11-2006

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Ann Vereecke
Ghent University

Roland Van Dierdonck
Ghent University

Arnoud DE MEYER
Singapore Management University, arnouddemeyer@smu.edu.sg

MANAGEMENT SCIENCE
Vol. 52, No. 11, November 2006, pp. 1737–1750
ISSN 0025-1909 | EISSN 1526-5501 | 06 | 5211 | 1737

DOI 10.1287/mnsc.1060.0582

A Typology of Plants in Global Manufacturing Networks

Ann Vereecke, Roland Van Dierdonck
Vlerick Leuven Gent Management School, and Faculty of Economics and Business Adminstration, Ghent University, Reep 1, B-9000 Gent, Belgium {ann.vereecke@vlerick.be, roland.vandierdonck@vlerick.be}

Arnoud De Meyer
Judge Business School, Cambridge University, Trumpington Street, Cambridge CB2 1AG, United Kingdom, a.demeyer@jbs.cam.ac.uk

The purpose of this paper is to propose a new, empirically derived typology of plants in the international manufacturing network of multinational companies. This typology is based on the knowledge flows between the plants. In our research, network analysis has been used as a methodology for understanding the position of plants in international manufacturing networks. The focus has been primarily on the intangible knowledge network, and secondarily on the physical, logistic network. Our analysis leads to four types of plants with different network roles: the isolated plants, the receivers, the hosting network players, and the active network players. Our analysis shows that the different types of plants play a different strategic role in the company, have a different focus, and differ in age, autonomy, and level of resources and investments. Also, the analysis suggests that the evolution of the plant depends to some extent on the network role of the plant. Finally, two scenarios for the development of a strong network role are identified. The research is useful for the scholar studying the architecture of knowledge networks, as well as for the practitioner who is in charge of an international network of manufacturing units.

Key words: manufacturing strategy; knowledge management; international manufacturing; plant networks
History: Accepted by William S. Lovejoy, operations and supply chain management; received May 23, 2002. This paper was with the authors 2 years and 1 month for 3 revisions.

1. Introduction

In 1964, Skinner warned, "the time has come when we must begin to sharpen the management of international manufacturing operations" (Skinner 1964, p. 126). As competition is globalizing and the complexity of the environment in which companies operate is increasing, managing an integrated international network has become an increasingly important task for manufacturing managers (Bartlett and Ghoshal 1989, Ferdows 1997a). However, despite the importance attached to it by both academics and practitioners, the field of international operations management is still at a relatively early stage of theory development (Roth et al. 1997) and could be enriched by insights from empirical research (Chakravarty et al. 1997).

In the field of international operations management, at least two categories of research can be distinguished (Chakravarty et al. 1997). The first category of research consists mainly of international comparisons. The basic question here is to what extent models and concepts in production and operations management are applicable in different countries or regions. The second category studies the management of international networks of facilities, suppliers, and markets. The basic question here is how to design and manage the flows of goods, people, technology, and information in international networks (Chakravarty et al. 1997). Our research contributes to this second category of international operations research.

Competitiveness today is not solely based on the application of state-of-the-art management techniques in each of the individual plants, but also on the implementation of an integrative strategy on the network of plants (Ferdows 1997a). From a logistics perspective, this requires the optimization of the company's supply chain. From an organizational perspective, it requires managing the creation and transfer of knowledge in the network. Plants adopt a different role in these networks. As plants differ in product allocation and in focus, they play different roles in the supply chain (Hayes and Schmenner 1978). As they differ in the level of creation, sharing, and absorption of innovations, they play different roles in the intangible knowledge network in the company (Ferdows 1997b). The purpose of our research has been to understand the different roles of plants in this knowledge network. Based on rigorous and in-depth case research, a new typology of plants has been derived. The plant types differ in the extent to which they share innovations with the other plants, in the level of visits to and from the other plants, and in the level of communication with the other plants. The analysis also shows that different roles in the knowledge network coincide with different roles in the supply chain.

2. Literature Review

2.1. Operations in a Multinational: A Network Perspective

Over the last two decades, research on the structure and organization of multinationals has shifted from a focus on the one-to-one headquarters-subsidiaries relationships toward a focus on managing a network of units (Kogut 1989). Ghoshal and Bartlett (1990, p. 620) claim that the network approach "is particularly suited for the investigation of such differences in internal roles, relations, and tasks of different affiliated units (...) and of how internal co-ordination mechanisms might be differentiated to match the variety of sub-unit contexts."

In the management of these networks, the focus has often been on the flow of information. Doz and Prahalad (1991, p. 160), for example, state that differences in the mission of subsidiaries are reflected in the "pattern and intensity of information flows." In their more recent work Doz et al. (2001) argue that the success of some multinational companies lays in their ability to "sense" information and knowledge and to distribute it rapidly throughout the network.

The information flow is only one type of network relationship between the subsidiaries and headquarters, and among the subsidiaries. The physical flow of components, semifinished goods or end products, financial flows, and "flows" of people moving around in the network are other types of network relationships (Bartlett and Ghoshal 1989).

This trend toward describing the multinational company as a network of units can also be observed in the manufacturing strategy literature. Work has been done, for example, in the description of the benefits and methods of the transfer of best practices across the manufacturing network. Chew et al. (1990) show that the improvement of the overall performance of multisite companies depends on the local innovativeness of the plants, as well as on the interplant transfer of these local innovations. Flaherty (1986, 1996) adds to this the importance of coordination. She argues that the coordination of international operations in a network can improve cost and delivery performance and enhance the learning from the experiences of units in the network.

However, the systematic analysis of the relationship between the plants in the manufacturing network requires an appropriate methodology. Nohria (1992, p. 8) claims that, "if we are to take a network perspective seriously, it means adopting a different intellectual lens and discipline, gathering different kinds of data, learning new analytical and methodological techniques, and seeking explanations that are quite different from conventional ones." Network analysis is a particularly powerful methodology for the description and analysis of the structure of networks and the position of the units in the network (Knoke and Kuklinski 1982). The next section describes the network relationships between the units in the manufacturing network from a conceptual perspective. The operationalization of these network relationships and the application of network analysis techniques are described in §3.

2.2. Network Position of Plants

The purpose of our research is to understand the position of manufacturing units in international manufacturing networks. Our hypothesis is that distinct plants play different roles in these networks by having relationships of different type and intensity with the other plants and with headquarters. Bartlett and Ghoshal (1989) recognize four types of relationships between subsidiaries: physical goods, information, people, and financial resources. The flow of financial resources in the strict sense of providing capital to subsidiaries is of lesser importance in our study of network relationships between plants, and will therefore not be discussed here. The three other types of relationships—goods, information, and people—differ in their degree of tangibility. Our interest lies primarily in the intangible knowledge network of the multinational, which is explained in the next two sections because we are exploring how the network of production facilities of the multinational may enhance the creation of strategic capabilities. The logistics organization of the multinational, which is reflected in the focus of the plants and in the tangible transfer of components on semifinished goods through the network, is discussed in §4.4.

2.2.1. The Information Network. Two types of information flow can be distinguished: the administrative information flow and the knowledge flow (Gupta and Govindarajan 1991). In a manufacturing context, the administrative information flows consist of information on inventory levels, purchasing requirements, forecasts, production plans, etc. These information flows depend to a large extent on the degree of centralization of manufacturing tasks, such as planning, inventory management, and procurement. From a manufacturing strategy perspective, the knowledge flows are the more interesting ones. It is commonly accepted that one of the main reasons for the existence of multinationals is the possibility to acquire, create, and use technological assets across national boundaries (Dunning 1993, p. 290). Consequently, the ability to transfer innovations through the multinational's network is crucial for attaining a competitive advantage. Three categories of innovation flows have been studied: the development and introduction of a new product, the development and introduction of a new production process, and the implementation of a new management system (Ghoshal and Bartlett 1988).

2.2.2. The People Network. The flow of people in the manufacturing network may take different shapes. A typical example is the position of a manager having line or staff responsibility in two or more plants. This can be at the level of the plant manager, as well as the functional levels reporting to the plant manager. This type of relationship can be called "interlocking management" by analogy with the interlocking directorship; i.e., one person being a member of the board of directors of two or more companies (Gerlach 1992). Of equal importance are the "dispatched managers," i.e., the managers who have been transferred from one operating unit to another, on a permanent or a temporary basis, by analogy with the dispatched director. A third shape of the flow of people refers to the day-to-day operations of the network. These relations between units are realized through "coordinators"—managers traveling frequently between operating units to share information and to accomplish cooperation between the units. The role of such coordinators has received a lot of attention in the organization literature. They are specific examples of what Galbraith (1977) and Mintzberg (1979) have defined as the "liaison devices" of an organization.

A major advantage of these coordinators is the opportunity they create for personal contact between people in the organization. Ghoshal et al. (1994) have shown that the relationship among subsidiary managers and the relationship between managers of subsidiaries and managers of headquarters have a significant influence on the frequency of the intersubsidiary communication and on the frequency of communication between the subsidiaries and headquarters. Communication plays an important role as a facilitator of the transfer of innovations in multinationals (Ghoshal and Bartlett 1988, Gupta and Govindarajan 1991).

We retain from this short discussion three variables that are particularly relevant for our study: (1) the flow of innovations between the units in the network; (2) the extent to which coordination exists in the network through managers traveling between the units; and (3) the frequency of communication between the units in the network.

Interlocking management has not been retained as such in the research because it can be regarded as a special reason for frequent travels between the two plants involved. Dispatching has not been retained either because we assume that this creates a tight relationship between the dispatching and the receiving unit only if the dispatched manager keeps in touch with his original unit. Measuring the communication between the two units then captures this.

3. Research Methodology

3.1. Case Research

The research reported here is part of a larger research study on the international plant configuration. The research was exploratory, i.e., we wanted to understand the "how" and "why" of the international plant network. Thus, case study research has been preferred over other research methodologies (Yin 1984).

To achieve precision and rigor, we followed the methodological guidelines proposed by Eisenhardt (1989), Miles (1994), and Yin (1984). Without being exhaustive, we mention that a strict research protocol has been designed, a questionnaire with both closed- and open-ended questions has been developed as guidance for the interviews, accommodations have been made to avoid interview fatigue, and both qualitative and quantitative data have been collected in a rigorous and structured way and have been analyzed in a systematic way. Several variables have been measured through multiple item measures. The reliability of these variables has been assessed by calculating the Cronbach alpha, and factor analysis has been used to reject or confirm the assumption that some theoretical constructs underlie the items (Carmines and Zeller 1979, DeVellis 1991).

To enhance construct validity, multiple raters have been used. This tactic avoids the risk that data comes from a single respondent with a biased view or with limited access to information (Speier and Swink 1995, Boyer and Verma 1996). The intraclass correlation (ICC) method has been used to assess the interrater reliability of the variables. The ICC index measures the variance of the scores of the raters within a plant, relative to the between-plant variance. Data on the ICC for all variables used in the analyses can be found in Appendix 1.

3.2. Data Collection

The case research has been carried out in eight manufacturing companies headquartered in Europe, in different industries: food products (two companies), textile goods, plastic products, leather products, primary metal, fabricated metal, and electrical goods. Thus, no single industry dominates the sample. The companies had between four and 10 manufacturing plants. The primary selection criterion for the cases has been diversity, at the level of the company as well as the plant. At the company level, it is important to have diversity in terms of the international environment in which the company operates because one of the research objectives was to explore the link between the characteristics of the company's international environment and the plant configuration in the company. Consequently, the cases are distributed over the integration/responsiveness grid, as defined by Bartlett and Ghoshal (1989). Two of the cases are classified as "global," two as "transnational," and four as "multinational" (Vereecke and Van Dierdonck 1999c). Diversity at the plant level has been obtained by selecting companies with a minimum of four plants, spread over a broad geographical region—the rationale being that with three plants or less, companies have few opportunities for differentiating the role and focus of their plants. A geographical spread of the plants (pan-European or even global) was expected to result in a broad range of drivers for establishing the plant, and therefore also in a broad range of plant roles (Ferdows 1997b). The sample was limited to companies with their headquarters in Western Europe.

Data have been gathered at two levels of analysis: the plant and the company.

- Interviews have been conducted with the general manager and with manufacturing managers at headquarters. In total, data has been collected on 59 manufacturing plants, through 37 interviews (with a total duration of approximately 120 hours). The number of interviews varied between two and six per case. A structured questionnaire with closed- and open-ended questions has been used as a guide through the interviews.
- A second questionnaire has been sent to the plant managers and/or the manufacturing managers in the distinct production plants. One hundred fourty four questionnaires have been sent to 54 out of the 59 plants. For five of the plants, headquarters asked us not to send a questionnaire to the plant managers. Eighty three percent of the questionnaires have been returned from 50 plants. This implies that in total we have received data from the plant managers on 50 out of the 59 plants (85%). The number of questionnaires returned from the plants varied between one and five per plant.
- Information has also been obtained from desk research on company brochures, publications, and company archives.

Fourty-two plants were located in Europe, spread over 14 different countries. The other 17 plants were spread over 10 different countries in East Asia and the Middle East, the United States and Canada, and South Africa and Australia. We thus have a truly international sample. The number of years the plant had been part of the company ranges between 0 (this plant was starting up at the moment of the research) and 50 years, with an average of 17 years. The number of employees in the plants ranges between 77 and 1,100 with an average of 340.

3.3. Operationalization of the Network Position of the Plants

In describing the manufacturing network of a multinational company as an information and people network, the network units considered are all the plants and the group of managers in headquarters responsible for manufacturing (in this paper, referred to as "headquarters"). As discussed earlier, the network relationships considered in this research are the flows of innovation, the use of coordinators, and the communication between the units in the network.

The innovation transfers have been measured by asking managers in the plants (through the mail questionnaires) and in headquarters (through the interviews) to enumerate and describe the transfers of product, process, and managerial innovations they know of over the past three years. A similar operationalization has been used by Ghoshal and Bartlett (1988). The information that has been gathered from these different sources has been checked, complemented, and corrected by at least one manager in headquarters, in the course of the in-depth interviews.

The presence of coordinators has been operationalized as the extent to which people are traveling from one unit to another. This information on people flows has been collected through the mail questionnaire to the plants. The measurement is based on the tool used in the research by Ghoshal (1986). The respondents had to report the number of days they had spent, over the previous year, in headquarters and in each of the plants in the company's network.

One of the questionnaire items measures the communication between the managers in the plants and in headquarters. However, such self-reported answers may suffer from recollection problems. This problem is severe if the data collection method consists of an interview or questionnaire asking the respondent to name the persons he/she communicates with frequently. This approach has been used in early studies of communication networks in R&D laboratories (Allen 1977). An alternative approach is to provide a list of people, and to ask the respondent with whom on this list he/she has communicated, rather than letting the respondent name the people he communicated with (Knoke and Kuklinski 1982). This approach has been followed in our research. A score of 3, 2, and 1 has been given to daily, weekly, and monthly communication, respectively. Bartlett and Ghoshal (1989) have also preferred this scoring system.

The primary network measure used in our research is the *centrality* of the plant in the network. If network relations are mutual (as is the case for the communication network), we measure centrality of the unit through its degree. The *degree of a unit* is defined as the proportion of other units with which a unit has a direct relationship (Knoke and Kuklinski 1982). If network relations are not mutual (as is the case for the flows of people and innovations), two degree measures are used: the unit's indegree and outdegree (Knoke and Kuklinski 1982). The *indegree of a unit* is defined as the proportion of relations received by the unit from all other units. The *outdegree of a unit* is defined as the proportion of relations from that unit to all other units.

Based on these definitions of centrality, the following network variables have been defined:

- The *communication centrality* of plant i captures the frequency of communication of the manufacturing staff of plant i with the manufacturing staff of the other units in the network.
- The *innovation indegree* of plant i captures the intensity of the innovation flow transferred (and implemented) from the other units to plant i.
- The *innovation outdegree* captures the intensity of the innovation flow transferred (and implemented) from plant i to the other units.
- The *people indegree* of the plant captures the number of days plant i has received visitors from the manufacturing staff team of the other plants.
- The *people outdegree* of plant i captures the number of days manufacturing staff people of plant i have been visiting other plants in the plant configuration

In network analysis, the consequences of missing data are severe because the lack of data from a single unit implies the lack of data on the $N-1$ possible relationships of this unit with the other units in the network. Estimates such as centrality can therefore be distorted if data are missing. Consequently, great care has been taken so as to maximize the response rate (Vereecke and Van Dierdonck 1999b).

3.4. Clustering of the Data

To ensure the validity of the network typology, a two-stage procedure has been followed to cluster the data (Ketchen and Shook 1996). We had sufficient data on 49 of the plants to involve them in the cluster analysis. Ward's hierarchical clustering method has been used to define the number of clusters. This number of clusters has then been used as the parameter in the nonhierarchical K-means clustering method with Euclidian distance measure. K-means clustering is preferred over the hierarchical cluster methods for the development of the typology because it is an iterative partitioning method and thus is compensating for a poor initial partitioning of the cases. Because the units of measurement for the network relationships differ substantially and Euclidian distance is used as the distance measure in the cluster analysis, the variables have been standardized prior to the clustering (Aldenderfer and Blashfield 1984, p. 21).

As suggested by Ketchen and Shook (1996), the number of clusters has been determined through the use of multiple techniques.

- Upon visual inspection of the dendogram, we recognize a structure with four clusters.
- A four-cluster classification accounts for 56% of the variance in the data. Disaggregation into five, six, and seven clusters adds approximately 6% to the variance explained at each step. After seven clusters, the increases in R^2 are low (below 3%). This observation points at a classification into four or seven clusters.
- The cubic clustering criterion (CCC) points at nine clusters. However, tests have indicated that the CCC may suggest too many clusters (Milligan and Cooper 1985).
- We have used the analytics software SAS to perform a number of the tests that have been put forward by Milligan and Cooper as most effective (Milligan 1996). The pseudo F statistic, developed by Calinski and Harabasz (1974), has local peaks at two and seven clusters. The pseudo t^2 statistic, based on Duda and Hart (1973), indicates a clustering of the data in two, four, or seven clusters.

We conclude that the different test routines point at a clustering into two, four, or seven clusters. Because there is partial agreement among the test results, Milligan (1996) suggests opting for the larger number, that is, seven. However, when going from the four to the seven-cluster solution, we see that the pattern of three clusters is roughly maintained, while the fourth cluster falls into four smaller clusters (including a cluster of one unit), which are difficult to distinguish. Consequently, the seven-cluster solution merely adds complexity without providing revealing insights. We have therefore opted for a classification into four clusters.

4. Empirical Results

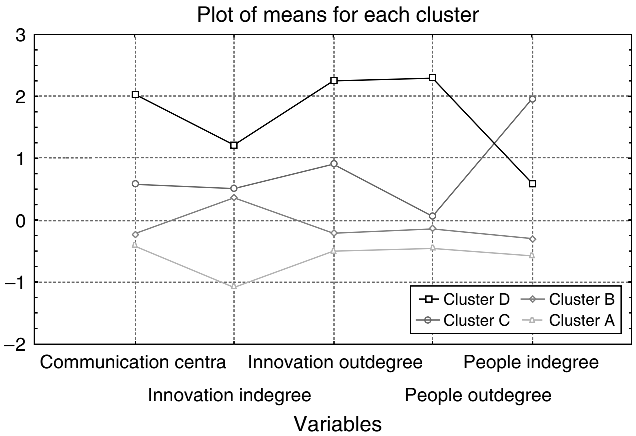
4.1. A Network Typology of Plants

The four clusters represent different positions of plants in the plant network of information and people. The average of the network variables in each of the clusters is represented graphically in Figure 1.

The typology of plants resulting from this cluster analysis is summarized in Table 1. We distinguish three levels for each of the variables: "low" for average value below 0; "medium" for average level between 0 and 1; and "high" for average value above 1. These cut-off values are defined on the standardized variables.

Plants in Cluster A occupy an "isolated" position in the plant network. Few innovations reach the plant, few innovations are transferred to other units, few manufacturing staff people come to visit such a plant, few manufacturing staff people from this plant go

Figure 1 Network Clusters: Graphical Representation



visit other plants, and there is little communication between the manufacturing staff people of this plant and the other manufacturing managers in the network.

A plant in Cluster B is comparable to the isolated plant on all but one variable: it receives more innovations from the other units in the network. We will therefore label these plants as "receivers." Clusters A and B thus consist of plants that are only weakly embedded in the manufacturing network. They represent 37 out of the 49 plants in the sample.

Clusters C and D consist of plants that are true network players. A type C plant frequently exchanges innovations, both ways, with the other units and its manufacturing staff communicates extensively with the other manufacturing managers in the network. A C plant is also frequently hosting visitors from other units in the network. In the network, the C plant thus takes the role of the "hosting network player."

The type D plants differ from the type C plants in two aspects: First, the level of communication centrality and the outflow of innovations are even higher in the type D than in the type C plants (significantly different at $p = 10\%$ for communication centrality and at $p = 5\%$ for innovation outflow). Second, the major flow of visitors is in the opposite direction. Whereas in type C plants the inflow of visitors is significantly higher than the outflow ($p < 1\%$), in type D plants the outflow is higher than the inflow ($p < 5\%$). The D plant is thus highly involved in the network, and takes a more active role than the C plant. We label them as the "active network players."

Table 1 Network Typology of Plants

Network variable	Cluster A Isolated	Cluster B Receiver	Cluster C Hosting network player	Cluster D Active network player
Number of plants in cluster	11	26	8	4
Communication centrality	Low	Low	Medium	High
Innovation indegree	Low	Medium	Medium	High
Innovation outdegree	Low	Low	Medium	High
People indegree	Low	Low	High	Medium
People outdegree	Low	Low	Medium	High

4.2. Cluster Validation

Analysis of variance on the variables used to generate the cluster solution is frequently used to test the validity of the cluster analysis solution. The test results are summarized in Table 2.

However, we do not want to overemphasize the value of this analysis of variance. Because the clustering method attempts to minimize variance within the clusters, it is logical that the *F*-test is significant (Aldenderfer and Blashfield 1984, p. 65). External criteria analysis is more appropriate. Such analysis is based on statistical tests on variables that have not been used to generate the cluster solution, and yet are relevant (Aldenderfer and Blashfield 1984, Milligan and Cooper 1985).

A variable that is strongly related to the typology discussed here is the concept of the "strategic role" of the plant. Building on the work done by Ferdows (1989), we define the importance of the strategic role of the plant as the extent to which the plant contributes to the other units in the manufacturing network (Vereecke and Van Dierdonck 1999a). We have measured the importance of the strategic role of the plant on a nine-point Likert scale, describing plants which have as their main goal "to get the products produced" at the lowest extreme, to plants that are a "center of excellence, and serve as a partner of headquarters in building strategic capabilities in the manufacturing function" at the highest extreme. Given our definition, the importance of the strategic role of the plants in Cluster D should be high. The importance of the strategic role of the plants in Clusters A and B, on the other hand, should be low because these plants make little contributions to the plant network. The plants in Cluster C are expected to play a strategic role of medium importance.

The average and median of the importance of strategic roles are shown in Table 3. We should note here that for the importance of the strategic role, as

Table 2 Analysis of Variance on Four-Means Cluster Solution

Network variable	*F*	*p*-level
Communication centrality	12, 18	0.000006
Innovation indegree	17, 38	0.000000
Innovation outdegree	21, 69	0.000000
People indegree	47, 81	0.000000
People outdegree	14, 76	0.000001

Table 3 Importance of Strategic Role of the Plants

	Valid N	Mean	Median	Median test: obs-exp below median*
Cluster A	11	4.80	4.67	0.39
Cluster B	26	4.52	4.69	1.73
Cluster C	8	5.76	6.44	−0.08
Cluster D	4	7.97	8.10	−2.04
Overall	49	5.07	4.80	

*Number of cases observed minus number of cases expected below the overall median level of strategic role, that is, below 4.80. A positive number shows the number of cases observed below the overall median, and consequently indicates a relatively low level of strategic role in the cluster.

well as for most of the plant characteristics that will be discussed later, the assumption of normality is violated. For those variables, the nonparametric alternatives to the ANOVA, the Kruskall-Wallis and Median Tests, have been used.

The Kruskal-Wallis test indicates a significant difference in the level of the strategic role between the clusters ($p < 10\%$). The Median Test confirms that the difference in strategic role follows the hypothesized pattern, as can be seen in Table 3. Cluster B contains slightly more cases below the median level of strategic role than could be expected if the strategic role were evenly distributed over the four clusters, indicating a relatively low level of strategic role. Cluster D contains more cases above the median level of strategic role than could be expected if the strategic role were evenly distributed over the four clusters, indicating a relatively high level of strategic role. The Mann-Whitney U-Test confirms that the level of strategic role in Clusters A and B is significantly lower ($p < 5\%$) than in Cluster D.

4.3. Future Strategic Role of the Plant

We have discussed the relationship between the network position of the plant and the importance of the strategic role played by the plant. Our research also provides information on the expected changes in the strategic role of the plant. The interviewees were asked to estimate the importance of the strategic role of the plant as they expect it to be in five years on the nine-point Likert scale described above. The data suggests that in Clusters C and D, only a few marginal increases and decreases in strategic role are expected. This suggests that the plants which occupy an integrated position in the network (Clusters C and D) are fairly stable in terms of the importance of the strategic role they play in the company. Several of the A and B plants, on the other hand, are expected to experience an increase in strategic role. For some, the expected increase is quite substantial. Given the relationship that we observed between the role of the plant and its network position, it is fair to expect that these plants will probably be moving from Clusters A or B toward Clusters C or D. Several of the other plants in Clusters A and B are expected to experience a decrease in strategic role. Again, for some, the expected decrease is quite substantial. It is clear that these two clusters of nonintegrated plants are less stable than the two clusters of integrated plants.

An example illustrates our point. Two of the "receiver" plants in the sample have been closed since we started the case research. We do not want to infer here that the plants in the "isolated" or "receiver" clusters are on the waiting list for closure. The examples of plants with a positive expectation in strategic role would certainly contradict this point. Our hypothesis is that the plants in these two clusters are in a variable position, and that this variability may lead toward an increase as well as a decrease in terms of the importance of the role the plant plays in tomorrow's network. These plants seem to provide strategic flexibility in the network.

It is interesting to mention that the decrease in strategic role that is predicted by headquarters for some of the isolated plants and the receivers is not expected by the managers in the plants. The lack of network relationships for the isolated plants and the receivers seems to create a gap between the expectations of plant management and the considerations in headquarters. It may also suggest that the managers in A and B plants are less involved in strategic decision making and, thus, are less well informed.

4.4. Characteristics of the Plant Types

To better understand the network typology of plants, the four types of plants have been compared on a set of plant characteristics. We have analyzed:

- The *age* of the plant (number of years the plant has been part of the company).
- The *size* of the plant (expressed in number of employees).
- The *focus* of the plant (Hayes and Schmenner 1978, Collins et al. 1989):

Product focus: the extent to which the plant focuses on a narrow portion of the company's product range, and

Market focus: the extent to which the plant focuses on a narrow portion of the geographical market served by the company.

- The *supplier/user relationship* with other plants in the network: the extent to which a plant supplies components or semifinished goods to or uses components or semifinished goods from another plant in the network. It has been measured as the centrality (outdegree and indegree) of the plant in the physical network of goods. The outdegree of plant i captures the portion of plants in the plant configuration, to which plant i supplies components or semifinished goods. The indegree of plant i, (analogously) captures the portion of plants in the plant configuration, from which plant i receives components or semifinished goods.

• The *level of investment*: A list of 14 potential investments has been included in the questionnaires. From this list of 14 items, four types of investment have been identified through factor analysis:

(1) Investments in the *production process*, that is, in setup time reduction, plant automation, process analysis, productivity improvement, and throughput time reduction (Cronbach alpha of the resulting factor $= 0.77$).

(2) Investments in *planning*, that is, in material and/or capacity planning and just-in-time systems (Cronbach alpha of the resulting factor $= 0.79$).

(3) Investments in *managerial improvement* programs, that is, in statistical process control, supplier partnerships, total quality management, and employee participation programs (Cronbach alpha of the resulting factor $= 0.73$).

(4) Investments in *new product development.*

• The *autonomy* of the plant. Both strategic autonomy and operational autonomy have been measured through questionnaires administered in the plants. A similar approach has been followed by Ghoshal (1986), Bartlett and Ghoshal (1989), and De Bodinat (1980). Two dimensions of strategic autonomy have been identified, through factor analysis:

(1) Strategic autonomy in decisions concerning the operations of the plant, that is, the decision to develop a new product or to introduce a new planning system and the selection of a new supplier (Cronbach alpha of the resulting factor $= 0.81$).

(2) Strategic autonomy in decisions concerning the design of the plant, that is, the decision to develop a new production process and the choice of a new technology (Cronbach alpha of the resulting factor $= 0.85$).

Two dimensions of operational autonomy have been identified, through factor analysis:

(1) Operational logistics autonomy, that is, in developing a production plan, placing purchasing orders, managing inventories (Cronbach alpha of the resulting factor $= 0.84$).

(2) Operational autonomy in design and engineering, that is, in developing new products and processes (Cronbach alpha of the resulting factor $= 0.88$).

• The *level of capabilities* in the plant. Two types of capabilities are distinguished: the capabilities to develop new products and managerial capabilities. They have been measured in the headquarters interviews through a 1–9 Likert scale. The Cronbach alpha for this construct was 0.85.

• The *performance* of the plant. Performance has been measured relative to the target set for the plant. Performance data has been obtained from a list of nine performance items, included in the questionnaire sent to the plant management teams. Because this performance data is self-reported, it is important to have data from multiple respondents per plant, and to evaluate the interrater reliability. Two dimensions of performance have been identified through factor analysis (see Appendix 1):

(1) Performance on time measures, that is, performance relative to the target set for manufacturing throughput time, delivery lead time, and on-time delivery to customers (Cronbach alpha of the resulting factor $= 0.85$).

(2) Performance on cost and quality measures, that is, performance relative to the target set for unit production cost, productivity of direct workers, defect rates, and overall product quality (Cronbach alpha of the resulting factor $= 0.83$).

The results of the (mostly nonparametric) comparisons of the four clusters on these variables are listed in Table 4. For those variables that showed a significant difference across the four clusters (with significance level $p < 10\%$), pairwise comparison of the mean or median is reported in Table 4.

We conclude from these comparisons that

(1) Plants in Cluster C are significantly older than plants in Clusters A and B.

(2) Plants in Cluster A are significantly more market focused than plants in Clusters C and D; and plants in Cluster B are significantly more market focused than plants in Cluster C.

(3) The outflow of components and semifinished goods is significantly lower for plants in Clusters A and B than for plants in Cluster D.

(4) The inflow of components and semifinished goods is significantly lower for plants in Cluster A than for plants in Cluster B; and is significantly lower for plants in Cluster B than for plants in Clusters C and D.

(5) The level of strategic autonomy in plant design for plants in Cluster A is significantly lower than for plants in Clusters B, C, and D. Plants in Cluster B have a significantly lower level of strategic autonomy in plant design than plants in Cluster D.

(6) The level of process investment in plants in Cluster D is significantly higher than in plants in Clusters A, B, and C.

(7) Plants in Cluster A invest significantly more in managerial improvement programs than plants in Clusters B and C .

(8) The level of capabilities in plants in Cluster B is significantly lower than in plants in Clusters A, C, and D.

Table 5 summarizes the characteristics of the clusters that result from these comparisons. The comments made throughout the interviews provide some additional insights in the profile of the clusters. These comments are listed in Appendix 2.

Table 4 Statistics on Plant Characteristics by Cluster

Plant characteristic	Variable	Mean/*median* A	B	C	D	Difference between clusters
Age	Number of years plant is part of company	11.1	16.8	30.6	19.7	Anova ($p < 1\%$) $A < B^{n.s.}/A < C^{**}/A < D^{n.s.}/B < C^{**}/B < D^{n.s.}/C > D^{n.s.}$
Size	*Number of employees*	*154*	*240*	*362*	*533*	Not significant
	Number of workers	*111*	*165*	*251*	*308*	Not significant
	Number of salaried workers	*43*	*43*	*126*	*226*	Not significant
	Number of manufacturing staff people	*13*	*21*	*41*	*40*	Not significant
Market focus	*Proportion of market range supplied by the plant*	*0.18*	*0.63*	*0.90*	*0.89*	Kruskal-Wallis Anova with $p < 5\%$ Mann Whitney U-test $A < B^{n.s.}/A < C^{**}/A < D^{\dagger}/B < C^{*}/B < D^{n.s.}/C \approx D^{n.s.}$
Product focus	*Proportion of product range*	*0.15*	*0.22*	*0.30*	*0.38*	Not significant
Supplier/user relationship	*Outdegree*	*0*	*0*	*0*	*0.47*	Kruskal-Wallis Anova with $p < 5\%$ Mann Whitney U-test $A \approx B/A \approx C/A < D^{**}/B \approx C/B < D^{\dagger}/C < D^{n.s.}$
	Indegree	*0*	*0.11*	*0.22*	*0.42*	Kruskal-Wallis Anova with $p < 5\%$ Mann Whitney U-test $A < B^{\dagger}/A < C^{**}/A < D^{*}/B < C^{*}/B < D^{\dagger}/C < D^{n.s.}$
Operational autonomy	Logistics	6.2	6.9	6.4	5.8	Not significant
	Development and engineering	4.4	4.8	5.8	6.2	Not significant
Strategic autonomy	Operations of the plant	4.1	5.2	5.1	5.4	Not significant
	Design of the plant	3.7	4.8	5.7	6.3	Anova ($p < 5\%$) $A < B^{*}/A < C^{**}/A < D^{**}/B < C^{n.s.}/B < D^{\dagger}/C < D^{n.s.}$
Investment	Process investment	5.5	5.3	5.1	6.8	Anova ($p < 10\%$) $A > B^{n.s.}/A > C^{n.s.}/A < D^{\dagger}/B > C^{n.s.}/B < D^{*}/C < D^{*}$
	Investment in planning	4.4	4.9	4.6	6.3	Not significant
	Managerial investment	6.5	4.9	4.9	5.7	Anova ($p < 5\%$) $A > B^{**}/A > C^{*}/A > D^{n.s.}/B \approx C/B < D^{n.s.}/C < D^{n.s.}$
	New product investment	4.9	5.2	5.7	7.0	Not significant
Plant capabilities	Level of resources	6.4	5.3	6.4	7.5	Anova ($p < 5\%$) $A > B^{\dagger}/A \approx C/A < D^{n.s.}/B < C^{\dagger}/B < D^{**}/C < D^{n.s.}$
Performance relative to target	Time performance	1.0	0.72	0.84	0.82	Not significant
	Cost and quality performance	*1.0*	*0.63*	*0.02*	*0.69*	Not significant

Notes. Variables for which the assumption of normality is rejected are in italic. For those variables, the median value is mentioned (in italic). For the other variables, the mean value is mentioned.
**Significant at $p < 1\%$; *significant at $p < 5\%$; †significant at $p < 10\%$; n.s.—not significant at $p < 10\%$.

5. Discussion

Some general lessons can be drawn from the plant typology and the characteristics of the four types of plants.

First, the plants providing innovations to the manufacturing network, the "hosting network players" and the "active network players," are at the same time receivers of innovations from other units in the network. Apparently, transferring knowledge is beneficial, not only for the receiver, but also for the provider. An explanation may be that the quality of the relationship between two units is a major factor in the exchange of innovations, or as Szulanski (1996, p. 36) has put it, "the relationship serves as a conduit for knowledge." Once such a relationship has been established, it works in both directions.

Second, the analyses show that there is a strong link between the position of the plant in the intangible network of ideas and in the tangible network of goods. This is in line with Nonaka and Takeuchi (1995), who argue that codified and noncodified knowledge complement and reinforce each other. The "isolated" plant, which is not actively taking part in the network of ideas, is also isolated in the physical sense: we observed very little flows of components or semifinished goods from these plants to the other plants in the network, and vice versa. The network players (type C and D), on the other hand, are typically sup-

Table 5 Summary of Plant Characteristics by Cluster

	Plant characteristics
A	Relatively young; market focused; little inflow and outflow of components and semifinished goods; relatively low level of strategic autonomy in plant design; relatively high level of managerial investment
B	Relatively young; little outflow of components and semifinished goods; relatively low level of managerial investment; relatively low level of capabilities
C	Relatively old; broad market; high inflow of components and semifinished goods; relatively low level of managerial investment
D	High inflow and outflow of components and semifinished goods; relatively high level of strategic autonomy in plant design; relatively high level of process investment

pliers to the other plants (in the case of Cluster D) or customers of the other plants (in the case of Cluster C) for components or semifinished goods. Kobrin (1991, p. 19) argued that "the two most important intrafirm flows are products and technology, and the latter is often embodied in the former," and also observed this link between knowledge and physical flows. Our research suggests that the product is not only a carrier of technological product and process innovation, but also of managerial innovations.

Third, we see that building network relations takes time. The average age of the networked plants (type C and D) is 28 years, whereas the average age of the two more isolated types of plants (type A and B) is only 15 years. The difference in age between these two groups is significant ($p < 1\%$). Networks apparently develop over a long period of time.

A fourth conclusion is that the four different network roles reflect very different plant characteristics. The "isolated" plant in Cluster A is very independent. In its isolated position, it does not contribute to the network, but on the other hand, it also does not depend on the other network units for its components or for maintaining or improving its manufacturing capabilities. Plant management has the capabilities to run the plant independently. The receivers in Cluster B typically are local players that need support—technical and/or managerial—of headquarters or the other plants in the network for their survival. They need this support either because of the negative attitude and lack of skills in the plant, or because of the strategic decision of headquarters to keep investments in the plant relatively low. The hosting network players (Cluster C) are typically fairly old, they supply a broad market, and they are characterized by a low level of managerial investment. The hosting network player has been observed in seven of the eight companies studied. With one exception, this role is played by only one of the plants per company. It is interesting that half of the eight C plants are the "mother plant," the earliest plant in the network, located close to headquarters. We hypothesize that because of its age, the broad market it supplies, and its easy access to headquarters, the plant has gained a lot of experience, which explains why the plant is seen as a competence center by other plants. The other four C plants are located close to another plant with which they have established tight relationships. The inflow of people in these C plants dominantly comes from this neighboring plant, which also has a higher level of strategic role. In two cases, the neighboring plant happens to be a D plant. The profile we see here is one of a satellite plant that is heavily influenced by the presence of another network unit. We conclude that the scenario which leads to a C-type plant seems to build on heritage: the network relationships exist because the plant has been in the network for a very long time and is located close to headquarters or to an active network player. The C plant seems to undergo this scenario in a passive way, rather than to play an active role in it.

The scenario that emerges from the characteristics of the type-D plants is more dynamic and active. These plants build capabilities through investments under a relatively high level of autonomy. Such plants are actively building network relationships by sending manufacturing staff to other plants and through extensive communication. It is their enthusiasm and their technical specialization that makes them an important network player.

From interaction with managers about the typology, we have noticed that the D cluster is an intriguing category for plant managers. The D plants are typically plants that act as a center of excellence or as a pilot plant for new products, they are regarded as the "think tank" or "engine" in the network, and are known as the technical "specialist" plant in the network (see Appendix 2). This intriguing profile raises questions as to the further evolution of these plants, which makes it an issue for future research.

Fifth, there is no significant difference in performance between the clusters. Reaching the targets on cost, quality, or time measures does not appear more or less difficult in the distinct clusters. This suggests that there is not a unique optimal network position for a plant. Rather, the network position of the plant should be regarded from a contingency perspective.

Finally, the analyses suggest that the future perspectives of the plant depend on the plant's network position. Plants that are strongly embedded in the production network are expected to maintain the high level of strategic role they are already playing in the network. The future of plants in rather isolated positions has been predicted to be in two opposite directions: some plants are expected to grow in strategic importance and are assumed to develop network relationships; others are expected to become less important and may even disappear from the manufacturing network. A possible explanation may be that in case of overcapacity and cost cutting, an "isolated" or "receiver" plant is a welcome candidate for disinvestment or closure. Closing such a plant implies a reduction of overall capacity, which is exactly what is aimed at. It does not imply, however, an important reduction in knowledge transfers because these plants do not contribute considerably to the other plants in the network. This is apparently a headquarters' decision plant managers are not aware of.

6. Contributions to Researchers and Practitioners

Previous classifications of plants have focused on the tangible characteristics of plants: the products the plant produces, the processes it has in place, the markets it serves, and the parts it supplies to other plants in the network (Hayes and Schmenner 1978). The typology developed in our research differs, as it classifies plants on the basis of their position in the intangible knowledge network. We focus primarily on flows of knowledge, rather than flows of goods. The conclusions of our work are therefore useful to any scholar who wants to study the architecture of knowledge networks in manufacturing, and eventually in other environments such as R&D or service operations.

The research has allowed us to identify, among the plants we studied, 12 network players, i.e., plants that showed a strong interaction with other units in the network. This interaction between plants is a fairly new trend, or at least, a trend not previously well documented. Moreover, our research offers a methodology for identifying network relationships in manufacturing networks.

To the manager in charge of a multinational network of manufacturing plants, the typology serves as a "toolbox" for drawing a map of the plant network. In our multiple discussions with managers about the typology, we learned that the typology has high face validity to them, and allows them to classify their plants, even without actually measuring the in- and out-flows of the plants. An evaluation of this map may help them in identifying possible gaps or unbalances. Because the position of the plant in the network does not impact the plant's performance, any of the types of plants can be effectively present in the network. If managers believe that their network would benefit from plants spreading best practices, they should identify which plants have active and hosting capabilities, and foster these plants in their network. However, the hosting network players seem to be a result of the past, while the existence of the active network players can be stimulated. Our research indicates what it takes to develop an active network player. On the other hand, the manager may find it wise to have some isolated plants or receivers (types A and B). These are quite mobile building blocks of the network. Reducing the number of isolated plants or receivers does not impact the potential for transferring knowledge. As such, the presence of isolated plants and receivers gives the manager some structural flexibility in managing his network.

To the plant manager, the research shows the danger of a protective attitude toward the exchange of knowledge. The isolated position taken by these plants may well result in a difference in view between plant managers and company managers about the strategic future of the plant.

7. Limitations and Future Research

An important limitation of the research is the focus on the intracompany network relationships. While we acknowledge that intercompany network relationships are important in creating sustainable competitive advantage, we have limited our research to the network relationships between units of the same company. Whether the hosting and active network players are also tightly embedded in the external, intercompany network with suppliers, customers, and other network partners remains to be studied.

Second, our research describes the strategic role played by plants in international plant networks. It identifies those plants that develop knowledge and capabilities and that transfer this knowledge to the other plants in the network. The research does not explain how this knowledge is developed, nor does it describe the mechanisms used for the diffusion of this knowledge and their effectiveness. Also, as stated earlier, the research is static and raises questions as to the further evolution of the plants and of their position in the network. This is an area of future research.

The absence of significance in the difference in performance in the network typology may point at a lack of difference in performance. However, it may as well be a consequence of the performance measure that has been used, which is static and rather restrictive (that is, performance relative to the target set for the plant) and operationalized as a perceptual measure. There is definitely still a need to study the relationship between plant performance and the position the plant plays in the manufacturing network.

Also, we did not make any assertions about the relationship between the portfolio of plants in terms of their network type and the performance of the company. We hypothesize that the optimal portfolio of plants is contingent on the company's competitive environment. However, this needs to be studied. As mentioned in the Methodology section (§3), this paper is based on case research. While one of the major advantages of case research is the depth of the information that can be collected, its major disadvantage is the limitation in sample size, and therefore the potential limitation in external validity. However, we are convinced that the careful selection of the cases from a diversity of industries improves the external validity of the work.

The cases have been limited to companies headquartered in Europe to avoid cultural differences between the cases. Whether the conclusions still hold in multinationals headquartered in other continents is unexplored and can be subject to future research.

Finally, the research focuses on manufacturing companies only. Whether a similar typology can be developed for service companies is an open question.

8. Conclusion

In the research, network analysis has been used as a methodology for understanding the position of plants in international manufacturing networks. The focus has been primarily on the intangible knowledge network, and secondarily on the physical, logistic network. A typology of plants in a manufacturing network has resulted from the research. Four types of plants, with a different strategic role, different characteristics, and different perspectives for the future have emerged. The typology indicates that flows of knowledge between plants seem to be reciprocal, and that there is a clear correlation between tangible and intangible flows in the network. The driver behind intensive network relations may be either heritage or a deliberate investment in capabilities inside the plant. Anyhow, building network relationships takes time. We have also observed that the future of plants that are tightly embedded in the network is more stable and secure.

Overall, this leads us to believe that in managing international networks of plants, managers can balance long-term knowledge development and medium-term flexibility. In approving investments in the network relationships, they allow some of the plants to play an active role in the creation and diffusion of knowledge in the network, thus creating long-term competitive advantage. The other plants provide the manager with strategic flexibility. Their role in the network can be adapted in the medium term, according to the changing needs of the business.

Appendix 1. Interrater Reliability Scores on Perceptual Measures

Construct	Factor	Item	ICC
Strategic role today			0.85
Strategic role 5 y Ahead			0.83
Operational autonomy	Logistics	Developing a master production schedule	0.81
		Developing material and capacity plans	0.78
		Developing the shop floor schedule	0.70
		Developing sales forecasts	0.89
		Placing purchasing orders	0.80
		Managing inventories	0.70
	Development and engineering	Developing new products	0.74
		Making changes to existing products	0.77
		Developing new production processes	0.78
		Making changes to existing production processes	0.79
Strategic autonomy	Operations of the plant	Decision to develop a new product	0.69
		Decision to make changes to an existing product design	0.76
		Selection of a new supplier	0.77
		Decision to introduce a new planning and control system	0.80
		Choice of standards, goals, and performance measures for quality management	0.70
	Design of the plant	Decision to develop a new production process	0.76
		Decision to make changes to an existing production process	0.78
		Choice of technology	0.73

Appendix 1. Continued.

Construct	Factor	Item	ICC
Investment	Process investment	Setup time reduction	0.67
		Plant automation	0.73
		Process analysis	0.73
		Productivity improvement	0.75
		Throughput time reduction	0.85
	Investment in planning	Material and/or capacity planning	0.57
		Just-in-time systems	0.72
	Managerial investment	Statistical process control	0.87
		Supplier partnerships	0.81
		Total quality management	0.89
		Employee participation programs	0.76
	New product investment	New product development	0.77
Plant capabilities	Level of resources	Capabilities in developing new products	0.66
		Managerial capabilities	0.62
	Not included in the analyses	Level of technical resources	0.34
Performance relative to target	Time performance	Manufacturing throughput time (from start until finish of production)	0.61
		Service level (on-time delivery to customers)	0.75
		Delivery lead time (from customer's order until delivery)	0.60
	Cost and quality performance	Average defect rates at the end of manufacturing	0.75
		Average unit production costs for a typical product	0.80
		Productivity of direct production workers	0.78
		Overall product quality as perceived by the customers	0.69
	Not included in the analyses	Rate of new product introduction	0.47
		Equipment setup time	0.54

Note. For most of the items the ICC exceeds 0.60, which is the cutoff value suggested by Boyer and Verma (2000). For the item "investments in materials and/or capacity planning," the ICC reaches 0.57. However, because this is very close to the cutoff level, the item has been retained in the analyses. The ICC cutoff level of 0.60 was not reached for the items "level of technical resources," "rate of new product introduction," and "equipment setup time." Consequently, these items have been omitted from the analyses.

Appendix 2. Overview of Interview Comments

Cluster A
- Independent (2×)
- Local (2×)
- Improved/learning (4×); problem solvers (2×)
- Manufacturing capabilities (7×)
- Motivated (2×); creative
- Development for their own
- Product focused

Cluster B
- Only executes (2×)
- *Some* development (9×); *a lot of* development (1×)
- Expert (in quality, service, material handling, CIM, energy savings)
- Limited; simple
- Complex; difficult; below expectation
- Local market (7×); Local improvements; local culture
- Needs help (2×); receives (technical) support (3×)
- Lives its own life; goes its own way; distance
- Lack of motivation; inflexible management; management problems (2×); lack of skills (4×);
- Insufficient experience; negative mentality; counterproductive mentality; mentality is to accept
- Problems as they come; social climate has improved
- Crew of Belgian managers; no own management; group of expatriates; satellite plant (2×);
- Management input from HQ; strong liaison manager in other plant

Cluster C
- Pilot plant (1×); test site (1×); development site (4×)
- Center of excellence (3×); center of competence
- Product know-how (3×); process know-how
- Training center
- Supports other plants (2×); motor for all products (1×)
- Close to HQ; home player; mother plant (1×)
- Quite motivated to experiment
- Lack of focus
- Lack of investment
- Satellite (1×)
- Product specialist

Cluster D
- Center of excellence (2×); development center; pilot plant (3×)
- Think tank; generator of ideas
- Atmosphere of activity; do-spirit; enthusiasm; happy to experiment
- Motor of the other plants; engine
- Gives technical assistance; high tech; specialist; process know-how
- Close to HQ (1×)

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