2015; Rudberg and Olhager, 2003) and turning into the so-called International Manufacturing Networks (IMNs). In particular, companies are involved in diversifying their production into several product families (Feldmann and Olhager, 2019). Considering that production can be divided into homogeneous product groups, also production processes and plants can be grouped into homogeneous clusters, which serve one or more product groups. In this perspective, the unit of analysis might change accordingly: from the analysis of the whole network to the analysis of clusters of plants producing the same product groups. However, in the IMNs literature, most of the contributions are at a network-level or plant-level. Despite the growing complexity of international production networks, there is still a lack of literature about the possible ways of decomposing the network; in other words, few contributions take into account the intermediate level of analysis between a single plant and the entire network (Cheng et al., 2015).

In this research, the theme of sub-network has developed starting from the key initial contribution by Ferdows et al. (2016), who proposed a reference model for decomposing the production network into *manufacturing subnetworks* groups of factories that work together to accomplish a manufacturing mission. The recent introduction of subnetworks still needs to be supported by further contributions; few papers have investigated the topic (Golini, Vanpoucke, et al., 2017), and the rare empirical contributions are very context-specific, for example, products assembled with product families that are reasonably easy to identify (Feldmann and Olhager, 2019). However, the proposed models have not yet answered the more operative aspects related to the application of subnetworks principles in today's organization.

Proper control of large networks through the optimization of flows, prioritization of production processes, and common practices among plants pursuing the same industrial objectives can lead to dramatic savings in efficiency and effectiveness. The reason to offer a contribution over subnetworks is that new management models for international networks can be brought to the surface, supporting a more dynamic strategic management from a perspective of simplification (Ferdows et al., 2016).

This paper aims to fill the gap between theory and practice by translating the theoretical subnetwork framework into a practical tool for managing them. The underlying research question for this research is:

How can subnetworks be identified within a multinational company and how to describe them in a systematic way? (**RQ3**)

A Design Science Research (DSR) approach was adopted for this work, with an interplay between case studies and the design science principles (Kaipia et al., 2017; Wagire et al., 2020). The DSR differs mainly from explanatory research in its objective to develop "a means to an end" (Holmström et al., 2009) and in its pragmatic approach to problem-solving. Particularly, through a DSR approach, it was possible to develop and show the application of a descriptive tool that provides practical support in three specific research objectives: a) identifying how many and which are the subnetworks in an IMN; b) mapping the activities, plants, and processes and their hierarchical decomposition among the different subnetworks, together with their supply-chain configuration; c) operationalizing the characteristics of subnetworks to help in the evaluation of their typology. The outcome of this research should be intended as a prototype for subnetworks identification, mapping, and operationalization, grounded on the literature and on the evidence of case studies.

This paper is organized as follows: first, the literature review with the relevant contributions to the subnetwork conceptualization is provided. The methodology is presented, together with the case studies that have supported the research. Then, the tool is introduced and its main characteristics presented. Lastly, the tool is applied within a multinational company, and its practical usefulness is shown. Theoretical and practical contributions conclude the paper.

5.2 Literature background

Plant-level and network-level analyses represent the two main blocks of the IMNs literature (Cheng et al., 2015). Manufacturing internationalization was initially analyzed by taking the plant as the unit of analysis, with particular attention to the plants' localization choices (Meijboom and Voordijk, 2003), where strong emphasis was given to the cost factor (Schmenner, 1979). Later, different researchers investigated the drivers for positioning factories abroad (Bolisani and Scarso, 1996; DuBois et al., 1993) and the role of the plants within the network (Bartlett and Ghoshal, 2002; DuBois et al., 1993; Feldmann et al., 2009; Feldmann and Olhager, 2013; Ferdows, 1989; Vereecke and Van Dierdonck, 2002). Some of the first and most relevant contributions about plants' role are those of Ferdows et al. (1989, 1997), that proposed six ideal types of plants - offshore, source, server, contributor, outpost, and lead-plant – according to two dimensions of analysis: site competences and the strategic reasons for the site.

Just more recently, the literature started to analyze multi-plant operations strategies (Cheng et al., 2015): within the literature on global manufacturing, a clear distinction can be made between the analysis of network configurations and the study of network coordination (Porter 1985; Porter 1986; Meijboom and Vos 1997; Rudberg and West 2008; Pontrandolfo 1999; Cheng, Farooq, and Johansen 2015). The IMN configuration is the static and structural element associated with the factories (Junior and Fleury, 2018), and it concerns the structure (the nodes) of the network (Meijboom and Vos, 1997). The IMN coordination instead deals with the infrastructure, i.e., the relational aspects and organizational processes between different plants (the arrows, namely the connections between nodes) (Colotla et al., 2003). Cheng et al. (2015) summarize three main streams of studies about coordination in IMNs: the introduction of practices related to IMN coordination, the transfer of technologies and knowledge within subsidiaries, and the optimization of the physical distribution.

Within the broad distinction between plant-level and network-level articles, some contributions have attempted to link the two streams, i.e., that have analyzed the effects of a change at the plant-level on the network (Cheng et al., 2011; Feldmann et al., 2013; Rudberg and West, 2008). However, scarce literature has focused directly on intermediate analysis, i.e., an analysis at the business unit level (Chang and Harrington, 2002; Wathen, 1995) or considering plants producing homogeneous product groups (Feldmann et al., 2013). The possibility of dividing plants and production activities according to what is produced within them implies the centrality of the product in the analysis. However, despite the importance of the product within the supply chain, the literature has rarely considered it as a key variable for decision-making in IMNs (Rudberg and West, 2008; Sweeney, 1994).

In this perspective, Ferdows (2009) offers a model that helps in managing the production network, focusing both on the product and the process. The article proposes a simplified conceptual model through which the production network is divided into different categories according to the characteristics of the products made and the processes used. Two archetypes are outlined for two different configurations: the footloose network, driven by the need for low-cost production, with a strong component of outsourced production, and usually studied under the supply chain management perspective (Rudberg and Olhager, 2003) and the rooted manufacturing network, developing complex products with complex systems and characterized by a high percentage of in-house manufacturing (intra-firm IMN) (Costa Ferreira Junior and Fleury, 2018). The model introduces some simplifications, but it has the advantage of classifying networks according to two ideal types, namely rooted and footloose. As ideal typologies, further research is needed to identify better the characteristics that allow the distinction among different types of networks.

Later, Ferdows et al. (2016) introduced the concept of "manufacturing subnetwork", dividing companies into groups of plants based on the product and process characteristics. Although the basic logic had not changed, the new model had evident singularities due to the change in the unit of analysis from networks to subnetworks. The authors provide an empirical application by clustering plants within global companies into different typologies of subnetworks, ensuring that each subnetwork has a clear and coherent manufacturing mission. The subdivision of the IMN into subnetworks has been hypothesized by taking an internal perspective of the multinational company, mainly aimed at an intra-firm analysis (Rudberg and Olhager, 2003).

Golini et al. (2017) provided further insights about subnetworks, suggesting preliminary management models for rooted and footloose subnetworks. Finally, Feldmann and Olhager (2019) analyzed twenty subnetworks (or product group networks) at five global manufacturing firms offering a taxonomy of manufacturing networks: they identified four different product-network types (Linear, Divergent, Convergent, and Mixed network structures), with specific characteristics in terms of roles of the factory, product, and process types, market types, sourcing channels, etc.

The approach offered by subnetworks analysis goes in the way to answer simple questions for complex systems. However, despite these pioneering contributions, the use of the theoretical model about subnetworks is still limited. This contribution aims to fill two main research gaps. First, the problem of identifying subnetworks seems to be given for granted but has never been appropriately addressed before. The literature does not provide adequate guidelines to facilitate the identification of different subnetworks within a manufacturing company.

Furthermore, there is no extensive support on how to map subnetworks once identified, for example, on how to allocate plants and activities of a company over the different subnetworks. Second, the literature has offered only partial contributions on how to understand the characteristics of subnetworks. Ferdows et al. (2016) offer some scales for evaluating the product, process, and plant features, but additional research is still required.

5.3 Methodology

5.3.1 A Design Science Research approach

The DSR is a methodology that has been increasingly used in recent years in Operations Management (Aken et al., 2016; Dresch et al., 2019). It is "*conceptualized as a research strategy aimed at creating knowledge that can be used in an instrumental way to design and implement actions, processes or systems to achieve desired outcomes in practice*." (Van Aken, 2016, page 1). It is oriented towards the construction or understanding of artifacts, including theories, frameworks, instruments, constructs, and models (Hevner et al., 2004; March and Smith, 1995; Pournader et al., 2015), and its primary purpose is discovery and problem solving, as opposed to the mere accumulation of knowledge (Holmström et al., 2010).

Our paper has a strong methodological foundation in the design science approach (Henver, 2004). The DSR has the twofold purpose of solving "authentic field problems" (Aken et al., 2016; Johnson et al., 2020) and implementing interventions and mechanisms that can be deployed in the same contexts (Aken, 2004; Denyer et al., 2008). The DSR approach implements the context-intervention-mechanisms-outcome (CIMO) logic (Denyer et al., 2008) as a means to implement actionable knowledge (Johnson et al., 2020). However, in this paper, we adopt a definition of DSR that underlines the process of exploration through design (Holmström et al., 2009; Simon, 1973b). DSR aims to explore new alternatives to solve problems, explain the explorative process, and improve the problem-solving process. Our approach emphasizes the creation of a solution, namely a descriptive tool, to an ill-structured problem, i.e., an issue in which even if the goals are clear, the means to achieve these goals are not fully understood or known.

In previous literature, the DSR approach was adopted to create maturity models (Schumacher et al., 2016; Wagire et al., 2020), where the emphasis was placed on the refinement of the solution. Similarly, our approach is pragmatic in its orientation: the research methodology, based on the design science principles, is grounded on the literature contributions enriched with real cases to explore the practical requirements needed to develop the tool. Given that there are still few empirical examples of subnetworks (Feldmann and Olhager, 2019; Ferdows et al., 2016), new examples and insights from the industrial world are needed for a solid construction of the tool. Therefore, this study builds exploratory cases to test the tool in a real environment, in line with the DSR approaches.

5.3.2 Research Design

The development of the descriptive tool is performed through a trial-and-error process. The iterative process helped in evaluating, refining, and enhancing the successive releases of the model. Coherently with previous research (Akkermans et al., 2019), our DSR-based process is modeled on the first three of the four phases described in Holmström et al. (2009) and applied in the OM domain by Dresch et al. (2019). The analysis has also relied on van Aken et al. (2016) guidelines in the approach.

After an in-depth analysis of the literature on subnetworks, it was perceived the lack of a suitable tool to understand the nature of subnetworks, identify them, and at the same time determine their main characteristics. After some preliminary interviews, the need to solve the practical problem became clear. Therefore, our attention has shifted from simply observing the phenomenon to its implementation and construction of a solution. This phase is Holmstrom's "*solution incubation*", which consists of "*framing the problem and developing the rudiments of a potential solution design*" (Holmström et al., 2009: page 72).

In the second phase, the tool has been implemented iteratively by developing five exploratory cases in multinational companies. The companies were selected for their presence in a global market. All the selected companies have at least one manufacturing plant in a foreign country. Furthermore, in order to preserve the feasibility of case selection, accessibility, and distance factors, as well as the willingness to participate, were also considered. After the initial site visits, at least two interviews, lasting 60-150 minutes each, were conducted in each case. In total, 15 face-to-face interviews were conducted. The interviewees covered the roles of Supply Chain Director, Logistics Director, NPD Manager, Global Operations Manager. All the interviews were transcribed verbatim, with an average transcription length of nine pages. These case interviews were further supplemented with follow-up interviews and documentary evidence of 35 archival documents (websites, balance sheets, press releases and news, observation notes), for triangulation purposes. At least two researchers were involved in the data collection, coding, and analysis, which increased the reliability and validity of the results (Voss et al., 2002). The choice to develop case studies is consistent with the fact that DSR and case research approaches are complementary (Kaipia et al., 2017). This phase can be defined as Holmstrom's "*solution refinement*", where the rudimentary solution is subject to empirical testing in a real environment (Dresch et al. 2019), a key element of any DSR project (Aken et al., 2016). The main information about the sample is provided in Table 5.1. The data and feedback collected during these cases allowed both to assess the feasibility and validity of the proposed tool and to improve it iteratively. Strong emphasis during the interviews was given to debate and contention on the application of the tool. Discussions with managers helped us bring out details, asymmetries, inconsistencies with what was reported previously by the literature or by our development, and continuously update the tool. After five preliminary case studies, saturation was reached (Eisenhardt, 1989; Yin, 2009), meaning that no other relevant changes to the tool were suggested in further discussions.

Table 5.1: Main characteristics of preliminary case studies

	Company A	Company B	Company C	Company D	Company E
Headquarter	Italy	Luxembourg	Italy	Italy	Germany
Industry	Industrial automation	Energy, gas, water	Manufacturing	Manufacturing	Industrial automation
Product Type	Linear guides	Steel pipes production	Microwave instrumentations	Lens cutting machines	Industrial Machinery, cabins
No. of employees (2018)	500-1000	>20000	250-500	250-500	500-1000
Revenues M€ (2017)	50-100	>3000	10-50	50-100	100-1000
No. of manufacturing plants	2	24	3	2	5
Total No. of sites (manufacturing and non-manufacturing)	7	69	6	5	15
No. of interviews	3	4	3	3	2
Interviewed managers	SC and Logistics Directors	Senior Director of Planning Europe	Supply Chain Director, NPD Manager	Global Operations Manager	Logistic Manager

Subsequently, the descriptive tool developed was applied and tested on a new and comprehensive case study (*Company Test*), giving empirical validity to the constructs formulated. Company Test is a global chemistry company with about 30 production sites in Europe, Asia, and the United States. Having a process-oriented structure, Company Test appears ideal for producing evidence of pragmatic validity (Aken et al., 2016). In particular, that company was deliberately chosen from an industry different from those typically analyzed by the subnetwork literature (Feldmann and Olhager, 2019; Ferdows et al., 2016), which were product-oriented industries. Our choice to test the tool in a process-oriented company aims at widening the extent of applicability of the model. Five face-to-face semi-structured interviews, lasting 90-150 minutes each, were carried out in the business unit analyzed. For triangulation purposes (Voss, 2002), relevant secondary data were also used, such as brochures, company reports, websites, podcasts, news, and press releases. The same approach used with exploratory cases for assuring rigor in the data collection and analysis was guaranteed. The main characteristics of the case study are reported in Table 5.2.

Table 5.2: Main characteristics of Company Test

Company Test	
HQ	Germany
Industry	Chemistry
Product Type	Polymer materials and plastic additives
No. of employees (2018)	16800
Revenues M€ (2017)	15000
No. of plants	34
No. of business units	3
No. of total factories	47
No. of interviews	5
Interviewed managers	Business unit manager

The third phase suggested by Holmström et al. (2009), labeled *Explanation I phase* (Middle-Range Theory), consists of the analysis and evaluation of the results from a theoretical point of view rather than a practical one, to develop substantive theory (Dresch et al. 2019). This phase exploits the first and second phases to evaluate the artifacts developed. It is important to notice that mid-range theories are described as context-dependent, i.e., they are dependent on the environment in which artifacts and solutions have been developed (Glaser and Strauss, 1967); thus, they might not be considered general theories. According to this perspective, the mid-range theory is not meant to be generalized to all contexts but to generalize theoretical concepts that may contribute to the theme of interest (Dresch et al., 2015). In this perspective, the aim is to extend Phase 2 by taking the proposed solution design and seeking a deeper theoretical understanding and contribution to it.

Concerning the Holmström's Phase Four, i.e., the *Formal Theory*, we cannot say to have fully engaged it. A formal theory is meant as theoretical propositions whose applicability is not limited to the empirical context being studied (Glaser and Strauss, 1967). It would require the development of complete, comprehensive theory, with the application of the designed artifacts in multiple contexts. The tool was developed by means of multiple case studies in multiple contexts and tested in a different environment compared to those typically analyzed by the OM literature. However, additional empirical testing in different environments would be needed. Thus, a full realization of phase four is out of the scope of this article. Figure 5.1 shows the research process with the three steps followed within the DSR approach.

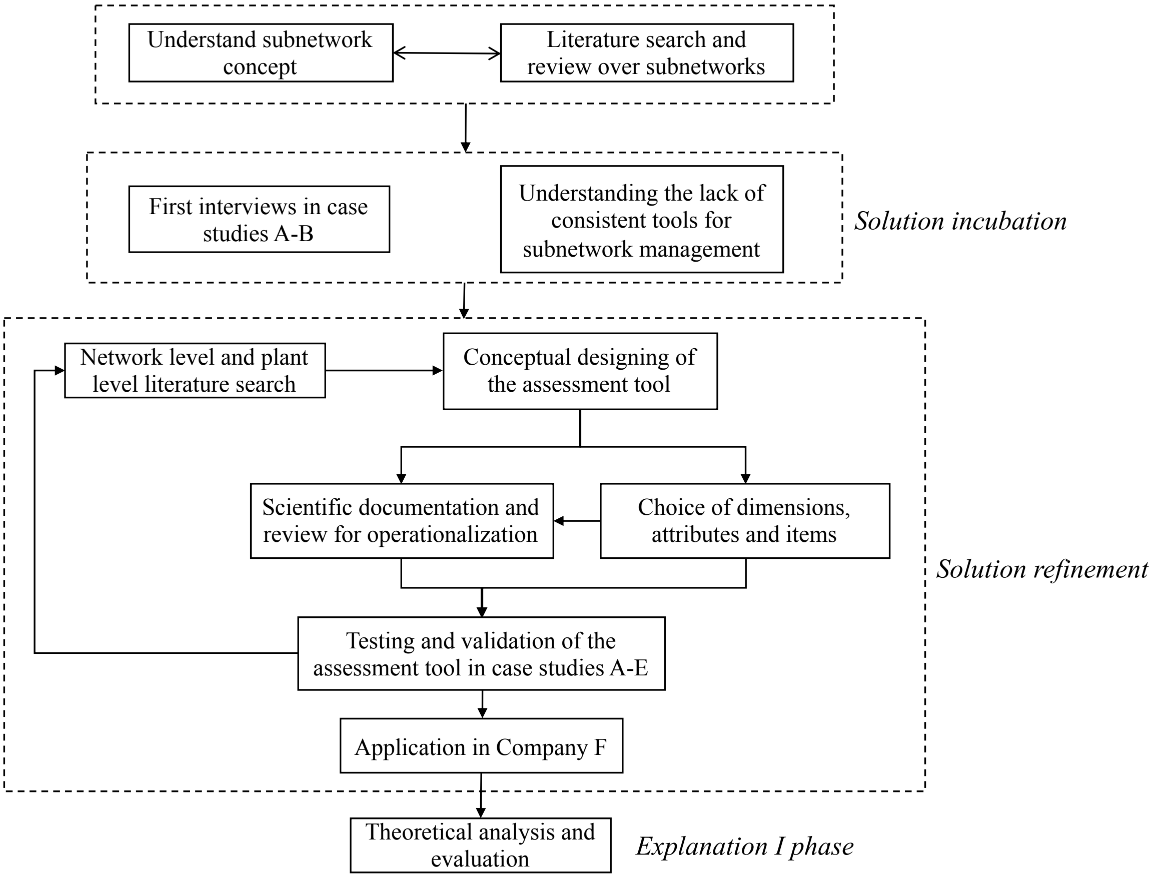

Figure 5.1: The research process for the development of the descriptive tool

5.3.3 Design of the descriptive tool

The tool proposed by this research supports the subnetwork identification and mapping, and operationalizes their characteristics within multinational companies. It allows us to collect essential information systematically. To do that, this study applied a design-oriented research approach (Hevner et al., 2004). In combination with the evaluation results, our descriptive tool represents the main outcomes of the research, in line with the DSR process (Peffers et al., 2007). The model's development adopted an iterative process that helped evaluate, refine, and enhance the tool. The analysis also relied on the step-by-step approach of Becker et al. (2009), suggesting the guidelines to develop a maturity model using a robust theoretical background from the design science research. Useful insights were taken from various contributions (Schumacher et al., 2016; Wagire et al., 2020) that adopted Becker's structure and refined it to answer specific needs for the developing maturity models. Although our descriptive model has different characteristics and purposes than maturity models, the analysis has benefited from a structured process (Neff et al., 2014) to create an evaluation instrument.

Our starting point has been an initial version of our model. This preliminary draft considered the need to identify the subnetworks and was based on the few empirical examples from the literature (Ferdows et al. 2016; Feldmann 2019). The draft was proposed in cases A and B, discussing it with managers and trying to extrapolate as much information as possible, before realizing that it needed relevant modification. From then on, there was a continuous iterative development of the tool in all five exploratory cases.

Following Becker's framework has been very useful, especially in this central phase, which they identify as “iterative (maturity) model development”, where the selection of the design level, the selection of the approach, the design of the model section, and the first testing are iterated (Becker, 2009). Finally, the tool was tested in a multinational company to validate it in a real-life application and gather feedback. Unlike the A-E cases, in the Company Test, the model was applied from scratch. The model was conducted without any pre-existing judgments or considerations about the company's configuration; in this way, the researchers were able to apply the tool to an unknown company.

5.4 Description of the descriptive tool

The three macro phases of the descriptive tool, namely identification, mapping, and operationalization, are represented in Figure 5.2 and described in the following (the complete tool is provided in Appendix 5.A). Chapter 5.4.1 explains how the tool was developed, while Chapters 5.2.2, 5.2.3, and 5.2.4 present the three phases in detail.

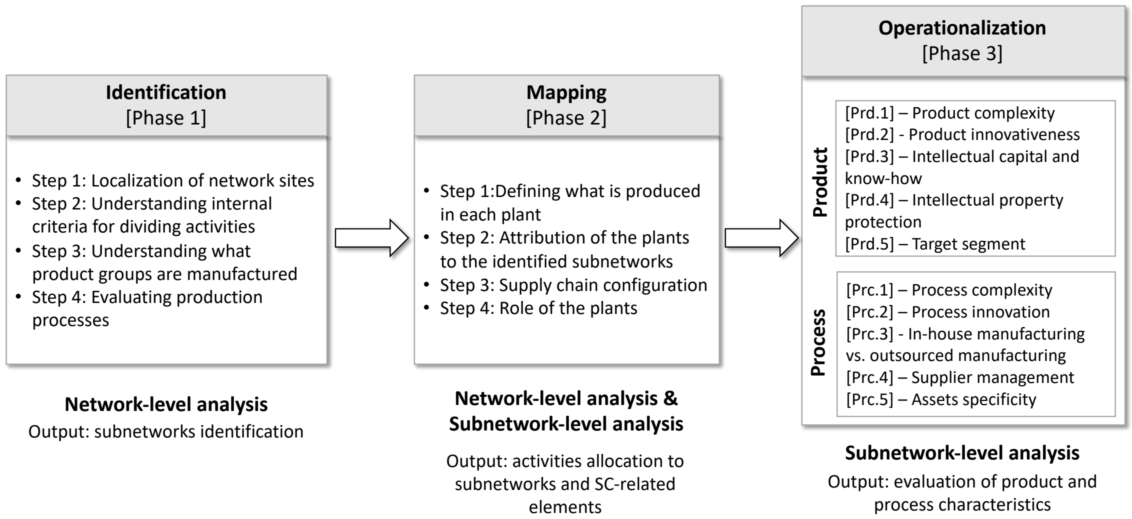

Figure 5.2: IMN subnetwork process model

5.4.1 Developing the tool: solution incubation and solution refinement

This paragraph explains how the process of construction of the tool has been carried out, in particular, bringing some evidence about the phases of solution incubation and solution refinement. In addition to the final result shown in the following chapters, it is equally important to describe the steps that led to the achievement of this model. At the Solution Incubation stage, the first exploratory interviews were conducted on cases A and B. At that stage, the interview protocol used was very different from the final product and significantly different from the one used in the interviews for cases C, D, E.

The *Identification* phase was limited to analyzing the company's plants, where they were located, and what they produced. The idea was that an understanding of the products was sufficient to define the subnetwork. The analysis of the Business Units in the company and its organizational structure, together with the description of the most relevant manufacturing processes are all elements that have been subsequently included in the protocol. The approach, in line with DSR principles (Aken et al., 2016; Holmström et al., 2009), was to apply, evaluate, and modify the initial idea and the steps initially conceived. For cases A-E, we cannot say that there was a real identification since the steps on which the current tool is based were still to be developed. What has been done can be summarized as follows: a) the researchers already had an idea of the division of products/processes made by the company (commercial reasons, products, processes); b) the researchers began the interviews by applying the various steps hypothesized up to that moment; c) the development of the cases has confirmed or denied (modifying it) the configuration and division into sub-networks that had been initially thought of, also thanks to the contribution of the interviewees; d) the n-subnetworks have been redefined in that specific case. From repeating the same process for all the cases, it was then clear which steps were helpful for understanding. This has allowed the implementation of a model iteratively modified.

The same can be said for the *Mapping* part that has gradually been populated: the questions about the effort of each plant on the identified subnetwork (e.g., the percentage of production value, volumes, valued-added indicator, revenues-costs, time effort, etc.) was added at a later date following the suggestion of the respondents from company B. The questions about the percentage of products produced for each subnetwork (in own plants or externally) have been added at the suggestion of company C.

Concerning the *Operationalization* phase, during the development of the interviews, the importance of attributing the products and processes developed within each plant to the identified subnetworks was understood; this was necessary due to the presence of plants in which products belonging to different subnetworks are produced. In addition, cases A through E provided insights and observations that were essential in reaching the final version of the dimensions included in the operationalization. In particular, in the Solution Refinement phase, the dimensions included in the operationalization (Phase III) have been strongly modified, as detailed in Chapter 5.4.3.

These are just some of the shreds of evidence that characterized the development of the A-E exploratory cases. They have been instrumental in deriving, improving, and legitimizing the development of a model which has been evolving and improving over time. However, it must be specified that the goal of cases A to E is to support the development of the tool. For this reason, they were considered as supporting cases and not real case studies in the paper.

5.4.2 Phase I: Identification

The *Identification* phase aims to define, through the analysis of both configurational aspects and the macro-structure of the company, how many and which are the subnetworks of the analyzed multinational company. The analysis is performed at a network level. After an introduction with some general questions about the main parameters of the company analyzed and its strategic priorities, the identification phase includes four sequential steps:

Step 1: *Localization of network sites*. In order to understand how many and which are the subnetworks in a company, it is essential to recognize the characteristics of the network in its entirety; this means having a clear view of which factories are active in the network and where they are located. Plants' categorization also implies discerning the typology or the value-added activities performed within the sites (i.e., headquarters, productive, R&D, sales offices, commercial office, warehouse).

Step 2: *Understanding internal criteria for dividing activities*. The objective of this step is the analysis of the macro-structure of a company, i.e., the presence of organizational units and the comprehension of coordination mechanisms between them, as well as the criteria through which activities are grouped (e.g., input-oriented criteria - knowledge, skills, processes - or output-oriented criteria - products, customers, geographic basis).

Step 3: *Understanding what product groups are manufactured*. The comprehension of product families or product groups manufactured is a key aspect. However, it should be noted that a product group does not necessarily correspond to a subnetwork. The inspection only of the product-types manufactured within the company is not sufficient for full comprehension and identification of subnetworks. Still, it can give a first understanding of how the company is organized. Subnetworks are defined according to the manufacturing perspective and not from a marketing perspective. For example, preliminary interviews in Company D allowed discerning three macro typologies of products, while from a marketing perspective, Company D divides its products into 6-7 categories.

Step 4: *Evaluating production processes*. It must go hand in hand with product evaluation. Two distinct product groups can represent different subnetworks, although they may also share relatively significant portions of production processes. In process-related industries, other product families can follow similar production stages before diverging in the following steps. Similarly, dividing processes that are performed in different stages of discrete manufacturing (or assembly), or distinguishing production according to the Customer Order Decoupling Point (CODP) might be helpful for recognizing subnetworks. For example, the portfolio of Company D is divided into two categories of products: machines, which occupy 90% of the turnover of the company, and cutters, a newly explored niche sector where the company is trying to grow. However, two macro-processes are identified within the machines, namely a process for industrial applications and a process for retail applications.

At the conclusion of these four phases, the researchers have the key information about the products and processes at the network level, along with the categorization of the BUs. This facilitates the identification of subnetworks within the IMN studied.

5.4.3 Phase II: Mapping

The *Mapping* phase allows to identify more precisely the activities related to each subnetwork, the connections among plants, and to determine the main characteristics of its supply chain. It is evident that some information about the allocation of the plants in the subnetworks configuration may also be available from the first phase; however, the mapping phase aims to delve deeper into each subnetwork, for example, by analyzing the specific processes performed and the manufacturing role of each plant (Cheng and Farooq, 2018; Ferdows, 1989). This phase includes:

Step 1: *Defining what is produced in each plant*. For each product group manufactured, the objective is to determine "What is produced and where it is produced" and look for the business unit and the plants in which the product group is manufactured. If possible, the physical flow of the material among plants is also traced.

Step 2: *Attribution of the plants to the identified subnetworks*. This step consists of assigning the production activities (with the relative plants) to the appropriate subnetwork, according to the information collected. The objective is to determine "what each subnetwork specifically do". Whenever possible, the total production value realized by each subnetwork is reported as a proxy for the proportional effort (adapted by Friedli et al., 2014).

Step 3: *Supply chain configuration*. The supply chain strategy, the level of vertical integration (Friedli et al., 2014), and the internal supply chain configuration (Feldmann and Olhager, 2019), with the geographic distribution, are analyzed for each subnetwork. According to the typology of production in the subnetwork (discrete versus process manufacturing), the internal SC configuration is evaluated.

Step 4: *Role of the manufacturing plants*. This step delves into the ways in which the plant performs its manufacturing role. The interest is in understanding whether the plants' role is only to be efficient (i.e., to get the products manufactured) or whether, vice versa, the plants are equipped with the skills and competencies to serve the network as centers of excellence and develop a contribution for the entire multinational company. The most relevant frameworks about the plant roles (Cheng and Farooq, 2018; Ferdows, 1989; Vereecke et al., 2006; Vereecke and Van Dierdonck, 2002) were taken into consideration, but adopting a subnetwork perspective.

5.4.4 Phase III: Operationalization

The *Operationalization* phase entails the transformation of theoretical variables into measurable items. Moving from identifying concepts to their conceptualization and operationalization is a matter of increasing specificity. The goal of this last phase is to define the characteristics of the subnetworks identified precisely. Ferdows et al. (2016) provide indications to understand subnetworks' position in the rooted-footloose spectrum, but their framework considers only a number of attributes of products and processes. Through this operationalization, our study offers an alternative that enriches previously proposed approaches. In this perspective, operationalizing the matrix implies a three-step process: first, to select observable *dimensions* for each factor (i.e., for both product and process); this first phase includes the synthetic definition of the property represented by the variable and the dimensional analysis of the property, i.e., its analytical specification.

Second, to determine a set of *attributes* for each dimension to convert ideas into a testable form; this step consists in choosing, for each dimension, one or more properties that are indicators of that dimension (indicator as an empirically detectable property, at a lower level of generality than the dimension to which it refers). Third, to specify how to measure each *item* in order to provide a qualitative evaluation; this third step concerns the operational definition of the variables chosen as indicators and the construction of measurable indexes. Some academic examples that offer conceptualizations and operationalizations (Keaveney and Hunt, 1992; Maddi, 2004; Ridley et al., 1994; Tasci et al., 2007) were used as methodological support for the process.

Table 5.3 provides an overview of the dimensions, their descriptions, attributes, and the source from which the dimension has been derived (either from the literature or from the case studies).

Table 5.3: Operationalization: dimensions and attributes

Product dimension	**Source**	**Dimension description**	**Attributes**
[Prd.1] Product complexity	Ferdows (2009, 2016)	It includes technical, design, and manufacturing attributes of the product. It depends on a series of characteristics related to the size, the dimensions, the number of parts embedded in the product, the level of innovativeness required, etc.	• Variety • Functional index • Structural index • Design index • Production Index
[Prd.2] Product innovativeness	Company D	Rhythm with which a product or a product family introduces new variants in its range. It requires to determine the extent of technological and application changes.	• Market • Technology • Internal • External
[Prd.3] Intellectual capital and know-how	Ferdows (2009, 2016)	It includes the skills and know-how required, the knowledge generation, and investment into R&D. It is a key factor in leveraging the company's learning process	• Scientific and technical based knowledge (STI) • Doing, Using and Interacting (DUI) mode
[Prd.4] Intellectual property protection	Ferdows (2009, 2016)	It refers to products whose design, modeling, production, or distribution has been protected through some ad hoc mechanisms (e.g., patents, trademarks)	• Intellectual property protection

[Prd.5] Target segment	Researchers	It evaluates the product market segment, i.e., whether the product type is oriented to an entry-level demand (lower-end segment) or, vice versa, to a premium segment. This attribute is important to verify the product's destination (market, segment, consumer).	• Perceived quality offered • Perceived value for the cost • Uniqueness • Price Premium

Process dimension	Source	Dimension description	Attributes
[Prc.1] Process complexity	Ferdows (2009, 2016)	It measures the complexity of the production processes considering only the transformation process.	• Process ramification • Process configurations
[Prc.2] Process innovation	Ferdows (2009, 2016)	As for products, manufacturing processes can also be more or less standard in the area of application. Standard processes are highly codifiable and available to market participants for a long time, and vice versa for innovative processes.	• Propensity to adopt new manufacturing processes • Propensity to create or adopt new business systems
[Prc.3] In-house manufacturing vs. outsourced manufacturing	Ferdows (2009)	Level and importance of contract manufacturers to fill temporary capacity gaps, lower production costs, or react more quickly to the market.	• Extent of outsourcing
[Prc.4] Supplier management	Company A	It evaluates the relationships with suppliers and the typologies of contracts established with them.	• Number of sources • Strategic relationship with suppliers
[Prc.5] Assets specificity	Company B	It concerns the degree to which an asset can be used in a variety of situations and purposes. It is important to understand how easy the equipment and installations can be adapted, modified, and configured for a different set of products.	• Site specificity • Physical asset specificity • Human asset specificity

The preliminary versions of operationalization included Ferdows' dimensions (complexity and proprietary information of both product and process) and a few dimensions introduced by the researchers (intellectual capital and know-how; target segments). They have been proposed during the first cases and continuously refined: other dimensions have been included after the discussions with managers during the exploratory case studies. The debates that emerged during the interviews allowed us to include some new relevant dimensions or discard others, which were not coherent with the analysis of subnetworks.

An illustrative example of change in the dimensions included in the operationalization occurred in case B: when evaluating product complexity for the company's product dimensions, the interviewee correctly pointed out a substantial difference between complexity due to the structure, architecture, and design of the product and, on the other hand, complexity due to product innovativeness and the frequency of design changes in a limited period of time. Furthermore, “Asset Specificity” was included to capture the degree to which an asset can be adapted, modified, and configured for a different set of products. This requirement was particularly evident in Case B, an extremely complex network, where production facilities are rarely exclusive, i.e., they do not produce a single product group per facility. Still in solution refinement phases, Case C indicated the need to consider the massive dose of patents, as well as scientific, technological, and instrumental preparation within the company's core business (advanced microwave sample preparation and microwave preparation systems).
To summarize, compared to the initial version, the following dimensions have been added:

- Product dimensions: Intellectual capital and know-how [Prd.3], Target segment [Prd.5].
- Process dimension: In-house manufacturing vs. outsourced manufacturing [Prc.3], Supplier management [Prc.4], Assets specificity [Prc.5].

After identifying the dimensions, a literature analysis was performed to find already used attributes and the respective items within the chosen dimensions. The literature analysis strongly relied on Roth et al. (2008) that provided a comprehensive review of constructs and metrics within the Operations Management domain. It was also supported by the contributions by Menor and Roth (2007) and Froehle and Roth (2007), for developing and assessing the items and measurable scales. Qualitative measures have been directly taken from previous contributions, or they have been re-elaborated and refined through the researchers' critical analysis. Items and measures are studied using the subnetwork as the unit of analysis. Five-points Likert scales were used to evaluate the metrics. For example, in order to calculate the item “Component variety” within the attribute Variety, the following measure was utilized: “The product group implies a very high variety of components”, evaluating it with a five-point scale where 1 means “really disagree” and 5 means “really agree”. The detail with all the items for each dimension, together with the reference from which they have been derived, is provided in Appendix 5.A.

5.5 Case-study

An application of the tool has been developed through the in-depth analysis of the Company Test. The identification phase started by decomposing the company into its three main product-based business units representing three different businesses in the chemical industry. In order to limit the width of the analysis, the decision was to focus on the business unit related to polycarbonates (BU1). BU1 is divided into different areas according to geographical criteria: in fact, the company decided to build a replicated structure in all the markets to be really “global” and sell almost identical products in distinct areas. In particular, to reduce the complexity in the analysis for such an extensive network (Szwejczewski et al., 2016), only the European network of BU1 was analyzed.

5.5.1 Application of the model

Following the tool developed, the first phase (***Identification***) found three subnetworks in BU1. The first subnetwork (SN1) is responsible for the upstream process of all the three subnetworks: the output is crude granules and belongs to a market that tends to be close to commodities. About 50% of the output of SN1 is sold. Subnetwork 2 (SN2) and Subnetwork 3 (SN3) use the other 50% of the output of SN1 as an input and produce different families of products in their plants (namely, treated granules and semi-finished products) by means of different processes. While in crude granules there is a price variation determined by fluctuations in supply and demand (typical of commodities), the outputs of SN2 belong to a market that respondents called “resilient business”, in the sense that there is a quite constant value over time. SN3 instead produces semi-finished plastic products. The differentiation among subnetworks is both from a commercial (i.e., different final markets) and from an industrial (i.e., different processes) perspective. Table 5.4 provides detailed information on the Identification phase.

Table 5.4: Details of the Identification phase in Company test

Step	Description
Step1	47 facilities: - 28 manufacturing plants (North America: 6; Europe: 12; Asia & Pacific: 10) - 6 manufacturing plants with also non-production functions (Europe: 4; Asia & Pacific: 2) - 13 non production sites (North America: 3; Europe: 4; Asia & Pacific: 6)
Step2	Three regional business units: - 10 plants working for BU1 - 14 plants working for BU2 - 19 plants working for BU3 Among these, 8 world-scale facilities
Step3	The product categories developed in the three business units have been studied. Focus on BU1, with 3 main product groups.
Step4	Focus on BU1: raw material is purchased (no full vertical integration). Main processes: polymerization; compounding, finishing (mineral addition, glass fiber, coloring, etc.). Partial overlap of processes in some plants.
Output phase I	Identification of 3 subnetworks in BU1: SN1: crude granules SN2: treated granules (4 different types with specific thermoplastic properties) SN3: semi-finished products

Regarding the second phase of the tool (***Mapping***), a structure comparable to a regional hub-and-spoke structure was found, where few large plants provide the raw material for the other plants. The structure of Company Test for the BU1 in Europe is summarized in Figure 5.3. SN1 is represented by one large plant (Plant A) where the polymerization process is performed. Granules are mainly sold in Europe to exploit the proximity of the market. The amount that is used as input within other plants is mainly used in Europe, apart from rare situations of lack of granules in other parts of the world. SN2 includes two other plants, one in Italy (Plant B) and one in Germany (Plant C), where the compounding treatment is performed: the granules are treated with dyes, flame retardant, and shockproof to create blended materials to be resold. Some small differences exist among the Tier-2 plants of SN2 for what regards the volumes, and the lot size produced: for the European context, plant B has lower volumes and higher flexibility and versatility, plant C vice versa. The final market is mainly the European market. These differences among Tier-2 plants are also present in other regions. Within SN3 instead, Plant D receives the crude granules coming from Plant A and transforms them into semi-finished plastic products through completely different processes. SN3 produces innovative products and still serves a marginal business for the company, whose distribution is fully concentrated in Europe. The large Plant A represents the overlapping between the three subnetworks. This type of structure is replicated globally, meaning that in the US and Asia-Pacific there are very similar, if not identical, plants like those in Europe.

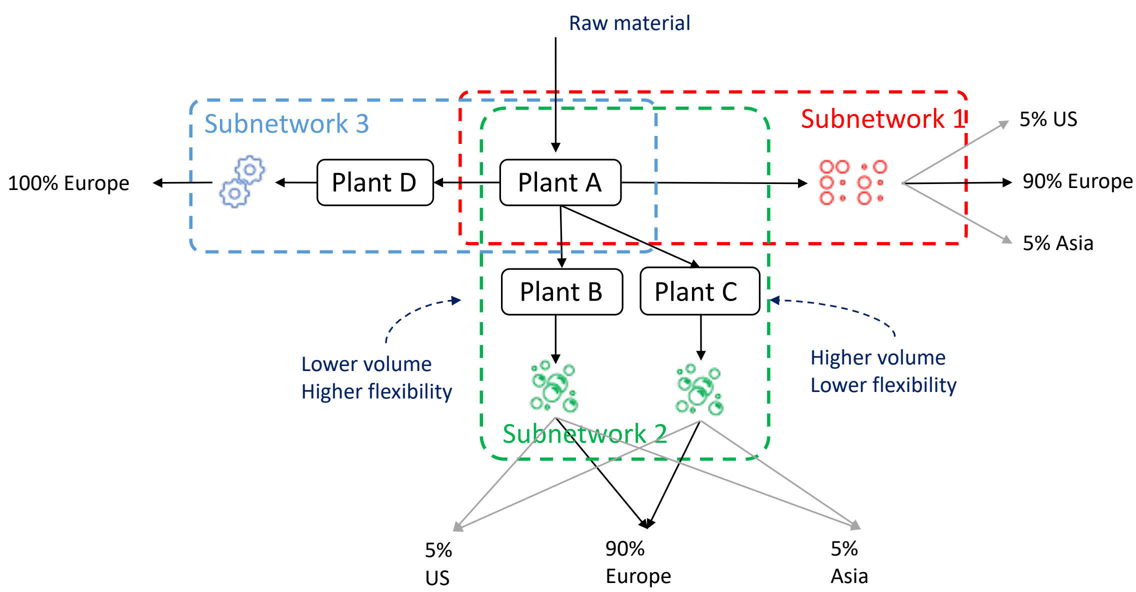

Figure 5.3: Subnetworks in Company Test

All the attributes and items of the third phase (***Operationalization***) have been tested. SN1 is characterized by the considerable importance and value of Plant A, given by the complexity of chemical reactions and safety regulations that come into play; however, the variety of products is minimal, and the final product is standard (commodity). The categorization phase for SN1 results in high values in R&D expenses for increasing process quality and efficiency, a significant percentage of highly skilled personnel, and the presence of patents as a protection mechanism. Given the characteristics of the product, the emphasis is entirely on process efficiency.

SN2 is characterized by a very high differentiation of the final product given by the multitude of additive materials and colors used. For example, plant B has a total capacity of 45 thousand tons per year divided into 25,000 combinations of different final products. The complexity lies primarily in the management of the thousands of combinations produced. The volumes are significantly more limited compared to those of SN1 (i.e., a ratio of 1:10). The small differences between Plant B and Plant C have been taken into considerations in the operationalization. However, on average, SN2 shows considerably higher levels in product variety, several functional requirements needed, and new customer value offered to the customers compared to potential competitors.

Finally, SN3 produces innovative semi-finished plastic products; both the processes (in terms of technology used) and the products manufactured (regarding, for example, blended materials, technical features) are characterized by a high degree of novelty. The categorization of SN3 shows high levels in the following items: newness of the market, performance enhancements, highly skilled personnel, cooperation with customers, perceived quality offered, customer availability in paying a higher cost. Table 5.5 summarizes the product and process characteristics of the three subnetworks.

Table 5.5: Qualitative assessment of product and process dimensions

	Dimension	**Sub1**	**Sub2**	**Sub3**
Product	[Prd.1] Product complexity	↓↓	↑↑	↑
	[Prd.2] Product innovativeness	↓↓	→	↑↑
	[Prd.3] Intellectual capital and know-how	→	↑	↑
	[Prd.4] Intellectual property Protection	↑	↑	↑
	[Prd.5] Target segment	↓↓	↑	↑↑
Process	[Prc.1] Process complexity	↑↑	↑	↑
	[Prd.2] Process innovation	→	↓	↑↑
	[Prd.3] In-house manufacturing vs outsourced manufacturing	↑↑	↑	↑↑
	[Prd.4] Suppliers Management	→	→	→
	[Prd.5] Asset specificity	↑↑	→	→

↓↓: very low level; ↓: low level; →: medium level; ↑: high level; ↑↑: very high level

Table 5.6: Product and process characteristics of three subnetworks

Subnetwork	Product	Process
SN1	Absolutely standard product, virtually considered a commodity. Limited variety of products: four types, in only one color. Minimum levels of Prd.1, Prd.2, Prd.5.	Complex processes due to chemical reactions and safety regulations needed (high levels of Prc.1). Huge volumes required: at least 200,000 tons per year to reach break-even point (Prc.5). Completely internalized process (Prc.3).
SN2	Five product families with thousands of combinations (Plant B and C imply considerably high levels in the items *Component variety* and *Product variety* within Prd.1). High managerial complexity. However, dissimilar values in the attributes of product innovativeness (Prd.2).	Upstream process equivalent to SN1. Downstream process (Plant B, C): medium-to-low process technological complexity (Prc.2). Need for flexibility, speed, versatility. Differences between Plant B and Plant C in batch production.
SN3	Semi-finished products from recent technological innovation. Medium-to-High product complexity (Prd.1) and innovativeness (Prd.2). Premium-segment product (high level of Prd.5). A strong effort in R&D is required.	Upstream process equivalent to SN1. Downstream process: characterized by considerable technological complexity and innovation (Prc.2). Need for further specific investments (Prc.5) to expand the business.

5.5.2 Observations from the case studies

The categorization provides us with an understanding of the characteristics of the product-process dyad through the analysis of attributes and items. It also allows us to derive some managerial and strategic considerations about subnetworks: in SN1, the product is standard and not differentiated, but the process is strategic also for the other subnetworks; the respondents told us that the company's goal is to reduce as much as possible the share of product that is sold on the market from Plant A (currently 50% of total output) to be able to serve the other two subnetworks. SN2 has the highest profitability (strategic products), although the transformation process is simple; however, the complexity lies in managing the process due to the flexibility and variety required. From a strategic point of view, the company aims to expand this subnetwork as much as possible, also due to market demands increasingly oriented to the flexibility and variability in batches. SN3 has a high marginality producing more technologically complex products (high levels of Prd.1, Prd.2, Prd.3). SN3 is still at the development stage and needs further specific investments. From this point of view, the company's objective for SN3 is to start producing semi-finished plastic products in more plants compared to the actual situation, despite SN3 maintains a lower priority than SN2.

Therefore, operationalization had the twofold objective of making a complete screening of product and process characteristics and highlighting different management approaches, specificities, and strategies for the future among the subnetworks. A higher interest to intervene on some plants rather than others has been highlighted. In general, Phase 3 can be useful for companies to constantly evaluate their asset base, prioritize interventions, and accelerate network review operations, reducing the structural inflexibility that typically characterizes IMNs (Cheng et al., 2015).

In general, the outcome for the company Test presented a different perspective (via subnetworks) than the ones managers usually do (via business units). For example, in the managers' perspective, the individual plant is usually analyzed as a stand-alone element, receiving inputs and outputs, less as an element within an ecosystem made up of n-other plants. The tool is designed to help in conceptually visualizing and mapping better complex business networks, which is in line with the fundamental subnetworks' objective of streamlining and simplifying operations within IMNs (Ferdows et al., 2016).

5.6 Discussion

The descriptive tool developed allows us to face the decomposition of a multinational company's IMN in subnetworks through a structured approach. Previous literature did not face the issue but divided plants according to unspecified evaluation criteria. The tool developed defines some guidelines on how to proceed in the subnetworks' evaluation and identification process.

From a theoretical point of view, some considerations that are part of the *Explanation phase* (Mid-range theory) in the process proposed by Holmström et al. (2009) need to be underlined. In fact, theories with a limited scope of applicability are often referred to as mid-range theories (Bourgeois Iii, 1979), where the purpose of these theories is to develop a deeper understanding of a topic in a specific context of application. In this perspective, the idea is to limit the work, where the word "limit" takes a positive meaning in the sense of contextualizing the scope of application of the tool. The objective of the explanation phase is to converge towards design theory (Gregor and Jones, 2007) and grounded management theory (Aken, 2004; Glaser and Strauss, 1967). Although we cannot affirm to have tested the tool in several contexts (Dubois and Gadde, 2002), it has been designed and built on five heterogeneous exploratory cases in order to adapt to different conditions and to provide practical support in the analysis of multinational companies of different sizes and industries. This process also produced a body of evidence on pragmatic validity of the tool, as well as a demonstration of theoretical utility. The aim of the research was precisely to create a tool that was adaptable, practical, and usable in different scenarios.

Although the tool has an evident and overriding practical purpose, we have tried to go further. Therefore, in this paragraph, the focus is on theoretical contributions in terms of the novel insight and understanding that the tool offers. The considerations that emerged by building and applying the tool are the following:

a) First, compared to previous contributions, the analysis has been developed at a higher level of specificity. The model goes into the subnetwork analysis but often up to the analysis of the individual plants. The design phase of the model analyzes the characteristics of the single plant, moving through all three perspectives (plant, subnetwork, network). This was done to clearly build the steps of identification and mapping phases (for example, define what is produced in each plant or understand the flows of material among plants). In the same way, in Company Test, only the European BU1, which consists of 4 plants, was analyzed in detail, sorting out the characteristics of subnetwork and plants; thus, under the consideration that the structure is also replicated in other regions, the focus is specifically oriented to a very limited number of plants. Compared to the Ferdows model, the complexity and articulation of the model imply a narrow focus and a higher level of detail.

b) Second, both identification and operationalization exhibit innovative theoretical contributions, enriching the OM literature. Regarding identification, a method for a systematic identification of subnetworks has not been proposed so far. The attempt to propose structured steps aims to help the user in a clearer and less arbitrary definition of subnetworks. This contribution can facilitate the adoption of a common method to understand how many and which subnetworks are present in MNE, always taking into account the specificities of each context. In this perspective, the tool helps to fill the gaps identified in Chapter 4. Regarding operationalization, our framework studies both product and process characteristics in a more articulated, rich, and structured way than previous contributions. This very context-specific phase is the one that highlights most the "science of the particular" (Aken et al., 2016). The work has incorporated the debates and incongruencies from the exploratory cases for an optimization of the dimensions to be considered, and it has been based on an important literature review for the choice of attributes and items (e.g., Roth et al., 2008). Ferdows et al. (2016) proposed Likert scales to evaluate product and process characteristics. They used a limited set of five attributes for evaluating products and six attributes for evaluating process; instead, our operationalization digs deeper into the analysis by extrapolating a larger amount of information (10 dimensions, 26 attributes, and a total of 69 items and metrics).

c) This research provides evidence that the typology of the company under examination influences the categorization phase. Already from the exploratory cases, a greater difficulty had emerged in the analysis of Company B in the categorization phase: the realization of a product group passes through the development of several production steps, even very different from each other, which make categorization more difficult. Therefore, we decided to apply the tool in a continuous manufacturing company (the chemical industry), and the issue appeared again. In Company Test, although the operationalization developed for the categorization phase allowed to clearly distinguish the characteristics of the three subnetworks, it was noted that the process-related dimensions were not easily detachable because of the nature of the subnetworks, i.e., the process-orientation of the company; in this case study, the categorization has revealed much more interesting results in the analysis of the products compared to the analysis of the process. The analysis of the processes for SN2 and SN3 was influenced by the evaluation of processes in SN1, given that Plant A was included in all three subnetworks. Considering the production of different product groups without separating the production stages is in line with the previous literature; for example, Feldmann and Olhager (2019) often consider two distinct phases (component and assembly) in discrete manufacturing companies. However, given the vertical integration of the Company Test, the decomposition of the network brings to clustering together processes strongly heterogeneous. It is consistent with prior studies, which emphasized that theories developed in OM are very often more applicable to discrete manufacturing than the process industries (Dennis and Meredith, 2000).

d) Fourth, the categorization into rooted and footloose subnetwork is sometimes difficult to apply. We hypothesized that the subnetworks found in Company Test could be traced back to the framework of Ferdows et al. (2016), but we noticed some critical issues in light of the above considerations. In fact, Ferdows adopts a high-level model that simplifies the classification of large networks into sub-groups with very different characteristics. Besides, they consider complexity and production processes in the single subnetwork without distinguishing between different process steps. By assuming a higher level of detail, as this research did, the specificities of individual plants are more emphasized, and therefore we tend to recognize more diversity than similarity. By applying the tool, the researchers understood the difficulty to cover all the steps especially under particular conditions, such as companies strongly integrated (see Test case) or companies with a strong component of outsourcing. In Company Test, it is not easy to establish the process complexity in a highly integrated subnetwork, where the phases are multiple and remarkably different. Therefore, the researchers conclude that this model applies mainly to rooted networks or footloose networks that maintain a good percentage of owned manufacturing networks. When a strong outsourcing component comes into play, the model may face difficulties in application. The conclusion is in line with considerations already present in Ferdows et al. (2016).

5.7 Conclusion

Despite the call for further research on the middle level of analysis between a single plant and the entire network (Cheng et al., 2015), surprisingly, there are few papers over subnetworks. Literature has usually analyzed manufacturing management in global networks from a high-level perspective, taking the network as a whole. Vice versa, the study of the company from a narrowly focused plant perspective answers to different needs and research questions compared to those related to the network configuration.

This paper offers an initial insight into the often poorly analyzed disaggregation of IMNs into subnetworks. This work's practical contribution is to provide a new tool for identifying, mapping, and categorizing subnetworks and position itself as an advancement of the model proposed by Ferdows et al. (2016). As it was conceived, it is a tool to be used with an intra-firm perspective (Rudberg and Olhager, 2003), i.e., comparing subnetworks of the same company and evaluating scores accordingly.

Our research offers a new DSR contribution as an answer to an authentic type of OM field problem. Our DSR-based approach follows three of the four phases presented by Holmström et al. (2009), applying DSR in the OM domain (Dresch et al., 2019). The analysis provides both the components of DSR, i.e., the explanatory and the design components (Aken et al., 2016). This contribution contributes to reducing the distance between academic research and the need for practical tools required by practitioners in organizations, especially in the problems of OM, and it helps to fill the gap in the intermediate level of analysis between plant and network.

5.7.1 Limitations and further developments

Finally, the limitations of this research need to be highlighted. First, the choice of the attributes and items in the categorization phase implies a certain degree of subjectivity. Our effort was oriented toward providing a framework grounded in theory and practice, that could be adopted regardless of the industry or other contextual elements. Given that developing a solution is always partly a political process (Holmström et al., 2009), it is noteworthy to recognize potential asymmetries arising from parties having different interests. Researchers refined the solution design to accommodate these idiosyncrasies. Considering that the analysis condensed the requests of several actors in the choice of the dimensions, some inconsistencies may endure.

In addition, it has been pointed out that the proposed tool is quite detailed in its various parts. If, on the one hand, this allows to have a particular level of detail, on the other hand, it requires much effort to be implemented, especially in large manufacturing networks. The evidence of this is that in Company Test, although the very complex network (28 manufacturing sites), we focused only on the European network of BU1. The operationalization phase, in particular, is quite long.

A fourth step after the operationalization of subnetworks could be introduced as a future development, i.e., the categorization of subnetworks within a framework based on the operationalization evaluations. This further step is not within the scope of this paper but is proposed to researchers as an interesting future development. In other words, the fourth step would position the subnetworks in a framework, considering the scores obtained during the assessment of phase III (Operationalization) and the new dimensions introduced. A categorization could be developed, defining some specific categories of subnetworks, starting from those hypothesized by Ferdows et al. (2016) (Rooted, Process innovation, Footloose, Low Investment subnetworks), defining their specific characteristics and proposing ad-hoc management models. The network review can be accelerated and simplified by deliberately choosing to focus on a single subnetwork. The new step proposed (Categorization) goes in this direction and might contribute to solving the inherent hysteresis, i.e., the delayed response to stimuli, which is one of the most relevant challenges faced by manufacturing networks over the years (Ferdows, 2014). Our perception is that a more comprehensive understanding of how to manage subnetworks could unlock very remarkable possibilities.

Finally, additional modifications could emerge after having verified the whole structure with other cases from different contexts. The case selection tried to be inclusive in choosing exploratory cases to take into account different sizes and types of companies in the creation of the model. However, the limited number of cases does not allow us to generalize outside the contexts in which it was tested. The tool offered will provide new insights and a basis to increase the number of empirical contributions on the decomposition of the international manufacturing network into subnetworks. Future research could go beyond in the above process, with the formal theory building and testing (Phase 4 in Holmström et al., 2009).

Appendix 5.A: Descriptive tool

List of abbreviations:

F	Factories (production plants and other non-manufacturing facilities)
P	Manufacturing Plant (productive or warehouse for intermediate products)
PG	Product Group
BU	Business Unit
Sub	Subnetwork
HQ	Headquarters (or local headquarters)
R&D	Research & Development
S	Service
C	Commercial office (office buildings, warehouses for final products, and retail buildings)

Context and environment

Name:

Headquarter:

Annual revenues:

Industry:

Approximately how many employees work for the company?	___employees
How many of the employees are production workers (direct and indirect)	___ workers
How many product lines or product families does the company produce?	__ product lines or families
What percentage of company sales comes from the largest selling product line?	___ % of sales
What were the company's sales last year?	___ total sales
What percentage of the company's sales last year was for export?	___ % of export sales

Phase I: Identification

Step 1. Localization of the network's sites

- How many and which are the different factories of the company?
- What are the value-added activities carried out within each plant?
  Remember that a factory can have multiple roles (e.g., HQ + Manufacturing plant + R&D center). Put manufacturing plants first.

Factory	City	Address	Country	Plant's typology (HQ, R&D, Manufacturing Plant, Commercial office, etc.)					Year of activity starting	% of control
F 1				HQ	P	R&D	S	C		
F 2				HQ	P	R&D	S	C		
F 3				HQ	P	R&D	S	C		
F 4				HQ	P	R&D	S	C		
F 5				HQ	P	R&D	S	C		
F 6				HQ	P	R&D	S	C		
F 7				HQ	P	R&D	S	C		
F 8				HQ	P	R&D	S	C		
F 9				HQ	P	R&D	S	C		
F 10				HQ	P	R&D	S	C		
F 11				HQ	P	R&D	S	C		
F 12				HQ	P	R&D	S	C		
F 13				HQ	P	R&D	S	C		
F 14				HQ	P	R&D	S	C		
F 15				HQ	P	R&D	S	C		
F n				HQ	P	R&D	S	C		

Step 2. Understanding internal criteria for dividing activities

- What is the organizational structure adopted by the company?

Simple		Description:
Functional		
Business Units (or divisions)		
Matrix		
Hybrid		
Other		

If any, which are the Business Units in the company?

	Name	Description
B.U. 1		
B.U. 2		
B.U. 3		
B.U. 4		
B.U. n		

Is there an internal subdivision of plants/factories? Examples

High/low-tech groups of plants		Description:
High/low-cost manufacturing plants		
Other		

Step 3. Understanding what product groups are manufactured

- Does the company have a precise classification of Product groups?

- Which are the different product groups (PG) of the company?

Product Group	Name	Description
PG 1		
PG 2		
PG 3		
PG 4		
PG 5		
PG n		

Step 4: Evaluating production processes

Plant	Most relevant manufacturing processes	Description / notes
P1 (Factory: __)	• __________ • __________ • __________	
P2 (Factory: __)	• __________ • __________ • __________	

P3 (Factory: __)	• ______________________________ • ______________________________ • ______________________________	
P4 (Factory: __)	• ______________________________ • ______________________________ • ______________________________	
P5 (Factory: __)	• ______________________________ • ______________________________ • ______________________________	
Pn (Factory: __)	• ______________________________ • ______________________________ • ______________________________	

Output phase 1. Identification of n (>=1) subnetworks

According to the analysis performed up to now, the information shared, the presence or absence of categorization criteria, and the overall understanding of the manufacturing network, is it possible to divide the network into subnetworks? How many subnetworks are there in the company? Briefly describe them.

Subnetwork	Description
Sub 1	
Sub 2	
Sub 3	
Sub 4	
Sub 5	
Sub N	

Phase II: Mapping

Step 1. Defining what is produced in each plant

Product Group	Name	Business units	Plants in which the product group is manufactured	Flows of process
PG 1		BU1 BU2 BU3 BU4 BUn	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	
PG 2		BU1 BU2 BU3 BU4 BUn	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	
PG 3		BU1 BU2 BU3 BU4 BUn	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	
PG 4		BU1 BU2 BU3 BU4 BUn	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	
PG 5		BU1 BU2 BU3 BU4 BUn	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	
PG n		BU1 BU2 BU3 BU4 BUn	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	

Step 2: Attribution of the plants to the identified subnetworks

Mark the product group which are included in the subnetwork.

Subnetwork	Plants included	Product groups included in the subnetwork	Notes
Sub 1	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	PG1 PG2 PG3 PG4 PG5 PG6 PG7 PG8 PG9 PG10 PG11 PGn	
Sub 2	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	PG1 PG2 PG3 PG4 PG5 PG6 PG7 PG8 PG9 PG10 PG11 PGn	
Sub 3	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	PG1 PG2 PG3 PG4 PG5 PG6 PG7 PG8 PG9 PG10 PG11 PGn	
Sub 4	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	PG1 PG2 PG3 PG4 PG5 PG6 PG7 PG8 PG9 PG10 PG11 PGn	
Sub 5	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	PG1 PG2 PG3 PG4 PG5 PG6 PG7 PG8 PG9 PG10 PG11 PGn	
Sub N	P1 P2 P3 P4 P5 P6 P7 P8 P9 P10 P11 P12 P13 P14 P15 P… P… P… P… P…	PG1 PG2 PG3 PG4 PG5 PG6 PG7 PG8 PG9 PG10 PG11 PGn	

Indicate the “effort” of each plant on the identified subnetwork showing the measure adopted (example, % of production value, volumes, value-added indicator, revenues-costs, time effort, etc.).

Plants	Measure adopted	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub N	Total
P. 1								100%
P. 2								100%
P. 3								100%

P. 4								100%
P. 5								100%
P. 6								100%
P. 7								100%
P. 8								100%
P. 9								100%
P. 10								100%
P. n								100%

Step 3: Supply chain configuration

What is the level of vertical integration for the different subnetworks?

Which is the internal configuration that best describes the whole network? Which is the internal configuration that best describes each of the subnetworks? (derived by Friedli et al., 2014)

		Description	**Notes**
Horizontal supply chain	World factory	Each plant is capable of producing in their entirety the whole product spectrum for the global market	
	Local-for-local	The sites are capable of producing in their entirety the complete gamut of products demanded by a market	
	Flexible networks	Sites are capable of manufacturing a similar range of products in their entirety	
Mix between horizontal and vertical supply chain	Global hub and spoke network	A few global component plants ("global hubs") supply components to assembly plants in close proximity to the market	
	Regional hub and spoke network	Equivalent of global hub and spoke, but at a regional level	

Vertical supply chain	Global value chain	Individual sites are responsible for single processes and interlinked	
	Regional value chain	Equivalent of a global value chain, but at a regional level	

Can you explain which are the typical relationships and the exchanges among different plants belonging to the same subnetworks?

Where are the products produced for each subnetwork (in own plants or externally)?
Note: consider only suppliers of products sold or sub-contractors (NO raw materials and components).

	Final goods sold are entirely produced in own plants	Final goods sold are partially produced internally and partially by external partners	Final goods sold are entirely sourced from external partners	
Sub1	%	%	%	=100%
Sub2	%	%	%	=100%
Sub3	%	%	%	=100%
Sub4	%	%	%	=100%
Sub5	%	%	%	=100%

For each subnetwork, show the internal SC configuration (Feldmann and Olhager, 2019)

- Discrete manufacturing: Suppliers → Component manufacturing → Assembly → Market
- Process manufacturing: show the process and the flows

Step 4. Role of the plants

What is the strategic role of each plant?

For each plant, indicate what role it plays in the company from 1(the plant has a clear focus on the production function only) to 9 (the plant represents the development and center of excellence and serves as a partner of headquarters for certain manufacturing capabilities). Be careful to describe on this scale what the plant does in your company, which is not necessarily what it should do.

(adapted from Ferdows, 1997, and Ferdows et al., 2016)

	Components	Assembly	The main goal of the plant is "to get the products produced". Managerial investment in the plant is focused on running the plant efficiently.		The plant has sufficient internal capabilities to develop and improve its own components, products, and production processes		The plant is a focal point in the company for the development of specific important components, products, or production processes		The plant develops and contributes knowhow for the company		The plant is a "center of excellence", and serves as a partner of headquarters in building strategic capabilities in the manufacturing function
P1			1	2	3	4	5	6	7	8	9
P2			1	2	3	4	5	6	7	8	9
P3			1	2	3	4	5	6	7	8	9
P4			1	2	3	4	5	6	7	8	9
P5			1	2	3	4	5	6	7	8	9
P6			1	2	3	4	5	6	7	8	9
P7			1	2	3	4	5	6	7	8	9
P8			1	2	3	4	5	6	7	8	9
P9			1	2	3	4	5	6	7	8	9
P10			1	2	3	4	5	6	7	8	9
Pn			1	2	3	4	5	6	7	8	9

Phase III: Categorization

This phase must be completed for **each** subnetwork. The information provided in this section aims to categorize the subnetworks based on a set of dimensions (from Prd.1 to Prd.5 and from Prc.1 to Prc.5). Each attribute provides some attributes, which in turn are decomposed into items. The measures you will provide will be used to qualitative position the subnetwork over a reference framework. Qualitative measures go from 1 (minimum level) to 5 (maximum level). Given that we are adopting an intra-company perspective, the measures will always be in comparison with other subnetworks of this company.

These measures go from 1 to 5:
1: meaning "really disagree" or "far worse than other subnetworks".
5: meaning "really agree" or "far better than competitors subnetworks".

Example:
In order to calculate the item "Component variety" within the attribute Variety, the following measure was utilized: "*The product group implies a very high variety of components*". In this case, 1 means to really disagree with the sentence, i.e., the product group has a very low variety in components (compared to other product groups in different subnetworks). Vice versa, 5 means to really agree with the sentence, i.e., the product group has a very high variety in components (compared to other product groups in different subnetworks).

One of the columns indicates a + or a – according to the direction toward which the considered item would impact the product or process axis on the matrix of Ferdows et al. (2016)

	Attributes	Description		Items			Measures					
Product												
Prd.1	**Product complexity**							**1**	**2**	**3**	**4**	**5**
Prd.1.1.	Variety	It is an index that measures fundamental variety among products. Variety is described in terms of unique products, components, and processes.	Prd.1.1.1	Product variety	(Benton and Srivastava, 1993; Cooper, 1992; Frizelle and Woodcock, 1995; Hu et al., 2008; MacDuffie et al., 1996a; Orfi et al., 2011; Sum et al., 1993)	+	The product group(s) in this subnetwork has a very high number of unique designs.					
			Prd.1.1.2.	Component variety	(Orfi et al., 2011)	+	The product group(s) in this subnetwork implies a wide variety of components.					
Prd.1.2.	Functional index	The number of required functional attributes adds product's complexity; the more functions the product has to perform, the higher the level of perceived complexity.	Prd.1.2.1	Number of functional requirements	(Ameri et al., 2008; Barclay and Dann, 2000; MacDuffie et al., 1996b; Pahl and Beitz, 2013)	+	The number of functional requirements to meet is very high.					
			Prd.1.2.2	Customer sensitivity	(Orfi et al., 2011)	+	The level of sensitivity of the customer to a specific function or attribute of the product group (how sensitive it is to a change) is very high.					
Prd.1.3.	Structural index	Structural complexity is defined in terms of the complexity associated with the physical makeup of the product.	Prd.1.3.1	Number of components	(Frizelle and Woodcock, 1995; MacDuffie et al., 1996b; Orfi et al., 2011; Pahl and Beitz, 2013; Rodriguez-Toro, 2002)	+	The number of components and parts of product groups in this subnetwork is high.					
			Prd.1.3.2	Degree of interrelationship	(Ameri et al., 2008; Barclay and Dann, 2000; Fagade, 1998; Rodriguez-Toro, 2002)	+	The product group(s) is done by non-assembled products with strong integrated relationships between components (integral architecture).					
Prd.1.4.	Design index	The Design Index dimension of product complexity is related	Prd.1.4.1	Coupling level	(Orfi et al., 2011)	+	A change to one component implies a change in other components.					

		to design aspects of the product and its components.	Prd.1.4.2	Control level	(Fagade, 1998; Rodriguez-Toro, 2002)	-	The design satisfies all the specified requirements for the product with a minimum number of component relations.					
Prd.1.5.	Production index	This dimension of product complexity is related to the number of possible paths and the volume of manufacturing processes. In our model, it is linked with process complexity.	Prd.1.5.1	Number and type of production paths	(Orfi et al., 2011)	+	There is a considerable number of trajectories or production paths available per product and its associated components.					
			Prd.1.5.2	Volume	(Barclay and Dann, 2000; Orfi et al., 2011)	+	The volume in this subnetwork is consistent.					
Prd.2	**Product innovativeness**							**1**	**2**	**3**	**4**	**5**
Prd.2.1	Market	The market dimension is linked to the changes that new product group brings about within the market. A key criterion is whether the innovation proposes or not a significant change in customer value compared to previous products (Chandy and Tellis, 1998).	Prd.2.1.1	New customer value	(Mcnally et al., 2010; Schultz et al., 2013)	+	New products of this subnetwork offer a new customer value not offered before by any other product.					
			Prd.2.1.2	Totally new market	(Mcnally et al., 2010; Schultz et al., 2013)	+	New products of this subnetwork create a totally new market.					
			Prd.2.1.3	Change the way the market functions	(Schultz et al., 2013)	+	New products of this subnetwork change the way our market functions.					
Prd.2.2	Technology	The technological aspect is linked to the changes in the technological components contained in the new products. In extreme cases, new technologies go hand in hand with a	Prd.2.2.1	New technological principles	(Schultz et al., 2013)	+	New products of this subnetwork are based on new technological principles.					
			Prd.2.2.2	Significant performance enhancements	(Mcnally et al., 2010; Schultz et al., 2013)	+	The technology used in this subnetwork allows significant performance enhancements.					
			Prd.2.2.3	Very new technological components	(Barclay and Dann, 2000; Mcnally et al., 2010; Novak	+	New products of this subnetwork can be characterized as being based					

		paradigm shift in technology or science (Garcia and Calantone, 2002).			et al., 2001; Schultz et al., 2013)		on very new technological components.					
Prd.2.3.	Internal	This dimension considers internal changes within the company that go hand in hand with innovations.	Prd.2.3.1	Change organizational structure	(Schultz et al., 2013)	+	In order to develop and introduce the new products/services this subnetwork has to change its organizational structure significantly.					
			Prd.2.3.2	Change production processes	(Schultz et al., 2013)	+	In order to develop and introduce the new products/services this subnetwork has to change its production processes significantly.					
			Prd.2.3.3	Change organizational culture	(Schultz et al., 2013)	+	In order to develop and introduce the new products/services this subnetwork has to change its organizational culture significantly.					
Prd.2.4.	External	Increased innovation can also lead to changes in the business environment (Salomo et al., 2007), such as industry regulations and standards.	Prd.2.4.1	New industrial norms	(Schultz et al., 2013)	+	In order to introduce the new products, changing industry norms have to be established.					
			Prd.2.4.2	New regulatory structure	(Schultz et al., 2013)	+	In order to introduce the new products in this subnetwork, a new regulatory structure has to be adopted.					
Prd.3	**Intellectual capital and know-how**							**1**	**2**	**3**	**4**	**5**
Prd.3.1	Scientific and technical based knowledge (STI)	It is the knowledge based on the production and use of codified scientific and technical tools.	Prd.3.1.1	Expenditures on R&D	(Artz et al., 2010; Edvinsson and Malone, 1997; Hall and Mairesse, 1995; Jensen et al., 2007; Lanjouw et al., 1998; Lettice et al., 2006)	+	The expenditures on R&D on this subnetwork as a share of total revenue are high.					

			Prd.3.1.2	Cooperation with researchers	(Jensen et al., 2007; Lettice et al., 2006)	+	For this subnetwork, the company often interacts with researchers attached to universities or scientific institutes.					
			Prd.3.1.3	Workforce composition	(Jensen et al., 2007; Lettice et al., 2006)	+	The subnetwork has in its staff a high % of scientifically trained personal, including personnel with a bachelor, master, or Ph.D. degree over the total.					
Prd.3.2.	Doing, Using and Interacting (DUI) mode	It is knowledge based on experience or informal processes of learning.	Prd.3.2.1	Employee involvement	(Jensen et al., 2007; Lettice et al., 2006)	+	The subnetwork makes use of practices for employees' involvement (interdisciplinary workshops, quality circles, workgroups, etc.).					
			Prd.3.2.2	Cooperation with customers	(Jensen et al., 2007)	+	The subnetwork has frequent interaction and contact with customers.					
			Prd.3.2.3	Function integration	(Jensen et al., 2007)	+	The functions working for the subnetwork are strongly integrated.					
Prd.4	**Intellectual property Protection**							**1**	**2**	**3**	**4**	**5**
Prd.4.1	Intellectual property protection	It is the level of effort needed to manage and protect the information and the knowledge.	Prd.4.1.1	Patent protection	(Artz et al., 2010; Goldense et al., 2017; Gould and Gruben, 1996; Ostergard, 2000; Rapp and Rozek, 1990; Seyoum, 1996; Sherwood, 1996)	+	The number of patents for this subnetwork is high.					
			Prd.4.1.2	Trademark protection	(Artz et al., 2010; Goldense et al., 2017; Gould and Gruben, 1996; Ostergard, 2000; Rapp and Rozek, 1990; Seyoum, 1996; Sherwood, 1996)	+	The number of trademarks for this subnetwork is high.					
			Prd.4.1.3	Copyright protection	(Artz et al., 2010; Goldense et al., 2017; Gould and Gruben, 1996; Ostergard, 2000; Rapp and Rozek, 1990; Seyoum, 1996; Sherwood, 1996)	+	The copyright protection for this subnetwork is high.					

			Prd.4.1.4	Trade secret	(Seyoum, 1996)	+	The importance of trade secret for this subnetwork is high.					
Prd.5	**Target segment**							**1**	**2**	**3**	**4**	**5**
Prd.5.1.	Perceived quality offered	It is the customer's judgment of the overall excellence, esteem, or superiority of a brand (with respect to its intended purposes) relative to alternative brands.	Prd.5.1.1.	Quality	(Keller, 1993; Aaker, 1996; Netemeyer et al., 2004)	+	Compared to other brands, the product groups of this subnetwork are of very high quality.					
			Prd.5.1.2.	Best product	(Aaker, 1996; Netemeyer et al., 2004)	+	This subnetwork works on products that are the best brands in their product class.					
			Prd.5.1.3.	Performance	(Aaker, 1996; Netemeyer et al., 2004)	+	This subnetwork consistently performs better than all other brands of similar products.					
Prd.5.2	Perceived value for the cost	It is defined as the customer's overall assessment of the utility of the brand based on perceptions of what is received (e.g., quality, satisfaction) and what is given (e.g., price and nonmonetary costs) relative to other brands.	Prd.5.2.1.	Worthy estimation	Aaker (1996); Netemeyrer (2004)	+	What I get from this subnetwork is worth the cost.					
			Prd.5.2.2.	Good buy	(Aaker, 1996; Netemeyer et al., 2004)	+	All things considered (price, time, and effort), the product of this subnetwork is a good buy.					
			Prd.5.2.3.	Good value	(Aaker, 1996; Netemeyer et al., 2004)	+	Compared to other brands, the products of this subnetwork have a good value for money.					
			Prd.5.2.4.	Good feeling	(Aaker, 1996; Netemeyer et al., 2004)	+	When the customer uses a product of this subnetwork, he/she feels getting his/her money's worth.					
Prd.5.3	Uniqueness	the degree to which customers feel that the brand is different from competitors.	Prd5.3.1.	Standing out product	(Netemeyer et al., 2004)	+	This subnetwork really ''stands out'' from other brands of similar products.					
			Prd5.3.2.	Different product	(Netemeyer et al., 2004)	+	Products of this subnetwork are very different from other brands of similar products.					
			Prd5.3.3.	Unique product	(Aaker, 1996; Netemeyer et al., 2004)	+	Products of this subnetwork are ''unique'' from other brands of similar products.					
Prd.5.4	Price premium	the amount that a customer is willing to pay for his preferred	Prd5.4.1	Switch to competitors	(Aaker, 1996; Netemeyer et al., 2004)	+	The price of product groups in this subnetwork would have to go up quite a bit					

		brand over comparable brands of the same size/quantity package.					before the customers would switch to another brand of similar product.					
			Prd5.4.2	Willingness to pay a higher price	(Keller, 1993; Aaker, 1996; Netemeyer et al., 2004)	+	Th customer is willing to pay a higher price for product groups in this subnetwork than for other brands of similar products.					

	Attributes	Description		Items			Measures					
Process												
Prc.1	**Process complexity**							**1**	**2**	**3**	**4**	**5**
Prc.1.1	Process ramification	It is given by the number of elements, machines, and operations to be fulfilled in the process.	Prc.1.1.1	Number of machines	(Deshmukh et al., 1998; Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	The number of machines per process used in this subnetwork is very high.					
			Prc.1.1.2	Number of parts	(Deshmukh et al., 1998; Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	The number of parts per product group considered in this subnetwork is very high.					
			Prc.1.1.3	Number of operations	(Deshmukh et al., 1998; Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	The number of operations to be accomplished for the product groups of this subnetwork is high.					
Prc.1.2	Process configurations	It is the intrinsic complexity given by the relationship among various elements and the layout in the process routings.	Prc.1.2.1	Flexible routings / Routing commonalities	(Deshmukh et al., 1998; Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	In this subnetwork, the production routes within the processes are highly flexible and adjustable to cope with contingencies.					
			Prc.1.2.2	Part scheduling	(Modrak and Soltysova, 2017)	-	In this subnetwork, the probability of parts being processed on individual machines according to scheduling order is high.					

								1	2	3	4	5
Prc.2	**Process innovation**							**1**	**2**	**3**	**4**	**5**
Prc.2.1.	Propensity to create or adopt new manufacturing processes	How much the company is willing, inclined, and proactive in creating or adopting new processes.	Prc.2.1.1	Development or adoption of new manufacturing processes solution	(Deshmukh et al., 1998; Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	The subnetwork actively develops in-house solutions to improve our manufacturing processes.					
			Prc.2.1.2	Criticality of new manufacturing processes	(Deshmukh et al., 1998; Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	The subnetwork sees creating new manufacturing processes as critical to our success.					
			Prc.2.1.3	Early adopters of new manufacturing processes	(Deshmukh et al., 1998; Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	The subnetwork tends to be an early adopter of new manufacturing processes.					
Prc.2.2.	Propensity to create or adopt new business systems	How much the company is willing, inclined and proactive in creating or adopting new business systems.	Prc.2.2.1	Development or adoption of new business systems	(Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	The subnetwork actively develops in-house information technology solutions.					
			Prc.2.2.2	Criticality of new business solution	(Modrak and Soltysova, 2017)	+	The subnetwork sees creating new business systems as critical to our success.					
			Prc.2.2.3	Early adopters of new business solution	(Deshmukh et al., 1998; Frizelle and Woodcock, 1995; Modrak and Soltysova, 2017)	+	The subnetwork tends to be an early adopter of new business systems.					
Prc.3.	**In-house manufacturing vs outsourced manufacturing**							**1**	**2**	**3**	**4**	**5**
Prc.3.1.	Extent of outsourcing	How much the company is relying on outsourcing manufacturing.	Prc.3.1.1	Existence of outsourcing	(Dabhilkar and Bengtsson, 2008)	-	Very high level of: % of outsourced manufacturing of any component or product in the past 3 years.					
			Prc.3.1.2	Purchasing status	Bengtsson and Dabhilkar (2008); Corswant and Fredriksson (2002); Mol (2001)	-	Very high level of: Share of material purchased and serviced / Total product cost for the main product line).					
			Prc.3.1.3	Outsourcing intensity	(Dabhilkar and Bengtsson, 2008)	-	Very high level of: % of purchased share / (100 - % of purchased share 3 years ago).					

Prc.4.	**Suppliers Management**											
Prc.4.1	Number of sources	How many suppliers are included in the process, and which is the preference of managers between single and multiple sourcing.	Prc.4.1.1	Number of suppliers	Chen and Paulraj (2004); De Toni and Nassimbeni (1999)	-	The number of suppliers for the product group(s) in this subnetwork is high.					
			Prc.4.1.2	Preference towards single sourcing	Swift and Coe (1994)	+	The subnetwork usually adopts a single-sourcing approach for this subnetwork.					
Prc.4.2	Strategic relationship with suppliers	The mutual activity of exchange between suppliers and customers in a long-term relationship, where both sides contribute resources such as capabilities or information to the relationship.	Prc.4.2.1	Long Term relationship	Prajogo et al. (2012); Chen and Paulraj (2004)	+	The subnetwork expects the relationships with key suppliers to last a long time.					
			Prc.4.2.1	Collaboration with key suppliers to improve quality	Prajogo et al. (2012); Chen and Paulraj (2004)	+	The subnetwork collaborates with key suppliers to improve their quality in the long run.					
			Prc.4.2.3	Suppliers' consideration	Prajogo et al. (2012); Chen and Paulraj (2004)	+	The suppliers see the relationships with the subnetwork as a long-term alliance.					
			Prc.4.2.4	Suppliers' consideration	Prajogo et al. (2012); Chen and Paulraj (2004)	+	The subnetwork sees its suppliers as an extension of the company itself.					
Prc.5	**Asset specificity**							**1**	**2**	**3**	**4**	**5**
Prc.5.1	Site specificity	Site specificity occurs when investments in productive assets are made in close physical proximity to each other. Geographical proximity of assets for different stages of production reduces inventory, transportation, and sometimes processing costs.	Prc.5.1.1	Distance between plants and key suppliers	(Alt et al., 1999; Riordan and Williamson, 1985)	+	The distance (km) between the supplier plant (manufacturing the highest volume component) and the company's plant is huge.					

Prc.5.2.	Physical asset specificity	Equipment and machinery that produce inputs specific to a particular customer or are specialized to use an input of a particular supplier are examples of physical asset specificity.	Prc.5.2.1	R&D intensity	(Alt et al., 1999; Riordan and Williamson, 1985)	+	The R&D expenditures of this subnetwork divided by value-added is high.					
			Prc.5.2.2	Focalization over a single subnetwork (adapted from Dyer, 1996)	(Alt et al., 1999; Riordan and Williamson, 1985)	+	The percentage of the supplier's total capital investments which would have to be scrapped if the supplier were prohibited from conducting any future business with the subnetwork is very high.					
Prd.5.3	Human asset specificity	Human-asset specificity refers to the accumulation of knowledge and expertise that is specific to one trading partner.	Prc.5.3.1	Job mobility	(Alt et al., 1999; Riordan and Williamson, 1985)	-	Annual gross increase plus annual gross decrease in jobs divided by total jobs is high for this subnetwork.					

6. HOW TO DEAL WITH A PLANT HAVING A TWOFOLD MANUFACTURING MISSION IN AN INTERNATIONAL MANUFACTURING NETWORK?

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Abstract

Plants within International Manufacturing Networks (IMNs) have usually been considered as clearly oriented units. Coherently, literature has stressed the concept of the focused factory, i.e., intending to accomplish only one strategic task. However, companies are increasingly geared towards producing very different product groups, resulting in overlapping multiple manufacturing objectives in the same plant. Thus, our objective is to study how a plant having more than one manufacturing mission is managed. This exploratory multiple case-study research analyses twelve plants belonging to international networks and where two strongly differentiated groups of products are manufactured. An original dataset, developed on the basis of a purposely design research protocol, was built through plant visits and semi-structured interviews. The analysis compares and contrasts the practices adopted by plants in managing their functions or departments (production, R&D, planning, purchasing, warehouse, and logistics) when two distinct product groups – one including standard or low-tech products, the other including personalized or high-tech products – are manufactured. The results highlight specific stages of function specialization as the difference between the product groups increases. Furthermore, by analyzing how plants that belong to different subnetwork in a company are managed, the research tests and discusses the presence of multiple "roles of the plant". This exploratory qualitative study develops propositions potentially testable in more analytical research.

Keywords: Multi-production Plants, International Manufacturing Networks, Case-study research, Plant role, Manufacturing Subnetwork.

6.1 Introduction

In previous chapters, it has been discussed how globalization has led to substantial changes in the global, political, and economic spheres in recent decades (Dicken, 2007). Nowadays, in order to meet the needs of a global market, companies operate in the form of international manufacturing networks (IMNs). An extensive literature has discussed the shift from a rigid, typically centralized corporate structure to a globally distributed network of factories (Lanza et al., 2019). As a consequence, the distribution of plants has led to a fragmentation of processes and an international dispersion of tasks (Norouzilame et al., 2014).

A substantial literature has proved that the customers served by a company are not homogeneous and, consequently, they can be divided into segments depending on a combination of elements (Beane and Ennis, 1987; Kotler and Armstrong, 2010; Lanza et al., 2019). To meet this challenge, companies are increasingly diversifying the range of their products by exploring new businesses and obtaining growing market shares (Morschett et al., 2015). Due to the segmentation and customization of customer choices, the configuration of production networks in multinational companies is also changing, with more and more companies dividing their factories according to the product groups manufactured and the production activities carried out (Eckel and Neary, 2010). IMN literature has long analyzed the ways in which a diversification of production can take place within a multinational corporation, and the problem has been analyzed from different viewpoints. In particular, there are two main perspectives with which looking at the topic.

The *first* perspective is the analysis of the groups of plants that are accountable for the production of a given product group. Despite the link between the plant level and the network level has been rarely researched (Cheng et al., 2015), literature has started to emphasize the analysis of product group networks (Feldmann and Olhager, 2019), i.e., networks of plants involved in the manufacturing of a specific product group. Yet, Ferdows et al. (2016) started from the presence of several product groups in the same company for their contribution to *manufacturing subnetworks*, disassembling the production network in bunches of plants with a "coherent manufacturing mission". Especially in the last decades, the single plant in an international network is often involved in manufacturing more than one product group (for example, in its Taiwanese plants, Canon produces both cameras, a complex product requiring continuous innovation, and optical lenses and glasses, a relatively simple and standard product for the industry). Feldmann and Olhager (2019) state that this implies a necessary shift in the unit of analysis, passing from the study of the whole network to product-related sub-groups of plants. They empirically found that many of the plants they analyzed were involved in two or more product groups, with a mean of 1.7 product groups per plant.

The *second* perspective concerns the analysis at a plant level. With a plant-based approach, the IMN literature has often considered plants capable of manufacturing only a limited set of products under a limited bunch of capabilities. This approach favors the specialization of production plants towards units dedicated to a single product group or a single category of products. Yet early contributions related to manufacturing strategy embraced this approach: for example, the concept of focused factories (Skinner, 1974) suggests that the best results can be achieved when the factory focuses on a series of physical features, processes, technologies, and infrastructures each strictly directed to a single manufacturing task. Other scholars (Ferdows and De Meyer, 1990; Voss, 1996; Wheelwright and Hayes, 1985) supported the seminal article of Skinner, suggesting that some variables might be set up to give support to a higher "plant's focus" (Lanza et al., 2019). Many contributions focused on plant's role in manufacturing companies at a plant level, mainly assuming that each plant has only one role (e.g., Cheng and Farooq, 2018; Ferdows, 1989, 1997; Vereecke and Van Dierdonck, 2002).

Although these two streams have made relevant contributions to the IMN literature, there is limited theoretical and empirical evidence on how plants are managed from an operational perspective when activities of different product groups are co-located (Bengtsson et al., 2010). There is a lack of evidence of how the plant behaves when engaged on two (or more) highly differentiated product groups or, in other words, when the plant belongs to different manufacturing subnetworks (Ferdows et al., 2016). For example, there is not a rich discussion on who is committed to which product groups, how responsibilities are distributed, what happens within plant's departments that follow different families, etc.

The analysis of multi-production contexts (factories producing multiple different product groups) is still fragmented. On the one hand, the literature considering groups of similar plants takes the single factory as belonging to one network or another (Feldmann and Olhager, 2019; Ferdows et al., 2016) without explaining the potential co-location of processes with divergent characteristics. On the other hand, literature on the role of the plant suggests that the decision-making process that affects the individual plant is mainly based on network decisions (Feldmann and Olhager, 2013), and contributions have not thoroughly investigated the coexistence of multiple product groups in the same plant. While the role of the plant is well-defined in situations of production of a single product group, more articulated is the case of a plant belonging to several product groups.

Thus, the overall purpose of this research is to delve deeper into a manufacturing unit that takes a double manufacturing mission in producing two quite differentiated product groups in distributed networks. Purposely and contrarily to most of previous research, the focus of this contribution is the “unfocused” plant. The objective is to study the configuration and managerial practices of factories involved in multiple productions within IMN. The research does not investigate "why" these plants exist, nor "if" these plants are more or less performing than plants producing only one product group. Instead, the research aims to understand how plants belonging to different subnetworks are managed knowing that these subnetworks have different missions. While it can be hypothesized that the needs that the plant must ensure for subnetwork A are different from those for subnetwork B, nothing has been said in the literature about the role, behavior, and management of the plant in the presence of multiple subnetworks.

A case study approach is used as the research methodology (Eisenhardt, 1989; Voss, 2002). The empirical part is based on 12 exploratory case studies in multinational companies' plants. In the development of the cases, only plants producing two distinct product groups were selected. Specifically, we chose factories where two product groups classified as suggested by Ferdows et al. (2016) could be identifiable: the first product group within the plant (**PG1**) has similar characteristics to the products managed within a *footloose* subnetwork (standard products with limited product and process complexity) while the second product group (**PG2**) has characteristics closer to the products managed by a *rooted* subnetwork (highly innovative/customized products, with high product and process complexity).

Two aspects were at the center of the empirical analysis: *first*, the analysis of the practices that companies adopt within each function (the work will refer to functions or departments as "functions") to better cope with the dual productive tasks they carry out. The empirical investigation highlights the presence of different practices; in some cases, the analysis has highlighted the presence of a real "plant-within-the plant", especially when PGs show significant differences. Moreover, the study explores how plants diversify their functions internally by dividing the operations of individual departments as the difference between PG1 and PG2 increases. *Second,* the paper aims to investigate the factory through a higher-level perspective by considering plants as part of multi-plant product group networks. The presence of multiple manufacturing missions as well as the possibility of a plant having multiple, even contrasting, “strategic roles” is debated.

To summarize, the contribution provides a link between operational and strategic decision-making in international manufacturing management. The research bridges the plant and subnetwork perspectives, offering an empirical base for tightening the large gap between plant-related and network-related literature in IMNs.

6.2 Related literature and Objectives

This research lays its foundations in the analysis of the strategic management of international production. The study proposes an exploratory question calling for several themes and theoretical perspectives to be combined. Thus, the research combines different strands of literature, covering international networks, plants’ role, and multi-product manufacturing. The literature related to the management of international manufacturing can be divided into three streams, according to the level of analysis (Blomqvist and Turkulainen, 2019): (1) multinational firms (2) individual plants, and (3) plant networks.

The research on multinational firms (1) mainly focuses on a strategic perspective. Numerous contributions have analyzed the strategies for entering foreign markets, foreign direct investments (e.g., Buckley et al., 1998), and coordination between subsidiaries (Morschett et al., 2015). This literature stream rarely makes a distinction between manufacturing units and other units (Blomqvist and Turkulainen, 2019). On the contrary, it takes a rather inclusive and heterogeneous perspective towards foreign factories. Given that this paper focuses on the manufacturing side of companies and the practices adopted in single plants within the network, attention will be primarily given to the literature about plant networks (3) and individual plants (2), which emphasize the plant as the focal point in the analysis. These two strands of literature will be detailed in the next paragraphs.

6.2.1 Research on individual plants and the role of the plant

With regard to the analysis of the individual plant, three streams of literature relevant for this paper:

The first is the already introduced concept of "**focused factory**". It was already used by Skinner (1974) and subsequently echoed by numerous other contributions (among the most relevant, Brumme et al., 2015; Ferdows et al., 2016; McGrath and Hoole, 1992). The key argument in these papers is that following multiple objectives can lead to a lowering of the focus on the core mission and thus to worse performance. In support of this, other authors have argued for a commitment to a "focused" solution. For example, some contributions (Ferdows and De Meyer, 1990; Voss, 1996; Wheelwright and Hayes, 1985) delved deeper into this proposition, suggesting that some structural variables (for example, location, process technology, machineries, etc.), infrastructural variables (organization, employee management, production and planning processes), and interfunctional linkages might be designed to enhance the factory's "focus" (Lanza et al., 2019). However, especially in recent years, the need to make different product groups calls for multiple manufacturing missions. From an intra-company perspective, it is not just a matter of scheduling effectively. In these conditions, companies need to manage potentially completely different needs, competencies, and operations within a shared space and often with shared resources. The concept of "manufacturing mission" is broad. The dominant meaning of manufacturing mission is the one that refers to the objective to be achieved. As a result, two manufacturing sites that make two significantly different product groups will have different manufacturing missions. When referring to a single plant, the expression "plant mission" has often been used. (Brush et al., 1999), where an independent factory may define its primary mission as serving a local market or customer. A clear example of different manufacturing missions is offered by Szwejczewski et al. (2016): a plant with a wide range of products to manufacture could not function as both a high-efficiency and high-flexibility plant, mostly having processes designed for large batch production. The plant was replaced with a new high-tech manufacturing facility to produce high-volume standard products with the task of serving a regional market.

Sometimes, manufacturing missions refer not only to the physical goods to be produced but also to the operational modes. For example, Brumme et al. (2015) shows three manufacturing missions (namely innovation mastery, operational excellence, and solutions delivery) that are related to different goals: innovation, efficiency, and service.

The second stream of literature is about the **co-location** or **separation** of activities or processes. This topic is part of the more extensive discussion about the range of operational capabilities that a plant develops. Companies adopt a multi-manufacturing configuration (i.e., they produce diversified product groups) for various reasons, for example, economies of scale, learning economies, transfer of skills between different product groups. The successful coordination of a manufacturing network is made possible by integrating factories and adapting to the company's strategic objectives (Cheng et al., 2011). This idea supports the belief that manufacturing network coordination might result in a specific allocation of resources to develop further individual site competencies (Meijboom and Vos, 1997; Szwejczewski et al., 2016).

With this regard, Hayes and Schmenner (1978) introduced the concepts of "*product-focused organization*" and "*process-focus organization*". They suggest that a process network configuration (i.e., the consolidation of the production of components in a single plant) would have less duplication of equipment for producing common parts. However, the firm would incur the incremental logistics cost associated with shipping standard components to other final assembly plants. Alternatively, a company may adopt a product network configuration where each plant is entirely responsible for the manufacturing and assembling of the final product. They suggest that the plant should make a choice between these two approaches and not try to achieve both, given the significant differences between the two options. Therefore, there are trade-offs between these two alternatives in terms of cost and opportunity (Kulkarni et al., 2004). The control is even more challenging in situations where multiple production stages are handled in the same plant or when multiple products are manufactured in the same site.

The third strand of research of particular importance is about the "**role of the plant**". Several models have been proposed for assigning a specific range of plant expectations to a global production network and some major models have been proposed for categorizing plants' roles, i.e., the range of operational capabilities a site has developed.

In one of the most relevant, Ferdows (1997) classified plants into six typology of roles - "offshore", "outpost", "source", "server", "contributor" and "lead" plants - according to site competence and the strategic reasons for site location. Ferdows' model represents one of the first attempt to explain the path of upgrading plants' strategic role, and it paved the way for further contributions within IMNs literature (Vereecke, Van Dierdonck, and De Meyer 2006; Cheng *et al.* 2011; Feldmann and Olhager 2013; Demeter, Szász, and Boer 2017; Szász *et al.* 2019) (see Chapter 1.2.3 for further details). The topic is as relevant as complex; new contributions are continuously expanding and refining the literature. Some recent contributions tried to broaden the perspective in the analysis of plants' role (among the others, Cheng et al., 2011; Demeter et al., 2017; Feldmann et al., 2013). Some of these connect the role of the individual plant with the structure and configuration of the network as a whole, for example, by stating what are the implications on the network level of a change at the level of the individual plant (Cheng et al., 2011). Of close interest to our research, Szwejczewski et al. (2016) analyze whether the manufacturing specialization of plants characterized by the same plant roles are shared or not, while Blomqvist and Turkulainen (2019) conclude that plants' roles have a complexity higher than what is conventionally considered, and they need further understanding at both plant and network levels.

The research has usually been oriented to the plant's analysis as a single element within the network and characterized by a unique productive role: this means that scarce attention has been put on the possibility of a multi-role plant. Although most contributions support the possibility of having multiple roles in the same network (Feldmann and Olhager, 2013), very few have commented on the possibility of multiple roles at the same facility (Blomqvist and Turkulainen, 2019; Ferdows et al., 2016).

6.2.2 Research on plant-networks: Multi-plant strategies

The importance of the multi-plant configuration problem has long been recognized as a key topic in operations strategy (Friedli et al., 2014). Different "multiplant manufacturing strategies", i.e., the criteria with which organizing production and activities, were identified during the years: the product-oriented strategy, process-oriented strategy, the market-oriented strategy, geographic strategy, or the flexibility-oriented strategy, with a mix of these (Friedli et al., 2014; Hayes et al., 2005; Hayes and Schmenner, 1978; Schmenner, 1982). Again, several frameworks have been proposed for network configurations and coordination in multi-plant networks (Meijboom and Vos, 1997; Netland and Aspelund, 2014; Rudberg and Olhager, 2003; Thomas et al., 2015). In this perspective of separating the plants according to the products manufactured and the processes used, the new theme of manufacturing subnetworks is being developed (Ferdows et al., 2016). The contribution of Ferdows et al. (2016) provides a strong impulse to the research that tries to divide the plants in a perspective of simplification of the network. They classified subnetworks according to the complexity and proprietary information of products and processes, highlighting in particular two types of subnetworks: *rooted*, characterized by innovative products manufactured with complex and proprietary processes, and *footloose,* characterized by simple, commodity-type products and simple processes. As already explained in the previous chapters, the rooted subnetworks are characterized by a high degree of stability, necessity of high levels of competencies and, consequently, a positioning that prefers high cost-countries. On the contrary, the footloose subnetworks are dynamic and continuously reconfigured, which often implies outsourcing or the positioning in lower-cost countries. Few recent contributions further supported the topic. In particular, Golini et al. (2017b) analyze the operations strategy at the level of the subnetwork. Their study tries to understand how organizational structure, location, knowledge transfers, and competences of subnetworks should be organized to accomplish their manufacturing objectives. Again, Feldmann and Olhager (2019) study 20 product group networks in 5 multinational companies, creating a taxonomy that explains the different types of networks. Their results show that many plants are engaged in the production of at least two relatively different types of products. The authors also reported that "*in some cases, a site has different roles for different product groups*" (Feldmann and Olhager, 2019, page 7). This is an important clue about the possible duality of a site's mission; however, the authors don't consider this situation.

Despite the growing interest in product diversification in IMN, multi-production contexts have not been accompanied by such comprehensive literature. The literature on multi-product firms has approached the optimization of resource allocation, contributing to the international trade literature on firm heterogeneity and on multi-product firms (Manova and Yu, 2017), or it has analyzed flexibility in manufacturing (Eckel and Neary, 2010), but without entering a plant level perspective. Most of these works are programming models (Kogut and Kulatilaka, 1994). Few studies have analyzed individual plant departments in this context, and in any case not in the IMN literature.

In IMN literature, there have been some studies that attempted to answer simple but important questions. For example, West and Bengtsson (2007) ask themselves whether plants that are located in different countries but producing similar products should use similar production processes. Kulkarni et al. (2004), instead, analyze manufacturing networks when products have technical commonalities, comparing two opposite configurations: a product-network configuration, where plants are divided according to product, and a process-network organization, where a firm consolidates common component production into a single plant. Even closer to the theme of this research, Bengtsson et al. (2010) explore the possible paradigms when a production plant assumes a dual role, of master and apprentice: of *master*, with the meaning of a factory achieving high volume production in close collaboration with the main manufacturing unit; of *apprentice*, with the meaning of a factory introducing a product group designed and initially industrialized in another geographically distant unit of the network. Their study brought some interesting insights on the topic of dynamic switching of roles within distributed networks. The authors suggest that "*one of the ideas behind the specialization of plants into master and server is that the former is expected to lead, guide and teach the latter*" (Bengstoon et al., 2010, page 419), raising the issue of managing knowledge and learning in customer and supplier relationships.

Despite these contributions, several areas remain unaddressed. For example, there are few contributions about how a plant works when engaged in more than one subnetwork or studies that explain how the interplay between different subnetworks is structured. Open points remain unanswered: how multi-product plants are managed, how departments are organized, what's the information exchange between functions, how knowledge transfer occurs, etc. The operations and the role of a single unit being involved in multiple manufacturing objectives still remain unclear. Both in terms of skills and in terms of organizational approach, there is the need for further stimuli on how to tackle the overlapping in production of multiple product groups (Feldmann and Olhager, 2019).

6.2.3 Research objectives

The analysis of extant literature reveals that most of the contributions on the individual plant have focused on plants producing only one type of product group. Besides, the rich literature on the plants' role usually considers the plant when oriented to a single manufacturing mission. Similarly, the contributions that intertwine the plant and network perspective do not offer significant insights into plants' behaviors when involved in the production of different product groups. Thus, the paper aims to bridge this gap by answering the following research question:

How is a plant having multiple manufacturing missions managed? (**RQ4**)

The objective is to explore the plant behavior when applying a subnetwork perspective. There are two specific research goals that the overall research question implies and derived from the findings in the literature:

1) The first concerns how the single plant is managed and organized when multiple product groups are made within it. In particular, the interest is on the management models of single departments (functions), their mutual interactions, and the shared or separate governance with respect to the products realized. Specifically, the paper individually analyzes some main business dimensions and functions: production, planning, warehouse and logistics, purchasing, R&D. The first specific research question is:

- *Are functions and departments within plants that produce several distinct product groups managed in a shared way, or is there a clear separation that leads to the two product groups being managed separately?*

2) The second point concerns the role of the plant in this type of context with multiple overlapping subnetworks on the same facility. The possibility of having twofold or multiple plant roles can have a significant impact on how to manage the plants, leading to interesting implications. Therefore, this work investigates how plants that belong to different subnetworks are managed, knowing that these subnetworks might have different missions and that, consequently, what is required of the plant in the first subnetwork may be different from what is required in the second subnetwork. The second specific research question is:

- *How might the manufacturing role of a facility that is part of several subnetworks be?*

The dual (or multi) role plant would unlock a wide discussion about how these multi-role plants should be managed, also in relation to the competencies they need. The initial observation, as Ferdows (1997) and other studies suggested (e.g., Cheng and Farooq, 2018; Schmenner, 1982; Vereecke et al., 2006), is that plants having different roles are supposed to have many different characteristics, so they accordingly need to be managed in different ways. With this regard, companies fulfilling different strategic roles should develop different management systems to ensure the effective fulfillment of these roles (Szwejczewski et al., 2016).

6.3 Methodology

An exploratory multiple case study approach (Eisenhardt, 1989; Yin, 2009) was adopted to address the research questions. Case study research is a methodology highly recommended for deepening theoretical and descriptive understanding of complex phenomena in a wide number of disciplines (Yin, 1994), and it is considered particularly suitable in operations management (Voss, 2002). The research is an exploratory investigation that sought to extend existing theory in IMNs and provide insights for more effective practice (Barratt et al., 2011; Eisenhardt, 1989; Eisenhardt et al., 2007; Voss, 2002).

The methodological guidelines proposed by Eisenhardt (1989), Miles and Huberman (1994), and Yin (1994) were followed in order to increase rigor in the analysis. A rigorous research protocol was designed, with closed and open-ended questions as a guide for the interviews. Both qualitative and quantitative data have been collected and analyzed systematically.

Despite the focal point of the thesis is the analysis of the single plant, there is a constant comparison between the operation of the plant and the activities resulting from the subnetwork, constantly bridging two units of analysis.

6.3.1 Case selection

Case selection aims to identify individual plants involved in the production of significantly different product groups within multinational companies. To meet the above objectives, only plants where two distinct product group networks are manufactured, one being more rooted and the other one being more footloose (Ferdows, 2016), have been chosen.

First, an investigation through secondary data was performed. Researchers looked for companies for which it was possible to deduce they were involved in producing more than one product group. The difference between the product groups manufactured in a factory can be considerable, both in terms of the technical characteristics of products and in terms of the complexity of the processes and technologies to be used. In order to distinguish different product groups, and not merely different products but based on the same infrastructure, this research relies on the contribution of Simpson et al. (2012), which describe a product group as "*a group of related products that are derived from a common set of components, modules, and/or subsystems to satisfy a variety of market applications*" (Simpson et al., 2012, page 141). In order to assure the reliability of the research, plants producing two strongly differentiated product groups were selected. We searched on websites, annual reports, and other secondary sources, those multinational companies for which the distinction between the product groups made seemed substantial. This distinction could be observed mainly from a commercial point of view, i.e., by observing how the categories of product groups were commercialized.

Second, once this initial selection was made, the identified companies were contacted. A set of companies quite heterogeneous in terms of industries and firm sizes and accessible by the researchers for geographic reasons was selected. The companies contacted were asked to confirm the information collected from the secondary data; in particular, only those companies for which the distinction between the various product groups also exists at a production level and not only at a commercial level were chosen. In other words, only the companies for which the products and production processes of the different product groups were substantially different were selected. Researchers have selected companies producing at least two product groups that have different characteristics, that is, one being more standardized and one being more customized. PG1 has lower quality characteristics (basic product-group), and PG2 has higher quality features (premium product).

Third, since the analysis is aimed at a single plant, only companies with at least one plant involved in the production of two distinct product groups have been selected. A plant having only limited contributions for one of the two product groups did not qualify as an interesting context; for example, the cases where the plant analyzed have only a marginal role in the production processes of one PG were excluded from the analysis. In order to understand the degree of commitment to PG1 and PG2, respondents were explicitly asked to give qualitative ratings from 1, meaning "the plant plays a minor role on the PG and covers marginal specific processing of the PG" to 5, meaning " 'plant plays a key role on the PG and is highly committed to the PG production processes" for each PG. Firms with a score of less than 3 on even one of the PGs were eliminated. The requirement to find plants with these characteristics has strongly reduced the potential sample of companies.

The final sample is composed of twelve international companies. The analyzed companies range from 3 to 24 manufacturing plants (not considering other facilities like R&D centers, commercial, or administrative offices), in line with other contributions in the IMNs literature (Blomqvist and Turkulainen, 2019; Feldmann and Olhager, 2019; Szwejczewski et al., 2016). The main information about the sample is provided in Table 6.1. The PGs analyzed, the number of plants in product group networks (i.e., the number of plants where PG1 and PG2 are manufactured), and the number of shared plants are reported. Considering that some product groups are manufactured in only one plant, other in multiple sites, data show that most of the product groups analyzed are produced in more than one plant.

Table 6.1: Overview of the companies

Comp.	Industry	No. of Plants	Respondent	PG1	PG2	No. of plants in each PG networks (PG1 | PG2)	Shared plants
C01	Aluminum for packaging	3	Industrial Director	Packaging cable	Products for food packaging	3 | 2	1
C02	Linen mill	3	CEO	Metric Linen "26"	World's thinnest yarn	3 | 1	1
C03	Steel production	12	CEO Italy	Plates - Sheet metal	Ingots	4 | 1	1
C04	Wood-working industry	3	Plant Director	Hobby carpentry machines	Professional carpentry machines	3 | 2	2
C05	Lighting design	4	CEO	Lamps A	Lamps B	4 | 1	1
C06	High design furnishing	4	General Director	Sink tap - Professional series	Fully customizable tap	4 | 1	1
C07	Commercial refrigeration	11	Plant Director	Food and Beverage exhibitors - not customizable	Remote Refrigerator connected to central cooling unit	5 | 2	2
C08	Filtration in the hydraulic sector	3	Logistic Manager	Filter elements	Filters	1 | 3	1
C09	Textile	7	CEO	Shirt fabric	Fabric for high fashion shirts	3 | 1	1
C10	Steel production	24	Maintenance Manager	Pipeline for water pipes	Extraction well pipes	7 | 5	5
C11	Chemistry	14	COO and Production Unit Manager	Caustic soda	Plurimethylen	3 | 2	2
C12	Mechanical production	4	CEO	Stainless steel pipes	Construction of automated assembly machines	3 | 2	2

6.3.2 Data collection

Semi-structured interviews with single or multiple respondents were conducted. Case research has been highly recommended as an ideal methodology for deepening theoretical and descriptive understanding of complex phenomena in a number of disciplines (Yin, 1994), including operations management (McCutcheon and Meredith, 1993; Voss, 2002). Specifically, 28 interviews were conducted. Data were collected through semi-structured interviews and using a structured questionnaire. The first part of the questionnaire was completed by e-mail before the semi-structured interviews to gather information on the typology of product groups manufactured, the processes used, the relative performance comparing the two product groups, and the company's configuration and layout. Interviews were partially performed through online video meetings due to the mobility restriction imposed by the Covid-19 pandemic. The interviews lasted for approximately 60-150 minutes. The interviewees covered the roles of CEO, COO, Industrial Director, Production Unit Manager, Plant Director, and other managerial positions. Attention was paid to the initial interview protocol as the research progressed to make sure that it was focused on the research questions (Gioia et al., 2013) even to the point of modifying the interview protocol.

Data triangulation (McCutcheon and Meredith, 1993) was obtained through the use of multiple sources of evidence. The case interviews were supplemented with 10 follow-up online interviews and documentary evidence of 75 archival documents (annual reports, media documentation, brochures, observation notes, marketing reports, etc.), which increased the reliability of the collected information (Voss, 2002). The semi-structured interviews were recorded and transcribed verbatim. Each interview transcription and related document were coded and analyzed using NVivo Plus 12.

6.3.3 Operationalizing variables and data coding

Different functions have been investigated. In particular, specific attention has been devoted to Production, Planning, Purchasing, Warehouse and logistics, and R&D. Following the previously prepared protocol, answers were transcribed and checked, and a within-case analysis was performed (Eisenhardt, 1989).

The *first part* of the interview aims at collecting general information about the company. In this phase, the overall structure of the company, its configuration, and the localization of the PGs were analyzed. From a configuration point of view, plants have also been scrutinized to figure out "what is produced and where", analyzing how many plants were involved in the realization of each product group. At an early stage, these questions also served to skim the companies for which the researchers decided not to proceed with the analysis. The tool designed and presented in Chapter 5 served as a starting point, and some of the questions included in the Identification (Chapter 5.4.2) and Mapping (Chapter 5.4.3) phases were also used.

Second, the characteristics of product groups and manufacturing processes in the plant under analysis were investigated. A number of dimensions derived from the literature were used, as shown in Appendix 6.B. In particular, much of the dimensions were derived from several academic contributions synthesized in the work of Roth et al. (2008) in the Operations Management domain. By means of these dimensions, the characteristics of the products made were analyzed and the differences between PG1 and PG2 were verified through the words of people experiencing the phenomenon of theoretical interest (Gioia et al., 2013). Appendix 6.B shows the characteristics of product groups and manufacturing processes in the plant under analysis; five-points Likert scales were used for specific products and processes dimensions to empirically verify the difference between PG1 and PG2. In particular, the characteristics of PG1 were evaluated compared to the performance of PG2 ("-2" meaning that PG1 performs much worse than PG2, "+2" meaning that PG1 performs much better than PG2). Aware that case selection was made by requiring PG1 to be oriented toward a Footloose model and PG2 toward a Rooted model, the researchers checked what the stakeholders' perceptions were about the two product groups.

Third, information related to the analysis of what happens within single functions was collected. Table 6.2 summarizes which are the dimensions analyzed for each function and the detail of the elements investigated.

Table 6.2: Dimensions of interest in the analysis of functions

Functions	Operationalization	Description of what was evaluated
Production	Layout	• Layout of the manufacturing department • Lines, departments, units, batches, flow production, continuous production
	Processes	• Types of machinery used for the two PGs • Processing steps carried out within this plant for the two PGs • Potential overlapping of activities and processes of the two PGs
	CODP	• Customer order decoupling point for the two PGs
	Automation	• Level of automation
	Outsourcing	• Level of outsourced production
	Saturation	• Level of saturation within the machinery and processes
	Formalization	• Level of formalization within the manufacturing department
	Plant autonomy	• Level of autonomy of the production department with respect to the other manufacturing plants
	Staff	• Number of employees working for each PGs • Ease in substituting production employees
Planning	Product portfolio decision	• Who decides the product portfolio • Responsibility for the production planning of the two PGs
	Joint planning	• Presence of joint development of the production planning of the two PGs
	Scheduling	• Presence of scheduling priorities for one of the two PGs • Length of the planning horizon for the two PGs
	Control	• How is production control developed
	Centralization	• Level of centralization for the two PGs • Number of people involved in the decision-making process
Purchasing	Quality level	• Relevance of the quality of the purchased material to affect the final products
	Stock level	• Minimum lot size • Level of stock material
	Typology of supply	• Number and typology of the strategic purchasing (e.g., single, dual, multiple sourcing) • Collaboration vs. competitive markets • Presence and importance of strategic suppliers • Presence and importance of exclusive suppliers
	Centralization	• Level of centralization of the purchasing process

Warehouse and Logistics	Material flow management	• Material flow management within the plant and among the two PGs • Inventory managed internally or not • Use of 3PL - Third Party Logistics
	Inventory costs	• Inventory level of the two product families • Responsibility for the transportation costs to the customers
	Lead Time	• Lead time of the two PGs
R&D	Localization	• R&D localization (only within the analyzed plant, also in other facilities, etc.) • Presence of jointly developed activities or separated activities for the two PGs
	Product vs. process	• Orientation towards product or process innovation
	R&D volumes	• Yearly average number of innovations introduced for the two PGs • Frequency of innovations activities performed in the analyzed plants vs. other plants of the company
	Trigger	• Independent research vs. specific customer-oriented research
	Competences	• Presence of shared or separated employees in the R&D department for the two PGs • Ease in transferring knowledge and in substituting R&D employees

The analysis was carried out with a within-case analysis and cross-case analysis (Eisenhardt, 1989), first analyzing the company structure as a whole and then the individual functions.

The coding started soon after the first cases were developed (Charmaz, 2000). We first collected a considerable amount of information, voluntarily making little effort to distill categories. Later, as the research progressed, we strove to find similarities and differences between the various information collected, taking suggestions from the axial coding di Strauss and Corbin (1998). Lastly, in trying to finalize the analyses of the data, we revisited the data and engaged in mutual discussions with the respondents to enhance the understandings and arrive at consensual interpretations (Gioia et al., 2013).

6.4 Results

6.4.1 Managing functions in dual role plants

This paragraph focuses on the operational and organizational practices within the analyzed plants, analyzing what happens in each function. The objective is to show both the general trends and the specificities that characterize the analyzed cases. The first aspect to evaluate is the physical layout of the workplace and the allocation of staff. We defined a function as *disjointed* (i.e., *not shared* between the two product groups) in two cases: if there is a) a clear separation about the physical infrastructure or the personnel or b) in case of different management models.

In the case of physical separation, a function is considered disjointed if approximately more than 75% of the equipment (in terms of locations, machinery, facilities, lines, etc.) is separated. Sometimes the functions are managed in the same physical location or without clearly defined physical boundaries, but the staff allocated to the two PGs is different; in this case, the function is considered as disjointed. In the case of staff separation, departments are considered disjointed if approximately more than 50% of the staff is separated.

As an alternative, the function has been considered disjointed also in the case of distinct management models, i.e., when the control between PG1 and PG2 (supervisory structure, KPIs used, etc.) is dissimilar and not jointly run. This evaluation was carried out by the researchers following the first meetings and subsequently validated by the interviewees. Vice versa, the function has been considered as shared. Table 6.3 describes the distribution of separated functions in the sample.

Table 6.3: Disjointed functions

Functions	**C01**	**C02**	**C03**	**C04**	**C05**	**C06**	**C07**	**C08**	**C09**	**C10**	**C11**	**C12**	**Total**	**%**
Production	**D**	s	**D**	s	**D**	s	**D**	**D**	**D**	**D**	**D**	**D**	9 / 12	75%
R&D	s	s	s	s	s	s	**D**	**D**	s	s	**D**	**D**	4 / 12	33%
Planning	s	s	s	s	s	s	s	**D**	s	s	s	**D**	2 / 12	17%
Purchasing	s	s	s	s	s	s	s	s	**D**	s	s	S	1 / 12	8%
Warehouse and Logistics	s	s	s	s	s	s	s	s	s	s	s	S	0 / 12	0%

S = Shared function; d = Disjoint function

- Production

The production department is the area where the most significant differences are observed in managing PG1 and PG2. Often PG1 requires a structured, consolidated, and not flexible process. PG1 is relatively standard within the industry, or it represents products that have been manufactured for several years using the same procedures. On the contrary, PG2 is a product that tends to be more recent, technologically complex and, most of the time, it requires non-standard technologies. Typically, PG2 requires higher customization and higher variability of lot sizes. The production is often not shared (75% of cases). Only in three cases (C02, C04, and C06), production is shared: this happens when PGs have a relevant part of the production process in common and differ only in the final steps of customization or in marginal operations. Sometimes, the area is organized as a “function-within-the-function", with complete separation and no contact points. In C01, the industrial director notes that "PG1 has a separate production department, managed separately. For the cables sector, the manufacturing is managed as a small factory in its own". There is a certain variety in the type of processes, mainly according to the industry of reference. Usually, the production configuration (flow, lines, departments, etc.) is the same in PG1 and PG2, with some exceptions. In C12, for example, the respondent confirms the presence of a situation where "there is a production line configuration for PG1, with low flexibility and high productivity. For PG2, there is a dedicated function, with a configuration aimed at high flexibility (Job shop)". Requiring specialized skills, PG2 is often realized only in one or two plants within the company, while PG1 is more distributed.

- R&D

Four companies (33% of the total) differentiate the R&D department for PG1 and PG2. In general, the larger the company and the more distinct the product groups are, the more significant is the difference between R&D conducted on PG1 on PG2; this is not only related to the physical separation of offices, but also to objectives, procedures, and people. The costs and effort of R&D are much more oriented to PG2. In almost all the cases, R&D is directed to the “process component” for PG1 and the “product component” for PG2. In some plants (e.g., C10, C01), the division of R&D is not based on product groups, not even on plants, but on processes: C01 has an R&D office for the production of aluminum foils and an R&D office for the converting phase, C10 has R&D in different geographical areas on macro-processes to respond to the specificities of local requirements. Sometimes, R&D is centralized in HQs or in other plants, and research is carried out only for peculiar requirements. In other cases (C07), R&D is separate for product families, in addition there is also non-product-specific research carried out in a different plant than the one analyzed. Regarding the objectives, PG1 has mainly internal motivations, and the research is carried out independently, PG2 instead addresses the customer's requests on detailed specifications.

- Planning

Different approaches have emerged in planning; for example, in case of partial overlapping among processes, sometimes PG2 is prioritized while PG1 can only saturate remaining availability. This behavior usually happens when the economic value of PG2 is higher than PG1 given the same output (for example, the PG2 of C02 is sold at 30 times the price of PG1 given the same volume). In some cases, PG1 has priority as a standard product because the time required by the customer is shorter, while PG2 can be delayed as the customer is willing to wait. In most cases, the planning is conducted by the same central office; there is no physical separation of offices (co-location), and the people involved are the same. PG1 and PG2 are linked due to the partial overlapping of machines, operators, or processes. Especially in transnational companies, decisions about what to produce often come directly from the company's HQ (which is a different factory than the plant analyzed). The allocation of production is based on what is decided at the network level, also according to the availability or need of other plants. Vice versa, in C08 and C12, there is a clear separation between the two offices (17% of the total).

- Purchasing

The structure of the purchasing office, the level of centralization and the strategic choices of the companies when selecting suppliers were investigated. The office structure is almost always shared between PG1 and PG2; many times, specific product-related purchases represent only a marginal part of the whole, and separated functions would entail more disadvantages than benefits. Only in one case (8% on the total), a separate purchasing office is dedicated to a leading customer of the international high-fashion industry (C09). Almost all companies prefer multiple sourcing in a competitive market. Some plants present exclusive suppliers on particular categories of products. It should be noted that the incidence of incoming product quality is high, especially for PG2, where companies select specialized suppliers with high levels of expertise. In terms of centralization, there is often a central office that provides guidelines and objectives. On average, the level of centralization (Hult et al., 2000) is high.

- Warehouse and logistics

In all the cases analyzed, the warehouse is shared. Sometimes, there is a common area for the semi-finished and intermediate products of both PGs and dedicated storage areas. The PG1 often works through stock material. PG2 usually has a limited amount of stocks (PG5, PG7, PG13, PG14), or it cannot work with stock but needs finale customization before being sold (PG10). Data analysis shows some situations in which the warehouse is centralized in another plant (C06), or it is fully managed through Third-Party logistics (C01; C11, that deals with the production of potentially dangerous chemical products). Regarding the CODP, a make-to-stock (MTS) approach for PG1 and a make-to-order (MTO) approach for PG2 were found in almost all the cases. The lack of personnel dedicated to individual product groups and the presence of similar procedures in managing orders can sometimes lead to problems. For example, in C07, the stock material is managed entirely through an MTO approach. This simplifies processes and operations; however, respondents told us that "PG1 should be managed through MTS. For corporate decision, both the PGs are managed in a similar way”. This challenge will be better analyzed in the next paragraphs.

Although the strict requirements in the case-selection process, it is noticeable in the sample a continuum between companies with products and processes undoubtedly divergent and companies with a less pronounced diversity between the product groups. For example, in C02, the difference between PG1 and PG2 derives from the use of specific materials and the customization of PG2; however, processes and final products are relatively similar. Vice versa, the difference in C12 is much more evident, both for the product (machines and pipes) and for the processes used.

If we analyze the differences between PG1 and PG2 according to the product and process characteristics, a matrix similar to the one by Ferdows et al. (2016) - i.e., a matrix that has the degree of similarity of the products and the degree of similarity of the processes on the two axes (Figure 6.1) - can be built. The differences among PG1 and PG2 for the investigated companies are derived qualitatively from the information provided by the respondents and supported by some of the values of Table 6.3. In Figure 6.1, the size of the represented dot represents the number of functions that are disjointed, i.e., that are physically separated.

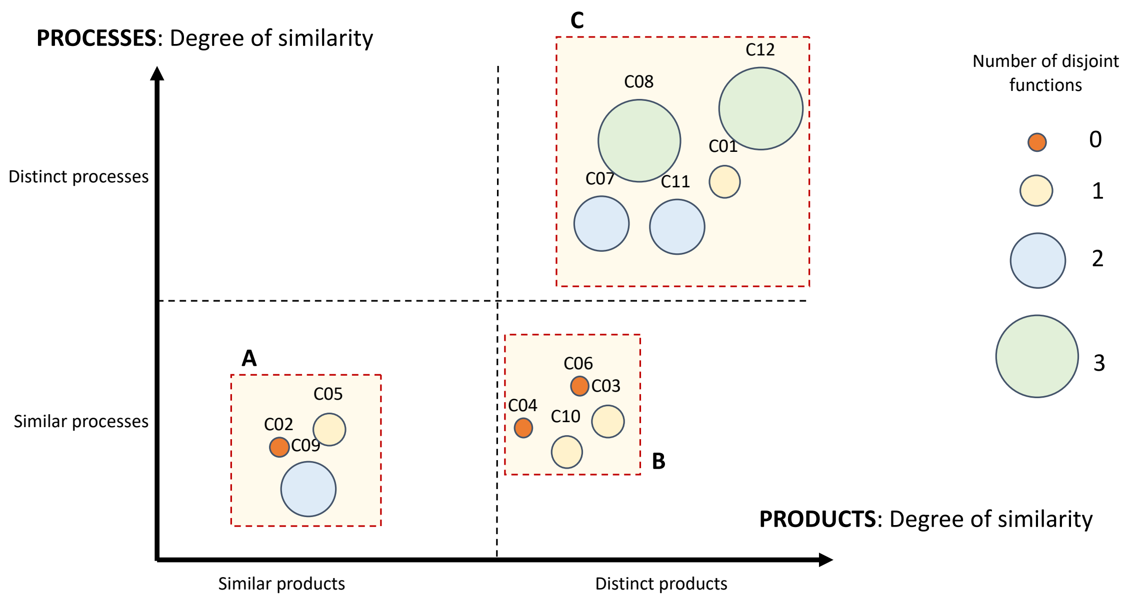

Figure 6.1: Matrix of product- and process-related dissimilarity between PG1 and PG2

The number of disjointed functions goes from 0 (all the functions are shared) to three. Theoretically, the quadrants on the main diagonal should be the most populated. This is consistent with the assumption that similar products tend to be made by similar processes (bottom-left quadrant) and that different products tend to be made by distinct processes (upper-right quadrant). Furthermore, it is also intuitive that distinct products could be manufactured thanks to similar processes (bottom-right quadrant), for example, when the differences between PG1 and PG2 are determined by few final manufacturing processes. Despite the limited number of cases, some interesting findings emerge from Figure 6.1. The *first* aspect is the absence of cases in the upper-left quadrant (distinct process with similar products). *Second,* although the number of cases is limited, we observe some differences across the quadrants:

1. *Cluster A*. Companies with relatively similar products and relatively similar processes (C02; C05; C09): these are companies that make products aimed at the fashion or design industry.
2. *Cluster B*. Companies with different products and relatively similar processes (C03, C04, C06, C10): these are companies whose operations are similar (at least partially) and often shared. Usually, the processes are strongly different only in the last production steps leading to products with significantly different characteristics, or the processes are similar in the plant analyzed, but they differ in the upstream and downstream processing.
3. *Cluster C*. Companies with very different products and very different processes (C01, C07, C08, C11, C12): they are really contrasting plants, which produce two very different finished products through processes that have no or limited points of contact in the analyzed plant.

Third, it seems that the specialization of the functions (i.e., the diameter of the dot in the matrix) increases as the difference between groups of products and between production processes increases. In other words, it seems that the companies favor disjointed functions when moving from the lower to the upper part of the matrix. Despite the limited sample, this behavior might suggest that the dissimilarity of processes (and products) is a criterion for companies to decide on shared versus separated manufacturing units. Specifically, in Cluster A and Cluster B, there are mainly cases with zero or one disjointed function; in cluster C, almost only cases with two or three specialized functions. Interestingly, no cases with more than three specialized functions were found. This configuration seems to suggest that a company tends not to diversify processes and functions for various reasons (for example, to benefit from economies of scale, not to alter employees' competencies and capabilities too much, etc.), up to the point in which the differences between product groups become too significant requiring two separate plants for PG1 and PG2.

There are two anomalous cases within the matrix: C09 in the first cluster has two specialized functions, specifically production and purchasing; this configuration is due to a leading customer operating in the luxury sector that requires a private channel and dedicated planning phase. There is a dedicated team both in the production and in the planning phase. The necessity is to assure higher quality and a preferential way to manage emergencies (shorter lead times, unexpected increases in demand, etc.). Instead, C01 has only one separate function (production) despite being in cluster C. The plant analyzed is the one where the complete separation between PG1 and PG2 takes place, i.e., where the production processes (never shared in this plant), lead to two completely different product groups. However, all the rest of the processes, upstream and downstream, are handled in a very similar way: both PGs are derived from raw aluminum coils, they arrive from the same factory, are sold and shipped in a similar way.

These observations might lead to a further consideration: there are exogenous factors that influence whether or not to separate functions in a multi-product plant in addition to the differences between products and processes. These factors may be of a different nature, such as the need to respond to multiple markets, the requirements of a particular customer, or the supply chain structure. It can be deduced that the separation of functions is not exclusively based on intra-plant considerations but on higher network-level considerations. To delve deeper into this issue, Figure 6.2 represents a matrix where the difference between the two product groups is represented on the horizontal axis (keeping a qualitative measure that synthesizes the two axes of Figure 6.1), and the number and type of *disjointed* functions are represented on the vertical axis. The four areas highlighted on the vertical axis indicate the number and type of *not shared* functions. Cases are mapped over this matrix.

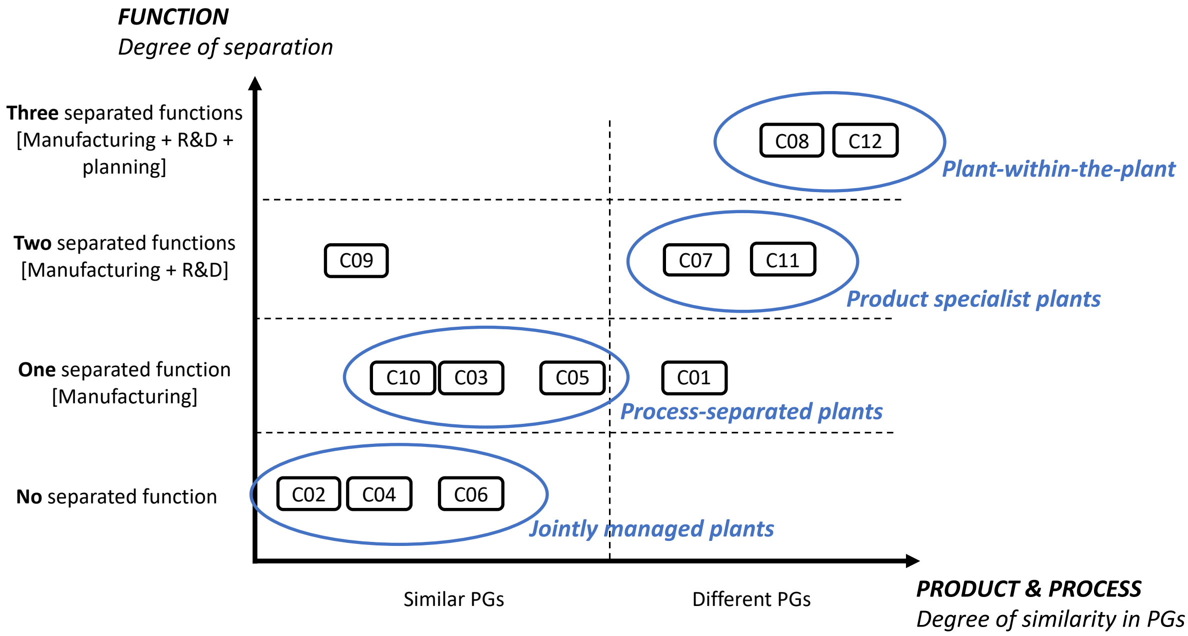

Figure 6.2: Disjointed functions based on PGs characteristics

Figure 6.2 allows us to give an interpretation of the higher or lower degree of separation of plants, categorizing a series of stages of diffusion:

a) *Jointly managed plants*: all functions are shared. The cases in this situation have standard (PG1) and customized (PG2) products, but where the difference is not sufficient to justify the separation of any function. Production lines are sometimes shared, sometimes not shared between PG1 and PG2, but in any case, they are managed within the same physical area and often by the same employees. PG2 usually has some initial production steps that are the same as PG1, and then some additional production steps to customize the products.

b) *Process-separated plants*: only the production department has an identifiable separation. Warehouse, purchasing, and planning offices share physical spaces, although with the possibility of having a partially dedicated staff. R&D labs, if any, are centrally managed and shared.

c) *Product specialist plants*: In addition to manufacturing, the R&D department is also separated between PG1 and PG2. Manufacturing and R&D are the two departments that first impact product and process characteristics. This is the configuration of companies that need in-house R&D aimed at achieving meaningful levels of innovation within the plant, especially on PG2. Notably, there are no cases with Production + Planning (without R&D).

d) *Plant-within-the-plant*: it is the highest level of disjunction among functions in the plant, with three or more separated functions. Usually, manufacturing, R&D, and planning departments are not shared between the product groups. Other departments could also be split up, depending on the specificities (for example, the sales office). Most of the plant's operations are effectively duplicated, with a separation of personnel over the PGs and a high specialization of skills and know-how. This configuration is similar to a *plant-within-the-plant* solution. It is the last step before the creation of a stand-alone factory.

This categorization in different stages uses the number of functions separately managed as a proxy of a plant's level of specialization over its product groups. Despite the simplification introduced, the categorization offers an interpretation of the degree of function collaboration within a production context. Interestingly, there is a pattern with which companies diversify their functions when they are engaged in a double productive role; the four stages of diffusion are positioned along the diagonal, excluding the outliers discussed above.

The discussion offers a new angle to the question "how should processes be designed?", already addressed by other studies in a multi-production context (e.g., Bengstonn et al., 2007). In particular, an alternative to manage *cross-functional integration* (Kahn and Mentzer, 1994; Maltz and Kohli, 2000) is offered, enriching the contributions through a plant-level perspective.

6.4.2 (Multi-)Role of the plants and subnetwork perspective

While a plant-oriented focus has been offered up to now, this paragraph analyzes the results by focusing on a sub-network perspective, discussing the consequences of the presence of two (or more) subnetworks of different nature that overlap in the same factory.

The problem of managing multiple manufacturing missions in IMNs has already been addressed by Ferdows et al. (2016), who proposed the manufacturing subnetworks as an alternative solution to simplify the management of the network. Following the same approach, also in this sample, some *subnetworks* (Ferdows et al., 2016) or, more generally, *product-group networks* (Feldmann and Olhager, 2019) can be identified, similarly to what has been done in Chapter 4 and Chapter 5.

The focus will be on companies with a reasonable number of plants. The division into subnetwork is arduous with some of the cases in the sample, due to the small size of the number of plants. In some cases (C02, C03, C05, C06, C08, C09), PG2 is realized only inside one plant, therefore not qualifying itself as a real sub-network. Vice versa, other cases (C04, C07, C10, C11, C12) show product-group networks with similar size to previous studies (Feldmann and Olhager, 2019). For instance, in C07, the product groups considered are produced in 5 and 2 plants, respectively (11 plants in total). In both plants where PG2 is made, PG1 is also produced. In C10, the two product groups are produced respectively in 7 and 5 plants, with a complete overlap determined by a strong process integration (process-industry). In C01, C11, and C12, PG1 and PG2 are made in 3 and 2 plants, respectively.

What discussed so far has significant evidence in a subnetwork perspective because it points out evidence of the partial overlapping of (even different) product-groups networks within the same plant. In this context, the research has always been interested in decisions on "where to produce what" to optimize network choices (Cheng et al., 2015). The localization decisions related to which processes are carried out in which plants have been among the most tackled issues over the last decades. However, previous studies that analyzed groups of plants in an intra-network perspective have often divided the factories according to the manufacturing mission and the product realized, in a product-oriented strategy perspective (Friedli et al., 2014), assigning one product (or product family) to each site.

Furthermore, as already highlighted, some cases more than others exhibit noticeable differences between PG1 and PG2. In particular, the plants positioned in the top-right quadrant of Figure 6.1 strongly respect the characteristics studied by Ferdows et al. (2016) and Feldmann and Olhager (2019) and their categorizations in production networks. To provide a relevant example, let's focus on C07: the company is sufficiently large in terms of the number of plants to justify a segmentation in subnetworks. The considered product groups are exhibitors - not customizable standard products in the electronic industry (similar to a footloose model) - and remote refrigerators - one-of-a-kind, technologically advanced products for the company (similar to a rooted model). Therefore, the plant in C07 contains an overlap between two subnetworks (one more rooted and one more footloose) with very different characteristics in two of the five plants analyzed.

From a theoretical point of view, previous studies support the idea of rooted and footloose subnetworks having really different characteristics. A rooted subnetwork and a footloose should be composed of plants with different skills (high-tech manufacturing for rooted, less technologically advanced for footloose), they should have a different configuration (need of stability and expertise in rooted, need of low-cost countries in footloose) and different management models. Moreover, in rooted subnetworks, the complex and proprietary production processes should be frequently reinforced (Ferdows, 2009; Pisano and Shih, 2012b; Vereecke et al., 2006), while footloose subnetworks stress production costs minimization. Golini et al. (2017b) hypothesized that the footloose subnetworks are more prone to have low complexity, medium-to-high levels of formalization and centralization, low to average competencies, and an absence of leading plants. Vice versa, rooted subnetworks should be characterized by higher complexity, low-to-average formalization, and centralization, a higher level of competencies supported by one or more leading plants. However, the presence of such different technologies, processes, and products in the same plant is ambiguous: in these kinds of plants with a twofold and conflicting manufacturing mission, which features are closest to a rooted model, and which are closest to a footloose model?

To provide an answer, in Table 6.4 the characteristics of C07, C11, C12 (the three most suitable companies to evaluate the characteristics of subnetworks) have been detailed, taking into account some dimensions used by Golini et al. (2017b). Table 6.4 creates a division between the aspects closer to a rooted model and the aspects closer to a footloose model. Specifically, three macro dimensions were analyzed: the location of the plant and the underlying reasons for the choice; the structure and operating procedures; the level of expertise (know-how, knowledge network, etc.).

- *Location and driver for establishment*: there are conflicting reasons for the plants' location, i.e., some leaning towards a solution close to a rooted model, others closer to a footloose model.
- *Plant structure and operations:* there are contrasting aspects on procedures as well. For operational activities within the plant, a high level of formalization - i.e.,

standardization through procedures, rules, norms (Beyer, 1981; Daft, 2012; Mintzberg, 1979) - and centralization – i.e., centralized decision making in the subnetwork (Daft, 2012; Mintzberg, 1979) - is observed on all three PG1s. This is in line with what Golini et al. (2017) hypothesized, and it addresses the need for coordination and economies of scale. In contrast, PG2 is characterized by less centralization and higher inherent complexity, both in terms of technologies and customization. The difference in the manufacturing objectives of PG1 and PG2 is managed in all three cases by "separating" production.

- *Competence:* Regarding the level of competence, aligning with Ferdows et al. (2016) and Golini et al. (2017), one might expect a low level for footloose networks and a high level of competence for rooted networks. However, the establishments under investigation tend to have a medium-to-high level of expertise, even for PG1s. This can be caused by several reasons, for example, the need to make a more technologically complex product as a PG2 in C07, or the presence of chemical processes in C11.

Table 6.4: Rooted versus Footloose characteristics

		Characteristics closer to a footloose model	**Characteristics closer to a rooted model**
1. **Location and driver for establishment**	C07	• Need to have low delivery times for Europe. Proximity to market. • PG1 also has plants in other areas (China, Turkey) for the above-mentioned reasons and to take advantage of lower production costs.	• Both plants producing PG2 are in Italy. High stability. • Access to skills and highly qualified workers.
	C11	• The plant was built 110 years ago, given the proximity of the plant to the raw material.	• Access to skills and knowledge is critical for both PG1 and PG2. • The company has high stability in plant locations, mainly due to the long time required to train staff.
	C12		• Proximity to market (plant located in the heart of Europe; PG2 sold mainly in Italy). • High stability is linked to historical reasons ("it has always been produced here") more than to specific drivers.

2. Plant structure and operations • Formalization, Centralization, Complexity • Manufacturing objectives	C07	• High formalization and automation, especially in the downstream procedures for the 60000 units produced. • Focus on process improvement on both PG1 and PG2. • Very low autonomy. The headquarter decides at production level for each plant (even the planning). Autonomy is very low on products, a little higher on the production process.	• For PG2, automation reduces as you move toward final processes to facilitate flexibility in assembly. • High integration, full in-house production. Low-to-no outsourcing for both PG1 and PG2. • MTO approach for both PGs despite PG1 is more apt for an MTS approach.
	C11	• PG1 realized with a fully separate cycle from PG2, machines never overlapped. • High formalization and centralization. • PG1: Focus on getting the outcome done (production), low level of innovation.	• Need for full integration of production for both PG1 and PG2.
	C12	• Production is divided for the two product groups. • Line-production for PG1, with low flexibility and high productivity. • Focus on the process for PG1. • Interestingly, they are considering outsourcing some of the components of PG2.	• Focus on the product for PG2. • There is a dedicated department for PG2, with a configuration aimed at high flexibility (Job Shop). • Low level of automation and formalization on PG2.
3. Competence • Plant's and subnetwork's level of competence • Knowledge flows with other plants	C07	• R&D is not on the single PG but on the process, in particular the upstream phases. Mother plant with a long history (even before the company's acquisition) and proximity to the HQ.	• Cutting-edge technical expertise for engineering and assembly of PG2 • The PG2 plant is the technological and information center. • Creation of new processes and products for the whole company.
	C11	• The production process is the result of twenty years of research and is basically optimized. Nowadays, little research is done only on processes (No product-related research).	• Know-how difficult to replicate, especially in production. • The staff has agreements not to disclose key information (limit competitors). • Very high barriers to entry (high costs and knowledge needed).

	C12	• In PG1: easily replaceable employees, established manufacturing skills. • Low product variability PG1.	• High specialization for PG2. High-level expertise in engineering, design, machine design. • Simple process development (Meijboom and Vos, 2004). • Flow of information (and Innovation) from PG2 to PG1 for maintenance and development of PG1 production lines.

		Role when considering PG1	Role when considering PG2
Plant strategic role	C07	Server Receiver/Hosting	(Almost) Lead Active
	C11	Server/Offshore Isolated/Receiver	Lead/Contributor Hosting
	C12	Server Receiver	Lead/Contributor Active

The empirical results also prompt to draw some considerations about the role of the plant. The last part of Table 6.4 highlights the plant typologies for C07, C11, C12, according to the plant typologies of Ferdows (1997) and Vereecke et al. (2006), and the measurement tool introduced by Meijboom and Vos (2004). There are some clear cases in our sample where the goals and the manufacturing objectives vary between PG1 and PG2.

C07: For example, in C07, PG1 is produced in five plants globally (in Europe, the US, Middle East) to remain close to the final market. Instead, for PG2, transport costs are not that impacting compared to margins, so the company chose two European factories for producing PG2 for a matter of skills and expertise. If we rely on the Ferdows model (1997), the analyzed Italian plant might represent a *server* role for PG1 (proximity to market and low site competence) with a “hosting network player” due to the frequent and extensive exchange and communications with other plants into the subnetwork related to PG. Instead, it would represent almost a *lead* role as for PG2 (access to skills and knowledge and high site competence, with product and process development).

C11: According to the information gathered, the plant in C11 would also be characterized by a role with a medium level of competence at the plant level if PG1 is considered (the result of years of experimentation leading to an established product, but little recent research). The strategic role when considering PG2 is above a *contributor* role (Meijboom and Vos, 2004), in the sense of possessing slightly more competencies than a contributor has by definition. Despite not being in charge of the development of new products and processes except for PG2, it combines a high level of know-how and a very high technical specialization, with particular attention to intellectual and patent protection.

C12: PG2 offers know-how and technological solutions to PG1, which therefore assumes a predominantly *receiver* role. PG2, on the contrary, plays an active and lead/contributor role.

Therefore, a first result that can be deduced is the potential presence of *multi-role plants* in the manufacturing network. Most of the literature on the role of the plants (e.g., Cheng et al., 2011; Demeter et al., 2017; Feldmann and Olhager, 2013; Ferdows, 1997; Szász et al., 2019; Vereecke et al., 2006) has studied the plant using a unique manufacturing mission, thus, a single role for each plant. The overlap between different product groups (assured by the way the sample was built) implies that different roles can characterize the two product groups. This is also visible from the conflicting objectives in manufacturing mentioned above. Second, the role of the plant is different between PG1 and PG2: the role of the plant is often influenced by the second PG in the plant or, more generally, by the other activities carried out in the plant.

6.5 Discussion

The issue of managing different roles within the same plant is both complex and challenging. These twofold or multiple roles of a manufacturing plant has sparsely been mentioned in the literature (e.g., (Feldmann and Olhager, 2019; Ferdows, 1997; Vereecke and Van Dierdonck, 2002) without the declared goal of highlighting different roles in facilities where two or more distinct product groups are produced.

Some of these studies have highlighted how the strategic role of a plant can vary over time in a dynamic perspective (Meijboom and Vos, 2004), describing the possible changes of the plants through an increase of the site competencies. The theme of competencies is strongly linked to the role of the plants. Several contributions have linked the role of the plant with the theme of capabilities and their dissemination within the network (e.g., Feldmann et al., 2009; Meijboom and Vos, 2004; Szász et al., 2019). In accordance with Blomqvist and Turkulainen (2019), a limited presence of low level strategic roles (Vereecke and Van Dierdonck, 2002). While in PG2 a high level of expertise is conceptually justified by the products and processes produced, in PG1 we would have expected a lower level of expertise and know-how. Instead, also considering the part related to PG1, the competencies tend to be higher than what is expected in a footloose subnetwork. On the one hand, this could be due to the growing trend of outsourcing of non-core manufacturing activities (Dabhilkar and Bengtsson, 2008; Gray et al., 2013). But first, the interplay that occurs within the plant between the elements related to the two subnetworks involves a transfer of expertise from one PG to the other. As detailed in chapter 4.2., in order to produce all the products with full-range processes, competencies must be aligned to meet the most technologically advanced side. Although all three plants analyzed exhibit clear separation in their key departments (production and R&D in C07, C11; production, R&D, and planning in C12), there is an influence between PG1 and PG2. Also in the literature, great attention has been paid to the fact that plant roles are mutually influential from one plant to another. For example, Cheng et al. (2011) demonstrate that changes in product or process within a plant have an effect within the same network by altering the strategic roles of the plants, and causing, in turn, adjustments of the network itself. In the typology of plants that we have analyzed, this fact seems to be even more emphasized. For example, the flow of tangible and intangible between PG2 and PG1 can influence one over the other, thus altering their roles.

With respect to this and taking the whole sample into consideration, some issues in managing operations have emerged due to the influence of PG1 on PG2 and vice versa. The identified critical issues have been highlighted several times within the cases and present a marked contrast to what happens in plants that typically produce only one category of products. The collected evidence allows to identify three main areas of criticality:

- *Contamination of quality*: the first problem is that the plant produces the two different product groups with a similar quality level. However, the market requires PG2 to have a higher qualitative level than PG1 (thus, the customers are willing to pay more for PG2). Despite not being recognized or required by the market, this causes delays, higher lead times, higher expenses without an economic return. Conversely, there is the risk of treating PG2 with the same care, quality, and final product timing as PG1. Instead, higher quality must be granted, or the production complexity is higher and needs a different treatment. For example, in C03, PG1 is characterized by low margins and quality standards in line with those of the market; the company strives to exploit economies of scale, producing high volumes and focusing on cost reduction. Vice versa, PG2 is sold at high prices compared to the market, focusing on too high quality (on PG2 refunds for manufacturing defects are up to 11 times the value of the product) and unique technical features. However, sometimes there is a tendency to produce PG2 with a quality not perceived by the final market, at the expense of production time and costs. Vice versa, the risk can also occur in the opposite direction: sometimes, plants present the risk of producing PG2 with qualitative levels similar to PG1; this affects the quality of the product and makes the PG2 less attractive on the final market. It can be an unwelcome effect when generated by an incorrect plant configuration and not by a deliberate strategic choice. In C07, the respondents pointed out that the number of defects found during quality control in the plant under observation is higher than in another plant where PG2 has no overlap with other product groups.

- *Conflicting manufacturing objectives between PG1 and PG2:* the two PGs work with different manufacturing objectives and with different strategies: PG1 usually aims to maximize production volumes, while PG2 aims for high-quality products and customization for the customer. The asymmetry, especially in the case of sharing (even partial) of the production processes, can lead to complications in managing the plant. For example, respondents in C06 explained that "while profit for PG1 is generated by high volume production, PG2 is based on the quality of final goods. This can become a problem in management and strategies. A product like PG2 requires a high flexibility of machinery and resources. A product like PG1 requires high volumes and, therefore, a saturation of the plants.".
- *Different decoupling points for PG1 and PG2*: the third criticality is related to the management of CODP, i.e., the level of customization that triggers the production activities. In our sample, companies often position the decoupling point further upstream for PG1 and further downstream for PG2. There are some examples of assemble-to-order (ATO), one of engineering-to-order (ETO) (C12 on PG2), but in most of the cases, PG1 is managed with an MTS approach (8 out of 12), while PG2 with an MTO approach (10 out of 12). While literature notes that there is typically one dominant CODP along with

the entire supply chain flow (Olhager, 2010), most of the companies in the sample have a decoupling point for PG1 which is different than the decoupling point for PG2. Despite not being aligned, the two CODP should be consistent with the market requirements and fully support the characteristics and objectives of each respective part of the supply chain. This implies a higher complexity of the investigated plants in managing orders, planning the production, and organizing supplies.

It is not our goal to try to understand how these subnetworks are managed. However, the research brings evidence to the potential mismatch to be handled: the coexistence of different subnetworks to which the literature has attributed contrasting management models might create tension within the plant. This paper can represent a first attempt to address Golini's call for new empirical research. The research deserves further investigation. Although without an empirical justification of performance, our work partially supports the work of Ketokivi and Jokinen (2006) in highlighting the complexity of managing unfocused factories in international scenarios.

6.6 Conclusions

To summarize, this paper offers an empirical contribution to the literature about manufacturing management through twelve case studies carried out in international manufacturing networks. Our research strives to fill the link between inter-firm and intra-firm relationships (Cheng et al., 2019), analyzing how a plant engaged in the production of more than one different product-groups is managed.

It has been mentioned extensively how the literature has instilled the idea of "focused is better" (Skinner, 1974), even exposing the disadvantages of having an unfocused plant. While many contributions on focused factory advocate that having multi-production objectives causes lower performance (Brumme et al., 2015; Hayes et al., 2005; Skinner, 1974), our work investigates companies where the twofold objective is a choice. Our research does not ask whether a focused solution is better than an unfocused, instead, it intentionally chooses to target unfocused solutions.

It has been explored how companies can organize their internal structure, exploring a range of solutions, going from an integrated one with shared functions to real plant-in-the-plant solutions. The contribution examined how the various departments within the same plant articulate their work according to the different product groups produced. An analysis has been carried out in the most relevant business areas (manufacturing, R&D, planning, purchasing, Warehouse, and logistics), highlighting the most typical features and the differences between PG1 and PG2. Furthermore, the exploratory contribution offered by this work leads to a greater awareness of the possible coexistence of multiple roles, therefore, the need for tools aimed at their systematic identification and their evolution over time, in line with recent contributions (Corti et al., 2014). In general, although models to manage the individual role of plants have been numerous over the years, as well as the proposed categorizations and taxonomies, one of the literature gaps is the fact that contributions suggesting the dual plant role are very scarce (Feldmann and Olhager, 2019) and not supported by empirical evidence. In addition, previous studies have pointed out that we actually know quite little about plants with different strategic roles in terms of the ways they are managed (Cheng 2018). Our initial contribution can provide a significant boost to the literature, trying to fill the voids in this area.

This work further enriches the literature on subnetworks offering some noteworthy contributions to the literature. Some takeaways can be drawn from this paper.

First, a common trend in separating functions exists in the analyzed sample. It seems that the more the products and processes differ, the greater is the specialization of the functions. By mapping the degree of similarity of products and processes, it is shown that the companies where there is a higher number of non-shared functions between PG1 and PG2 are those where the difference between product groups is more remarkable (in terms of the technologies used, the specificity of the processes, the difference in the strategy followed). The production department is the one that is divided first, followed by R&D, and then by planning and other functions. A qualitative representation and a categorization of the four stages of function separation are offered. In some cases, real *plant-within-the-plant* solutions have emerged, with a considerable separation of most of the operations.

Second, factories can have more than one "plant role" (Ferdows, 1997) role in the plants due to the presence of more than one subnetworks. Some plant features were found to be closer to footloose models and other features closer to rooted models. In the cases analyzed, PG1 acts mainly as a receiver, and the plants have a high or medium-high level of knowledge. The presence of multiple roles within the same plant also leads to misalignments and critical issues, largely due to interactions within departments.

Third, some critical points have to be addressed when managing different production objectives within the same factory. Specifically, three main criticalities - the potential quality contamination, the presence of conflicting goals in productions, the need to manage different levels of customization – have been recognized by managers.

A deep understanding of the type of role for each plant is not a goal of this paper. However, further research can find interesting insights by applying the contributions from a perspective of double manufacturing objective, also in relation to the different stages of functions' separation highlighted above. By examining plants with dual roles, it is possible to build greater optionality in the network structure and accommodate the changes of the production plan from a perspective of "dynamic switching of roles" (Bengtsson et al., 2010).

6.6.1 Limitations and further research

The paper provides a case-based analysis with a heterogeneous sample. This is in line with the exploratory approach adopted (Karlsson, 2016; Voss, 2002) but hampers the generalization of results. Only a few cases suggest rooted and footloose models with a relatively high number of factories. Further studies could investigate this topic providing additional empirical support.

The management of a plant with a twofold manufacturing mission deserves further attention. Future research might explore what drives managers in defining the plant strategy: is it the real difference in terms of technology and know-how in PG1 and PG2, or is it the way the company perceives and evaluates the product group? Furthermore, concerning the framework in Figure 6.2, this research has described the different stages of diffusion based on the degree of separation of the plants' functions and the differences between the product groups manufactured. However, further developments could regard the categorization of the specific characteristics of these four stages, also according to the possible evolution of the stages over time.

Further contributions could also be directed to the analysis of the management models for a plant being part of two distinct subnetworks, as emphasized above. The hybrid role of the plant engaged in multi-production tasks is still ambiguous: what are the necessary skills and competencies? What is the best approach in terms of configuration? Is it better to localize factories in low-cost countries or high-tech but high-cost countries? The reflection opens up interesting theoretical and operational perspectives. Future contributions could integrate site competencies and the overlap of different product group networks in the same plant, answering the call for further research in the IMN domain (Feldmann and Olhager, 2013).

Appendix 6.A: Sample description

Appendix 6.A.1: Company's characteristics and product groups manufactured

Company	Description
C01	Production of aluminum laminates in different sizes, with varying thicknesses depending on the destination. Totally integrated production, the company takes care from the aluminum fusion to its realization in laminates. Products do not have machines and productive operators in common unless in the upstream phase. • PG1: Aluminum foil used in the telecommunications sector. • PG2: Ultra-thin and customized aluminum foil for the confectionary sector.
C02	Linen mill with an integrated and 100% European supply chain. 4.5 million kg of yarn produced annually. Customers are weavers, knitters, garment makers, and the entire distribution sector. • PG1: metric linen "26". Standard processes in the textile industry. Costs are much lower than PG2. • PG2: linen metric "110", the finest yarn in the world. Made exclusively in Italy also to take advantage of the "Made in Italy". High-quality product.
C03	Steel processing company. The European division employs around 2,000 people at its production facilities in Belgium, Denmark, France, and Italy. The end customers are mainly large production companies in the automotive, shipbuilding, construction, and energy sectors, as well as manufacturers of offshore wind turbines. • PG1: Plates (sheet metal). It is considered a commodity. The main cost factor is the raw material (70% of the final price). The main target is high volumes. • PG2: Ingot cast with defined chemical definition and hot-deformed by forging. Sold directly to the market or further processed by forging for other plastic deformation. Small volumes, high quality, and service.
C04	Machinery and industrial components in the woodworking industry and part of a group of companies with more than 4,000 workers operating in all five continents. Three major production centers in Italy. • PG1: Hobby carpentry machines. • PG2: Professional carpentry machines, highly customized
C05	One of the global leaders in the lighting industry. Development of innovative solutions for architectural lighting design in the museum, retail, and outdoor sectors. • PG1: Lamps A. Mostly produced externally, consolidated product. • PG2: Lamps B. Completely produced internally. Distinctive features: design, innovation, high technological content. Very long testing and engineering phase.
C06	Production of plumbing fixtures, faucets, drainage columns. Four production sites, sales in over 60 countries. Vertically integrated company. • PG1: Sink tap. Standard series with low margin. Only 4 types. Need of high volumes and saturation of plants. Outsourcing in case of peak demand. • PG2: Fully customizable tap for a specific customer. High margin, refined design, and fully customizable product.

C07	Production of systems for commercial refrigeration (refrigerated counters, cells, and warehouse systems in supermarkets). Recently they acquired 5 companies (3 service and 2 production centers). • PG1: Food and Beverage exhibitors - not customizable. • PG2: Remote Refrigerator connected to a central cooling unit. Considerable complexity and size: 60,000 counters (PG1) and 800 central units (PG2) are produced annually.
C08	Filtration products for the hydraulic industry. Subsidiaries in Germany, France, United Kingdom, Canada, USA, China, India, and Russia. • PG1: Filter elements (e.g., vacuum switches, differential pressure indicators). • PG2: Filters, with thousands of variants: Although it has high customization, it has lower margins: the profit is based on customer loyalty and, therefore, on the sale of filter elements (frequent consumables).
C09	Textile company specializing in shirting fabric. Strongly Italian imprinting. Complete control of the supply chain. Direct and complete control of the production chain, from raw materials to fabrics. • PG1: Shirt fabric. Availability in stock of more than 6.000 fabrics ready for delivery. • PG2: Fabric for high fashion shirts. Dedicated to one customer only.
C10	Manufacturer of pipes and related services for the global power industry and other industrial applications. The production system integrates steel production, tube rolling and forming, heat treatment, threading, and finishing in 16 countries. Global service and distribution centers in more than 30 countries. Globally, more than 19000 employees. • PG1: Pipeline for water pipes. Low margin, competing on price and lead time (importance of proximity to market). • PG2: Extraction well pipes. Oil companies represent its primary sales market.
C11	Chemical industry with manufacturing, sales, and marketing operations in 8 European countries, employing more than 4,200 people. Extensive international supply chain. Products are used in industries as diverse as automotive, building and construction, paints and adhesives, food, health care and medical, personal care, textiles, and water treatment. • PG1: Caustic soda: used in several industrial applications and sectors. Standard product. • PG2: Plurimethylene: customizable with different formulations and percentages depending on the customer. The product goes in pharmaceutical and robotics.
C12	Steel processing company. A part of the production is processed to obtain precision tubes with centesimal tolerances and make cannulae for hypodermic needles. The company also deals with the design and construction of automated assembly machines. • PG1: Stainless steel pipes: tubes with diameters from 3 to 76 millimeters. High volumes and low margins. It is mainly sold in Europe. • PG2: Construction of automated assembly machines for the assembly of highly technological, customizable, and certified plastic and metal components.

Appendix 6.B: Product Group comparison

Appendix 6.B.2: Performance of PG1 compared to PG2

Appendix 6.B.2 illustrates the result of the preliminary analysis of the differences between PG1 and PG2. For example, the PG1 of the company C01 has very low *Product customization* characteristics (value = -2) compared to PG2. Vice versa, PG1 performs very well (value = 2) in *Delivery speed*, when compared with PG2.

Dimension	Reference	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12
Manufacturing unit cost	(Tatikonda and Montoya-Weiss, 2001)	1	2	1	1	0	0	1	1	1	1	-2	2
Total Business Costs	(Amoako-Gyampah and Boye, 2001; Ward et al., 1995)	1	2	1	-1	0	0	2	1	1	1	-2	2
Product customization	(Rabinovich et al., 2003; Raffi and Swamidass, 1987; Vickery et al., 1999)	-2	-2	-2	-1	-2	-2	-2	-1	-2	-2	-2	-2
Supply chain integration	(Dong et al., 2001)	-1	1	1	-1	-2	-2	0	0	-1	-1	0	-1
Delivery speed	(Karlsson and Åhlström, 1995; da Silveira, 2005; White, 1996)	2	1	2	1	1	1	1	1	1	1	0	2
Rapid volume changes	(Diaz et al., 2003; Joshi et al., 2003)	-1	-2	-2	1	1	2	1	1	-1	1	-1	2
Fast changes in product mix	(Diaz et al., 2003; Joshi et al., 2003)	-2	-1	-2	0	-2	0	0	1	-2	-2	-2	-1
Manufacturing Lead Time	(Karlsson and Åhlström, 1995)	2	1	1	1	1	2	1	1	1	1	0	2
Product development time	(Droge et al., 2004)	1	0	1	1	1	1	2	1	2	1	0	2

This table helps to show that, from an intra-plant perspective, the differences between PG1 and PG2 are rather substantial. Most of the dimensions derive from several academic contributions synthesized in the work of Roth et al. (2008).

7. CONCLUSIONS

This concluding section discusses the main findings, implications, and limitations of the work. Section 7.1 summarizes the results of the underlying research questions. Section 7.2 outlines the theoretical and practical contributions of this dissertation. Section 7.3 recognizes its limitations and suggests areas for further studies.

7.1 Summary and outlook

This dissertation deals with the analysis of MNEs, with a focus on the manufacturing side and on IMNs. Previous contributions agree on the importance of aligning production strategy with the plants' manufacturing practices to achieve superior performance (Ketokivi and Schroeder, 2004). The thesis has the general objective of linking the role of the single production plant to the other plants within the network in a manufacturing subnetwork perspective and to value-added activities within the value chain. Chapter 3, Chapter 4, Chapter 5, and Chapter 6 provide the main findings of the dissertation, which are study-specific.

The first research objective aims to understand what drives MNEs towards different levels of specialization of manufacturing and R&D functions. This objective was made explicit through the **RQ1** *"What is the combined effect of different factors on higher or lower levels of manufacturing and R&D specialization in globally dispersed subsidiaries?"* and addressed in Chapter 3. A fuzzy-set Qualitative Comparative Analysis (QCA) is conducted to examine the configurational effects of six conditions (company size, average units' size, dispersion of manufacturing and R&D networks, distance among all the network's units, average distance among manufacturing and R&D units) over the specialization of manufacturing and R&D networks. The results showed the presence of combinations of these factors that influence the higher or lower level of cross-functional integration. By means of the set of factors found, an interpretation of the four quadrants in the specialization matrix (Figure 3.3) is given.

The second research objective is more oriented towards the manufacturing perspective. It focuses on the concept of subnetwork, one of the possible ways the network can be fragmented by recognizing groups of plants with common characteristics. The two research questions associated with this objective are handled in Chapter 4 and Chapter 5.

Chapter 4 addresses **RQ2** "*What is a manufacturing subnetwork?*". The literature does not provide a clear conceptualization of subnetworks and fails to show its usefulness compared to other criteria for grouping plants. Chapter 4 walks along with three directions: first, it provides a definition and a clear conceptualization of the manufacturing subnetwork, as introduced by Ferdows et al. (2016). Second, it highlights the main differences and similarities between subnetworks, networks, and business units. Third, it discusses the usefulness, challenges, and practical implications that the subnetwork perspective might bring on three well-known issues in IMNs: the plant role, the theme of (plants and networks) capabilities, and the manufacturing strategy.

Instead, Chapter 5 addresses **RQ3** *"How can subnetworks be identified within a multinational company and how to describe them in a systematic way?".* The essay designs and applies a descriptive tool to identify subnetworks within a production network and map their characteristics; then, it develops an operationalization to understand the characteristics of products and processes. A Design Science Research (DSR) approach (Hevner et al., 2004) based on the first three phases of Holmström et al. (2009) was used to design the tool, thanks to five exploratory case studies (*solution incubation phase* and *solution refinement phase*), and a further in-depth case study that provided an example of application (*explanation phase*). The operationalization enriches the previous models in considering a higher number of attributes and a higher level of specificity.

The third research objective is to evaluate how the production plant behaves when engaged in highly differentiated multi-product contexts. The objective stems from the willingness to understand the operation of the single plant when it is part of multiple productive subnetworks. The essay in Chapter 6 answers **RQ4** *"How is a plant having multiple manufacturing missions managed?".* The analysis has been directed to the practices adopted by plants in managing their functions or departments (production, R&D, planning, warehouse and logistics, sales) and the multi-role that the plant assumes in such a situation. The results highlight a common trend in unbundling functions and the presence of cases with *plant-within-the-plant* configurations. The work also examines the complexity of conflicting manufacturing missions and the potential presence of more manufacturing roles within a single plant where two or more subnetworks overlap. Related challenges and criticalities are discussed.

7.2 Research contributions and implications

The overall goal of this thesis, as described in Chapter 2.1, is *to enhance the understanding of multinational companies, offering a perspective that connects the role of the individual plant, the entire production network, and the related functional networks within the global value chain.*

The insights generated in this dissertation provide several implications for science and practice. The contributions of the individual papers have already been presented from Chapter 3 to Chapter 6. In the following paragraph, an integrated, cross-paper discussion is offered to summarize the theoretical and managerial implications.

7.2.1 Theoretical implications

The thesis contribution touches on different areas of manufacturing strategy, such as the management of manufacturing operations and the plant configuration, mainly in international manufacturing strategy settings. The findings of this dissertation contribute to the theory on MNEs and IMNs in different ways, filling several research gaps identified.

- One of the major theoretical contributions of the thesis is to link the plant and network perspectives through the **conceptualization** and **definition** of the concept of **subnetwork**. By breaking the network into its single components, the subnetwork represents the research arena to understand, model, and study the interplay between the two levels of analysis. Few empirical studies actively connect the plant and the network level (e.g., Colotla et al., 2003; Feldmann et al., 2013; Miltenburg, 2015; Thomas et al., 2015), but in general, the link has been rarely investigated. The subnetwork stands as a fundamental intermediate level between the single plant and the entire set of globally dispersed facilities, potentially adding a new unit of analysis to the two levels - plant and network - that have concentrated most of the literature on IMN (Cheng et al., 2015). The dissertation presents an important step in understanding manufacturing subnetworks, following Ferdows' initial contribution (2016). The concept has been introduced recently, and there are still few contributions, both theoretical and empirical. This dissertation introduces a sound and clear definition of manufacturing subnetwork, which can be beneficial for OM scholars. This paper allows us to avoid ambiguities and to facilitate the alignment of the research.

- The thesis began to study the **interplay between** different **subnetworks** within the same network. When considering the subnetwork as an intermediate level between the plant and the network level, even the perspective of analysis can be positioned closer to one or the other level. In Chapter 5 and Chapter 6, the subnetwork has been studied with a pronounced attention to the individual plant. Being able to disaggregate plants falls within the initial scope of Ferdows et al. (2016), which is to simplify the management of complex networks. One of the theoretical contributions of this thesis is having shown the interplay between different subnetworks and the overlapping of subnetworks on the same plant, both concepts only mentioned by Ferdows et al. (2016).
- This perspective of overlapping subnetwork also has an impact on the theme of **plant roles**. The literature on the role of the plant has been rich in contributions (see Chapters 4.2.1, 5.2, 6.2.1), but there is still room to explore new horizons (Cheng and Farooq, 2018). For example, Ferdows' model (1997) is useful for the description and evaluation of the current network of plants, but it is constraining to categorize any new plant that could be added to the network. Likewise, previous literature highlighted the need to explore further the concept of "dynamic switching of roles" (Bengtsson et al., 2010), as well as the possible co-existence of a plurality of roles, only mentioned in Feldmann and Olhager (2019). This dissertation shows the possibility of having multi-role plants in IMNs, which is a perspective rarely investigated before at the theoretical and practical levels. Besides, the analysis discusses the presence of conflicting manufacturing objectives within the plants, discussing potential critical issues within IMN.
- The dissertation enriches the literature with a contribution that studies the **manufacturing and R&D integration** of MNEs. Chapter 3 goes in the direction of studying the manufacturing network in relation to other functional networks, helping to bridge the gap identified by Cheng et al. (2015). They highlighted how the internationalization of manufacturing "can further be accompanied by the internationalization of other value chain activities (such as service, sales, engineering,

and research and development (R&D)), which accordingly leads to the development of coordinated aggregations (networks)" (Cheng et al., 2015 page 408). Chapter 3 analyzes the spatial organization of MNEs. The theory on MNEs can benefit from this work: it explores the configurations that lead to a more or less pronounced geographical distribution of roles and a higher or lower integration between different functional networks. While the research had previously focused on the effect of individual factors on network configuration, the essay verifies conjunctural causation and equifinality (Rihoux and Ragin, 2008), and helps to capture the complexity of the relationships considering the different factors together.

- Finally, the contribution given by the **operationalization of process and product characteristics** of a subnetwork can also be extended to areas beyond IMNs. The paper in Chapter 5 proposes a specific categorization of product and process dimensions, with a high level of detail on the items and measures. The operationalization results from a meticulous analysis of the primary metrics used in the OM literature (e.g., Froehle and Roth, 2007; Menor and Roth, 2007; Roth et al., 2008), and it will be helpful for future research within and outside the IMN and MNE domains. Scholars could take advantage of this operationalization as a roadmap for studies about product and process characteristics in different manufacturing management streams.

7.2.2 Managerial implications

Nowadays, managers require a holistic system perspective for understanding, designing, and optimizing their manufacturing networks. This thesis limits its scope to the intra-company networks, with a particular focus on manufacturing management. Besides the scientific contributions, this dissertation also provides managerial implications and improves the management practices of MNEs and IMNs.

- First, the concept of **subnetwork** can show practitioners a different perspective to interpret the productive role in the company and thus support them in the decision-making process. Increased comprehension of the benefits of delayering a company into relevant subnetworks reduces its management complexity. To do this, several ways have been explored: a) Chapter 4 defines and conceptualizes what a subnetwork is, explaining its function, possibilities, and differences from business units; b) Chapter 5 explores how a multinational company's network is decomposed and how it has organized subnetworks; c) Chapter 6 proposes real-world cases of what are the manufacturing roles of the plant within a plant in which two or more subnetworks overlap. This raises awareness of the use of the subnetwork and marks an important step towards the management of interrelated manufacturing plants. For example, in Chapter 6, the management of internal procedures and the division of functions are addressed in a subnetwork perspective, together with an analysis of potential conflicts that may arise in plants with multiple manufacturing missions. Managers can draw on this evidence as support for rethinking operations in their companies.

- A significant impact come from the tool described in Chapter 5, that offers practical support to **identify, map, and operationalize subnetwork**, and that is grounded on the practical purposes of the DSR approach of solving authentic field problems (Aken et al., 2016; Johnson et al., 2020) and implementing interventions (Aken, 2004; Denyer et al., 2008). Proper handling of the global production networks requires a continuous alignment between network configuration, overall manufacturing strategy, and plant operations (Friedli et al., 2014). This tool facilitates the partitioning of the whole network and the understanding of the characteristics of products and processes in detail. The final purpose of the paper is to provide a practical tool for managers that can be further tested by additional research.
- Practitioners can benefit from this thesis with regard to the **distribution of different plant typologies on foreign subsidiaries**. The configuration of the network has long been seen as a medium-to-long-term process, but the time frame is shortening, especially for companies with many sites: companies are expected to review their strategy faster than in the past and to get rid of the typical inflexibility that characterizes them (Johansen et al., 2014). The practical benefit of the thesis is to have highlighted the configurations (i.e., the bundle of factors) that lead a company towards high or low specialization in manufacturing and high or low specialization in R&D. Managers might influence configurations of their companies according to purposeful decisions, also based on the evidence of this thesis.
- Lastly, practitioners could take some guidance from Chapter 6 to understand **how to configure functions** within a single site when multiple product groups are realized. The chapter provides various case studies highlighting the integration or separation of

functions and how they are managed. Studying best practices embedded in real cases provides insights for comparison: for example, the fact that, apart from production and R&D, other functions are rarely divided logically and physically can serve as a starting point. Studying them in a variety of companies with different challenges can provide practitioners and managers with a foundation for how to configure a particular type of IMN.

Table 7.1 summarizes the main research contributions.

Table 7.1: Theoretical and practical contributions

Results	Chapter	Contribution to theory	Contribution to practice
Definition and conceptualization of the manufacturing subnetwork	Ch4	High	Medium
Operationalization of the characteristics of products and processes in manufacturing subnetworks	Ch5	Medium	High
Interplay and overlapping of multiple subnetworks on a single plant	Ch4, Ch5, Ch6	High	Medium
Plants role in facilities with multiple manufacturing objectives	Ch5, Ch6	High	Low
Separation of functions in plants with multiple manufacturing objectives	Ch6	Medium	High
Factors driving towards a configuration with high/low specialization in manufacturing and R&D	Ch3	Medium	High

7.3 Limitations and suggestions for further research

This dissertation also faces limitations regarding both content and methodology. Further research should attempt to overcome the aforementioned limits, but also cover different trajectories provided by this dissertation.

First, the subnetwork is still an ill-structured and under-investigated topic and needs more empirical work. As there are still few empirical studies on this subject, there is a need for more data. The definitions and conceptualizations provided in this thesis can be a stimulus to new contributions from IMN scholars. Always related to subnetworks, a potentially interesting topic in the future is the analysis of how they should be managed, following the work started by Golini et al. (2017b). The theory has recognized different types of subnetworks, and this dissertation has helped define how the product and process characteristics can be identified and mapped. However, it has not been analyzed prescriptively how different subnetworks should be handled or how they should behave. For example, it would be helpful to delve deeper into rooted and footloose subnetworks to investigate their management models empirically. Likewise, it would be interesting to analyze the critical skills required by different typologies of subnetworks to accomplish their manufacturing tasks. This type of analysis would open up to very intriguing questions. A richer analysis of subnetworks would contribute to the intention of reducing the complexity of global production networks (Ferdows, 2018; Ferdows et al., 2016). The research could find fertile ground in the investigation of perspectives usually analyzed at the plant level but still scarcely explored at the subnetwork level: a) the alignment between the coordination, configuration, and strategy of the subnetwork; b) the relationship between the subnetwork and the plant; c) the management of different subnetwork capabilities.

Second, the application of the DSR-based approach in Chapter 5 is modeled on the first three of the four phases described in Holmström et al. (2009). As regards Holmström's Phase Four (i.e., the *Formal Theory*), the paper did not fully address it. In addition to testing and validating the descriptive tool by collecting quantitative and qualitative data on new cases, next steps of research might regard the completion of Holmström's Phase Four, with the application of the designed artifacts in multiple contexts to define a complete and comprehensive theory.

Third, as regard as Chapter 3, it considers only some factors potentially impacting manufacturing and R&D specialization. This is due to the fact that the chosen methodology (fsQCA) supports a limited number of conditions (Fainshmidt et al., 2020; Schneider and Wagemann, 2010). However, future research might address different or complementary factors. More qualitative or relational aspects could be explored, such as personnel interrelationships or knowledge exchange between manufacturing and R&D. Exploring different factors could lead to the development of tentative propositions over sets/combinations of conditions that are equally interesting. In addition, considering the characteristics of the QCA and its ability to grasp complex phenomena, further empirical research on a larger scale (Leischnig et al., 2018) might open up relevant insights for OM scholars. For example, in addition to the “why” question, scholars could also explore “how” the specialization or co-location of different value-added activities in MNEs are managed. Further studies could stress the coordination rather than the configurational aspects, to understand how integrated factories coordinate their work. Besides, by introducing the subnetwork perspective, new studies could explore how co-location takes place by considering groups of heterogeneous factories: for example, it could be investigated whether the intensity of R&D and manufacturing specialization depends on the characteristics of products and processes or how production and R&D networks are managed according to the typology of subnetworks involved in the company.

Forth, while the goal of Chapter 6 was intentionally to study "unfocused" factories, future research could delve into an underlying question that remains open: are “dual” plants more, less or equally effective in comparison to “focused” ones? The research in this direction would allow to deepen the topic further, unraveling if the various conflicts and criticalities underlined in the thesis.

Finally, the possibility of having multiple roles in a plant needs further attention. In the empirical cases of Chapter 6, some plants involved in a twofold manufacturing objective were analyzed; however, the companies in which subnetwork principles could be applied were few, due to both the limited number of plants of some companies and to product-process characteristics. For these reasons, further empirical research could give a boost to the theme. Additional studies could support the initial insights of this thesis, test the robustness of the findings, and provide new theoretical frameworks to the rich literature on plant roles in IMNs.

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