Strategic positioning of global manufacturing virtual networks in the aeronautical industry

Carlos Rodriguez Monroy* and José Ramón Vilana Art

Departamento de Ingeniería de Organización, Administración de Empresas y Estadística, E.T.S.I.I., Universidad Politécnica de Madrid, Madrid, Spain

The evolution of organisations that work in multinational environments has considerably altered their production strategies. One of the consequences has been the appearance of global manufacturing virtual networks (GMVNs), which include all kinds of production centres. These networks establish a new type of vertical and horizontal collaboration between independent companies or even competitors who launch occasional collaborations on projects they could not take on individually. The purpose of this paper is to analyze the main reasons that determine the formation of GMVNs as well as the strategy of the companies involved in these organizations and how GMVN will evolve in the future. For that purpose, a conceptual framework is proposed based on four network features: strategy, structure, communication systems and culture. This work will delve into the strategy network feature by applying a strategic positioning model to a practical case in the aeronautical industry to gain a better understanding of how GMVNs work, its effectiveness by clarifying and putting these organisations in perspective and how they may evolve in the future.

Keywords: global manufacturing virtual network; manufacturing strategies; mass customisation; aeronautical industry

1. Introduction

Today, the concept of plant or production centre is becoming increasingly more ambiguous. In many industries, there is growing collaboration between production centres and manufacturing networks that seek to respond to market demands more efficiently and obtain competitive advantages in an increasingly globalised environment. In some industries, such as the aeronautical industry (Chen, Shi, and Gregory 2003), the electronics industry (Shi and Gregory 2003) or the car industry, there is mention of global manufacturing virtual networks (GMVNs) based on a new manufacturing architecture model with a high development potential to satisfy an increasingly demanding and fragmented market (Shi and Gregory 2001). In short, these networks represent a compendium of the new tendencies within the production organisation, such as global manufacture, strategic alliances, flexible production and mass customisation.

The purpose of this study is to analyse how GMVNs appear in the market and evolve in the future by considering their main characteristics that will determine their strategy positioning through a period of time. Some special tools will be proposed to study this strategic decision that will determine the starting point of the GMVN building process. Subsequently, other network features and their potential evolution will be considered to achieve a better understanding of how and why these organisations work. For achieving that purpose a case study about the engine manufacturer Rolls-Royce will be developed by analysing already established and known facts on a new perspective that allows us to gain a comprehensive understanding about GMVNs. There appear to be very few theoretical models or studies on actually how GMVNs work. Even though they are known to develop on a large scale and involve a complex number of participants that include enterprises, organisations and institutions, there are no complete models that define in a clear manner how they function and why they emerge. The initial descriptive approach about GMVNs, mostly developed in Section 5, based on the new perspective given by the conceptual models defined in Figures 2 and 5 allows us to gain a broad understanding of how these organisations work. Finally, Subsection 5.3 and Section 6 give some prescriptive propositions about how GMVNs should work and efficiently evolve in the future.

The environment in which enterprises currently work with increasingly globalised markets, company consolidation and strategic alliances is forcing companies to find new forms of collaboration to improve the integration and synchronisation of the various functions and stages of their product value chain (Zhao, Shi, and Gregory 2001). GMVNs allow companies to focus on their core competences, maintaining their participation in the design and manufacture of complex integrated systems. These networks can be considered as extended manufacturing systems where various companies can co-operate on a specific project whose result is the manufacture of a product or the provision of a service and where each company is expert in one or more of the areas that give the product its value (Elmuti and Kathawala 2001).

The implications in the various manufacturing fields are manifold and knowing how they are structured, how they coordinate and plan their needs and implement their supply chain management, what their specific competences are and how the different members of the network

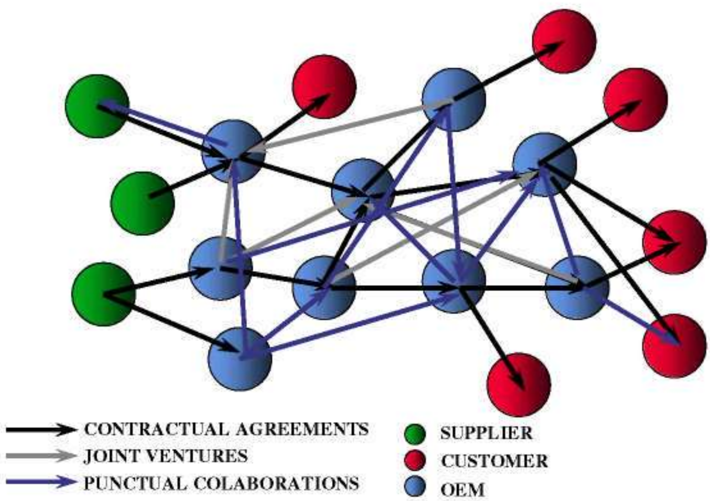

Figure 1. Structure of global manufacturing virtual networks.

communicate are some of the features this paper seeks to clarify. In addition, market demands for increasingly customised products and services lead to the implementation of new manufacturing techniques such as mass customisation, where the complexity of the implementation, the information flow or the planning of resources complicate the management of this type of network even further. Figure 1 gives a simple example of the structure of this type of network, together with the relations between the nodes.

2. Literature review and theoretical background

First studies about multi-plant organisations started by early 1980s. These works were principally based on location criteria. When a network structure was implanted each factory was considered as an independent centre ignoring the network structure (Schmenner 1982) and potential synergies. During these years, even though globalisation of markets started to rise, operations and production organisation studies were only concerned about independent manufacturing centres.

In the late 1980s and early 1990s, because of the intense growing demand of global markets, many companies seriously considered the benefits of interconnected manufacturing networks. A number of scholars have approached network manufacturing research from different perspectives: Shi and Gregory (2001, 2003), Shi, Fleet, and Gregory (2005) and Rudberg and Olhager (2003a, 2003b, 2008) assessed these organisations from a strategic approach. Shi and Gregory (1998) analysed the interdependence of manufacturing centres where all matrix connexions where considered. Khurana and Talbot (1999) studied how factories could influence each other in a network structure. DuBois and Toyne (1993) and Ferdows (1997), Sturgeon (2002), Williams et al. (2001), Colotla (2002), Vereecke and Van Dierdonck (1999), focused on structural issues. Gailbraith (1990) and Flaherty (1996) analysed their communication systems and Sturgeon (2002) surveyed the cultural aspects of these networks.

First manufacturing networks were constituted by a number of factories dispersed geographically to obtain certain competitive advantages like access to low production costs, qualified labour and proximity to strategic markets (Ferdows and Ferdon 1989; Ferdows 1997; Vereecke and Van Dierdonck 1999). Anyhow, all these manufacturing centres were mostly owned by one or very few companies. Thus the ‘virtualisation’ degree of the network was very limited. It is understood that the virtual component of the network is related to the intensity of the collaborations with companies external to the organisation itself (Shi and Gregory 2001). This is the case for DEC where Arntzen et al. (1995) analysed how Digital Equipment Corporation redesigned its network including the relocation of some of its nodes at a corporate level. Other relevant studies about manufacturing networks with low ‘virtualisation’ are Acer (Mathews and Snow 1998), Procter & Gamble (Camm 1997) and Hewlett Packard (Lee 1995).

Li, Shi, and Gregory (2000) were the first to name ‘global manufacturing virtual networks’ by proposing a strategic positioning model for these organisations based on three vectors: globalisation, strategic alliances and value and supply chains. These networks are more complex structures formed by several companies and several production centres based on horizontal and vertical relations among independent companies or even competitors that establish punctual collaborations in projects that they could not afford individually. In some industries such as aeronautics (Shi, Fleet, and Gregory 2005), electronics (Shi and Gregory 2003) and the automotive industry (Sturgeon 1999), GMVNs have become a growing phenomenon with a high potential for development in order to satisfy an ever more demanding and fragmented market (Shi and Gregory 2001).

Other relevant works about these organisations were made by Johansen and Comstock (2005) who analysed the production strategy change of the aeronautical manufacturer SAAB AERO to join the Airbus manufacturing network. Meixell, Wu, and Kamrani (2004) studied the convergence of these organisations with mass customisation systems and Williams et al. (2001) surveyed the relations among supply chain members and offset strategies in the global aerospace sector.

In the late 2000s, many scholars have approached the GMVN phenomenon from different perspectives to achieve a detailed understanding of some network features such as their structure, information systems or alliance models. Anyhow, some research fields, such as collaborative strategies among network actors or cross-cultural attributes at network level, need further development. Future works should also delve into a comprehensive understanding of all features of GMVNs and their interdependence. By understanding the main building blocks of these organisations and their management processes, it will be possible to formulate a strategy and design process for developing effective GMVNs in the future.

3. Research design and methodology

This paper is a part of a research work about modelling of GMVNs. Since little is known about how GMVNs work with a comprehensive perspective, methodology used has been exploratory and descriptive (Yin 1994) based on a case study with a qualitative approach. Exploratory studies are appropriate when the research problem is difficult to define and the availability of data and knowledge is difficult. A qualitative case study approach has a distinct advantage when 'how' or 'why' questions are being asked about a contemporary set of events over which the investigator has little or no control. This qualitative approach, based on a case study, has been applied to the engine manufacturer, Rolls-Royce. Thus, it will allow us to study this GMVN phenomenon from the inside and gain a deeper understanding as opposed to a quantitative approach which is more convenient when a clearly stated hypothesis can be tested on well-defined narrow studies. The data for this paper, which was collected through interviews, literature reviews, documentation studies and on-site observations, will give the research relatively high construct validity (Yin 1994).

Data were obtained through a number of visits over a six-year period (1999–2005), to the most relevant engine manufacturing plants within the aeronautical industry in Europe: Volvo Aero (Trollhättan, Sweden), SNECMA (Evry-Corbeil, France), MTU (Munich and Hannover, Germany), GE Aero (Caledonian, UK and Eskiseir, Turkey), ITP (Zamudio and Ajalvir, Spain), IAI (Israel) and Rolls-Royce (Hillington, UK and Oberursel, Germany). These companies and locations were chosen because of their high level of participation and cooperation in international projects to manufacture several types of aero engines.

Finally, Yin (1994) affirms that since case studies rely on analytical generalisations, external validity of findings should be high. However since this work only involves one case study, the ability to generalise is rather low. Thus more extensive case studies in the future involving other similar companies or different industrial sectors where GMVNs are starting to grow rapidly (e.g. automotive or electronics industries) might underline and agree with the findings of this work.

4. Development of the conceptual framework

To study this new phenomenon of collaboration between production centres and understand the nature of GMVNs in more detail, a conceptual framework is proposed in accordance with the diagram shown in Figure 2, based on Ayers's customer-centric model (2002) and the proposal put forward by Johansen and Comstock (2005). The said framework is to be used as a platform for

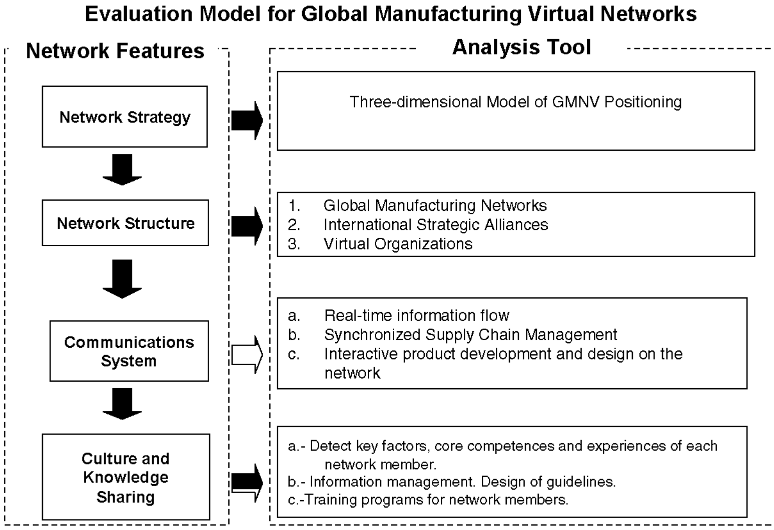

Figure 2. Evaluation model of global manufacturing virtual networks.

analysing this type of network. This diagram enables the sequential analysis of all the characteristics that affect the design of a GMVN, such as its strategy, structure, communication systems and network culture.

The strategy of GMVNs is one of the network features to bear in mind. The manufacture of some aeronautical motors involves the participation of the great majority of manufacturers (competitors) in the market, as in the case of the GP 7200 that powers the new Airbus 380 whose manufacture is being done by an alliance between General Electric and Pratt & Whitney with collaborations from MTU Aero Engines, SNECMA and Tech Space Aero. This paradox is permitted by the OEMs (original equipment manufacturers), because the benefits obtained through this collaboration are much greater than the inherent risks of collaborative manufacturing. The close collaboration between competitor OEMs in the same sector is very frequent in GMVNs and, therefore, one can consider the validity of the classical two-dimensional Porterian model. Strategy in GMVNs follow different patterns and, for a better understanding of this phenomenon, a three-dimensional model for strategic positioning will be developed in this work.

The network structure feature includes the performance of its main actors (the nodes of the network), as well as the type of relations and collaborations that are established among its members. These collaborations can be long-term based strategic alliances (e.g. the CFM 56 aero engine manufactured by a 50–50 joint venture between GE and SNECMA) or punctual collaborations with high virtual relations. The nature of its nodes (network actors) and their relations must not just be regarded as something static and rigid but instead as a system undergoing a continual process of change with, in some cases, diffuse and variable structure.

The third relevant network feature of GMVNs is the network's communication system. This feature would include all IT and communications tools that the network needs to operate. Many authors have studied this field including Li, Yu, and Fang (2004) on manufacturing grids and Jiao, Xiao, and Kumar (2006) on collaborative manufacturing. These studies analyse how to coordinate the utilisation of design and manufacturing resources that are heterogeneous, independent and distributed throughout the network. In the new development of the model 787 Boeing, a new concept of virtual design and manufacture has been implemented known as Global Collaborative Environment formed by a platform on the Internet that links up all the participants, internal and external, in the project, independently of their location and permits them to jointly design and virtually simulate not just the functioning of the parts independently, but also the entire process of structural sub-units of the plane. A final relevant aspect of GMVNs is their culture. Analysing how to overcome the fear inherent to collaborating with companies outside of one's organisation, in some cases competitors is one of the challenges of GMVNs.

The mutual dependence and influence of these four network features is something to be taken into consideration. The degree of 'virtualisation' of a GMVN will be inversely proportional to the intensity of formal and informal information flows and will influence the type and efficiency of communications systems in the network. The strategy chosen (e.g. more international alliances with external companies in order to access new markets, diversify financial risk or access new technologies) will influence the network structure (e.g. increase of virtual relations), communications systems (e.g. supply chain synchronisation or harmonisation, Rudberg and Olhager 2003a) and cultural aspects of the GMVNs. This paper will investigate the strategy network feature by analysing a practical case in the aeronautical industry, i.e. the global network of the engine manufacturer, Rolls-Royce (RR).

5. Global manufacturing virtual networks in the aeronautical industry: Rolls-Royce – a practical case

From its origins at the beginning of the 20th century, the aeronautical industry in a comparatively short period of time, has adopted various production strategies and organisation methods ranging from the craft processes of its beginnings to the GMVNs that constitute the way in which commercial aircraft are manufactured today, including the mass production systems that were implemented during the Second World War, technological innovations and the future mass customisation systems that will constitute the trend of this century (Figure 3). This industry may

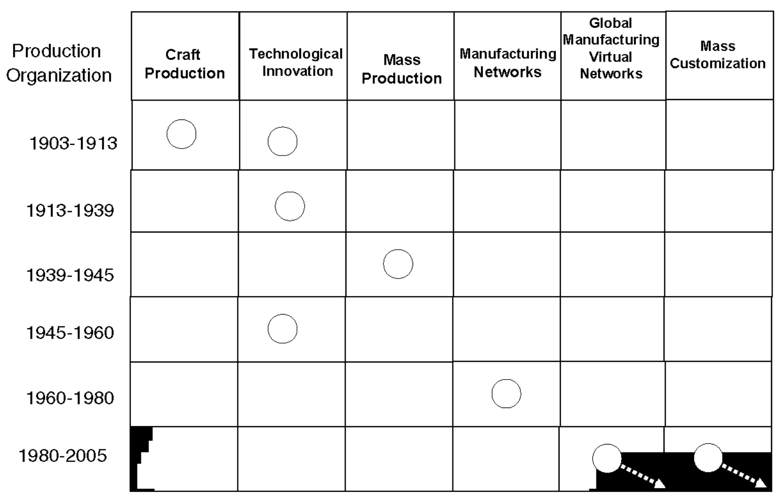

Figure 3. Production organisation evolution within the aeronautical industry.

represent a good compendium of how production strategy has evolved and will be used to apply the conceptual model described above.

Rolls-Royce is currently one of the world leaders in the manufacture of engines for the civil and military aeronautical industry. The structure of the RR manufacturing centre network in the world is organised in such a way that each centre specialises in one or more engine components, which enables greater technical specialisation and larger economies of scale. As a result, today, unlike the organisation it had in the 1960s and 1970s, no single centre is capable of manufacturing an entire engine.

To see how the network is structured, it must be understood that for each engine model or project, there will be a different supply chain on the network itself in accordance with a set of basic premises. Each manufacturing network will use the internal and external resources it requires, such as research centres, technology or component suppliers, own manufacturing centres, as well as horizontal collaborations with companies that manufacture engines.

Figure 4 shows a simplified diagram of an aircraft engine to give an example of how its components might be manufactured at the various manufacturing centres in the network, the result of the collaboration between GE and RR on a new engine.

5.1. *Global manufacturing virtual network strategy*

At present, companies need to focus strategically on their main competences to offer greater value added in the supply chain. Accordingly, a growing trend today is the subcontracting of the manufacturing process to external collaborators or suppliers. The traditional relations between vertically integrated manufacturers, component suppliers and distributors are currently under reconsideration and being compared with horizontal business collaborations between OEMs, highly specialised technology companies, component suppliers and distributors that form dynamically changing collaboration networks depending on each product, client and moment in time. In these GMVNs, the main company does not need to maintain internal manufacturing resources to cope with unpredictable variations in demand (Li, Shi, and Gregory 2000). Rather, they are based on relations with the various components of a virtual network that enables the company to design a specific supply chain in accordance with each client or specific contract. Therefore, this type of network is not based on the possession of certain resources that condition what can be produced, when, and how much, but rather on managing and sharing the network resources.

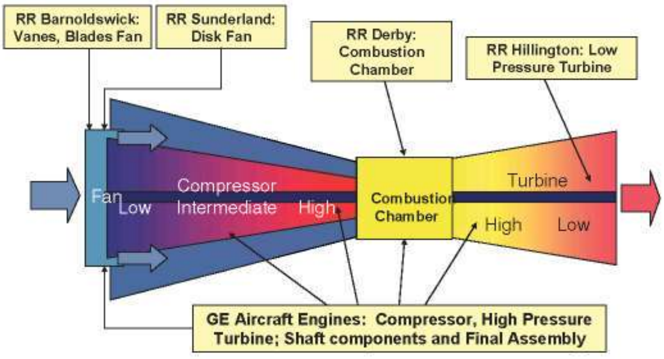

Figure 4. Example of a new engine manufacturing diagram in a GE–RR collaboration.

One of the most significant trends in the changes occurring to today's manufacturing systems, especially in the aforementioned industrial sectors, is the substitution of vertical integrations or relations with horizontal relations between competitors or enterprises specialising in very specific technologies to allow companies to focus on their main competences (Colotla 2002). Paradoxically, this type of collaboration, which leads to a GMVN, will allow them to provide their clients with highly flexible global solutions depending on market demands at any given time.

When designing a GMVN, consideration must be given to the strategy of the preferred manufacturing system. Accordingly, three basic factors are taken into account:

(1) Internationalisation of the manufacturing process: the manufacturing process is no longer considered as one single production centre, but rather has to include expansion or dispersion plants in accordance with the company's current strategy. In this case, it will be necessary to take decisions about location criteria to obtain certain competitive advantages like access to low production costs, qualified labour or proximity to strategic markets.
(2) Supply and value chain: the various tasks involved in the manufacturing process and carried out on the network must be defined throughout the product value chain. Subsequently, which part of the chain will be controlled by the company or will be outsourced to the network resources must be specified. In addition, this comprehensive view of the process will enable optimisation through the selection of internal and external activities and collaborators to achieve higher value and competitive advantage.
(3) Strategic alliances: a very broad range of possible forms of intercompany collaboration must be assessed, ranging from specific collaborations on certain projects to long-term joint ventures or strategic alliances.

These three factors described above should be considered as the basic manufacturing strategic decisions to be taken when designing a GMVN. They cannot be considered separately, but rather as part of an integrated manufacturing system. The source of these factors, to be taken into account when designing a GMVN, must be consistent with the own company strategy.

Figure 5, based on a three-dimensional model developed by Shi, Fleet, and Gregory (2005), represents in a clear manner, these three factors. Each dimension corresponds to one of the three mentioned independent factors to take into account when analysing a GMVN: (1)

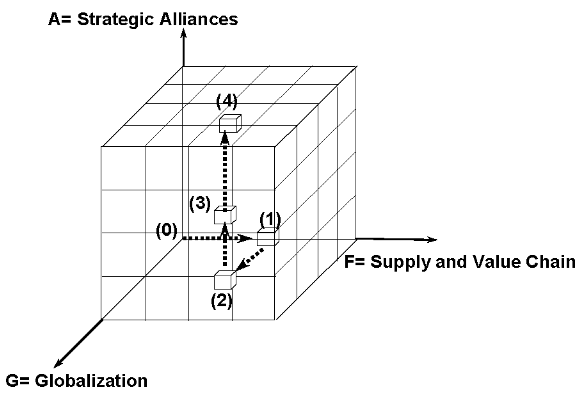

Figure 5. Strategic positioning of Rolls-Royce global manufacturing virtual network.

Internationalisation of the manufacturing process, (2) Supply and value chain and (3) Strategic alliances. The vector resulting from these three factors, referred to as the integration process, summarises the type of GMVN, synthesises this new manufacturing strategy into the company and provides a qualitative idea of its strategic positioning.

Once the strategy positioning of a GMVN is defined, the other network features described in Figure 2 like structure, communication systems and culture can be subsequently determined. These four network features have a mutual influence and interdependence. For example, a network strategy based on more international alliances with external companies to have access to new technology or diversify financial risks will determine the network structure (e.g. increase of virtual relations), communications systems (e.g. collaborative manufacturing IT platforms) and network culture (e.g. inter-company cultural issues). The next section will investigate the strategy network feature by analysing a practical case in the aeronautical industry, i.e. the global network of the engine manufacturer (RR).

5.2. *Global manufacturing virtual network positioning of Rolls-Royce*

The three-dimensional figure shown in Figure 5 describes the positioning of the GMVN in which RR has changed its production strategy over time.

In Figure 5, G represents the degree of globalisation or internationalisation of the manufacturing system, F represents the creation of value obtained from the integration of the various supply and value chains formed by the companies that take part in the network, determined by the synergies and value added resulting from the integration of the various production centres, and A represents the level of collaboration between the various companies that define the strategic alliances on the network. Strong strategic alliances will allow for closer, long-term collaborations whereas more occasional collaborations will furnish the network with greater flexibility.

A dimension, in other words, represents the degree of 'virtualisation' of the GMVN. It is understood that the virtual component of the network is related to the intensity of the collaborations with companies external to the organisation itself (Shi and Gregory 2001). Obviously, the relations among the nodes of the network will be largely determined by whether or not one belongs to any organisation of the network and the flows of information, materials or synchronisation of the different nodes will depend on the type of organisation on which they depend in the network. A network with low virtualisation would be formed by just one or a few companies with some dependent manufacturing centres constituting a network with strong relations among its nodes that can specialise in terms of product or process, following different strategic criteria of the company. In these organisations, the important thing would be the nodes of the network where aspects related to the optimisation of the manufacturing centres would have more importance, as if one were dealing with a 'black box', an endogamous model based on the internal efficiency of the production process. In GMVNs with high 'virtualisation' degree, the important thing would be the relations established between the different nodes. In this type of network the location of the different centres of a company will be a decision taken at the independent corporate level but which will take into account the location of other centres of independent companies in the network. In GMVNs, their members can choose a specific supply chain of the network depending on the type of product or service desired. When discussing the size of a GMVN aspects will be taken into account such as the relations between the different nodes of the network and the number of organisations that the network encompasses.

The vector resulting from the three-dimensional variables provides a qualitative idea of the type of GMVN in question.

It is interesting to note that in the design of traditional manufacturing systems, the dimensions of internationalisation (G) or collaboration (A) are rarely given consideration and only the impact of the manufacturing process on the product value chain (F) is considered. The current studies carried out on manufacturing systems are usually limited to two dimensions: on the one hand, the companies that consider only the G × F plane, where consideration is given to internationalisation and the product supply and value chains, but collaboration with external companies is ignored; and, on the other, the G × A plane, which studies the internationalisation of production processes and strategic alliances without considering the value added that could be obtained through the integration of the corresponding value chains. The overall view of the three dimensions has been the subject of little study and, therefore, the true potential of GMVNs has not been analysed.

Point (0) of Figure 5 refers to RR's beginnings in 1953, when it started up its aircraft engine manufacturing activity with a model called Dart, manufactured entirely at one of its plants in the UK. Point (1) shows the decentralisation of the manufacturing processes begun by RR after it was privatised in 1987. Point (2) indicates the company's internationalisation after privatisation; however, this process did not include any significant collaboration with other companies. Point (3) shows the current situation, which presents a highly globalised company with manufacturing centres distributed all over the world (each centre specialising in one or more engine subunits), integrated supply chains that add value and a high level of participation in international projects in collaboration with other companies to form an authentic virtual network.

The aim of this network is to satisfy a number of requirements that previously limited its expansion policy, such as the possibility of incorporating technological innovations into its engines, reducing financial risks with regard to new engine projects, reducing its own manufacturing resources by subcontracting subunits to collaborating companies, with each centre specialising in one type of engine technology, and achieving economies of scale by the production process of each manufacturing centre on the network specialising in one or more engine components or subunits. In addition, by reducing its manufacturing resources, RR has become more flexible with regard to reacting to changes in market demand, maintaining the main competences of its organisation, which, within the scope of the manufacturing process, include the design and development of the engines and the assembly and final testing stages.

Rolls-Royce's strategy in the network is to change the supply chain in accordance with the project or engine type in question. In the case of its Trent engine family, there is very little horizontal collaboration, because it has a highly consolidated position in the market and has been manufactured for many years. The manufacturing process is carried out at RR manufacturing centres or companies in which the company has significant holdings in the share capital. Each centre makes one or more engine components that are finally assembled and tested at its facilities in Derby in the UK. However, in the case of the new TP 400-D6 engine that powers the Airbus 400M, the supply chain is based on horizontal collaboration with manufacturers, in some cases, direct competitors (e.g. MTU, ITP and SNECMA), to form an authentic virtual network whose external participants work together on the specific manufacture of the engine. The benefits of this type of collaboration are beyond question since they allow an approach to high-financial-risk projects, resulting in greater technical specialisation of the components and a highly flexible production.

Point (4) in Figure 5 indicates the company's trend for the coming years, where external collaboration will be used more and more to the point where the company's own resources would be decapitalised. The future of this type of network is not based on the internal maintenance of manufacturing resources to satisfy unpredictable variations in demand. Rather, it is based on relations with the various components of a virtual network that allow the company to design a specific supply chain in accordance with each engine type or client. Therefore, this type of network is not based on the possession of certain own resources that condition what can be produced, when it can be produced and how much, but rather on managing and sharing the network resources.

Figure 6 is based on the three-dimensional figure shown before and can be used as a very interesting analysis tool (Shi, Fleet, and Gregory 2005). It is related to the A dimension of the three-dimensional strategic positioning model of Figure 5 where the nature and dynamics of external collaborations are more detailed. As described before, a high A value means more external collaborations in the network, but these collaborations can be formed by a broad range of intercompany relationships. Figure 6 shows the range of possibilities for positioning a network between virtual organisations (VO) and international strategic alliances (ISA). GMVNs can be positioned within this spectrum in accordance with their strategy and based on the flexibility afforded by virtual organisations to attract new business opportunities or enter new markets and the ability of strategic alliances to increase levels of capacity and improve relations in the long term. This positioning should not be considered as an immovable, hierarchical concept, but rather as a dynamic positioning that can be modified in time in accordance with the market situation as it changes.

Figure 7 shows some of the engines and projects in which RR takes part. The more stable projects appear at the top of the table, with more lasting relations between the members of the network in the form of strategic alliances, as is the case with the Trent engine family and the company's long-term relations with enterprises such as ITP. For projects at earlier stages, where the risk is higher, such as the new TP 400-D6 engine that powers the Airbus A400M, specific horizontal relations are established. Between the two, there are projects such as the new Trent 900 engine for the Airbus A380, based on collaboration with external companies, albeit true that the project is still clearly led by RR.

5.3. *Rolls-Royce GMVN case considerations*

In most cases, the formation of GMVNs follows four strategic focuses: (1) operative excellence; (2) access to new markets – geographical, product, client segments and offset strategies; (3) diversification of financial risks; and (4) access to new technologies.

The three-dimensional model of Figure 5 applied to the production strategy of RR over time has provided a qualitative idea of the evolution of its manufacturing strategy since the beginning in order to estimate the trend for the coming years. This tool may allow us to compare the strategic positioning of RR with other engine manufacturers or to estimate a better strategy for the future. Figures 6 and 7 have provided a good idea of the nature and dynamics of external collaborations of RR manufacturing network as well as the flexibility that can be adopted depending on each engine or project.

The development of virtual relations by companies within GMVNs is a good strategy when they want to enter into new projects and thus diversify financial risks or have access to new technologies. Anyway, the more these projects consolidate (e.g. stable market share or technology maturity), the less 'virtualisation' degree they should have to avoid or minimise some inherent risks with these kind of collaborations such as technology transfer, role cannibalisation or loss of manufacturing process control. Virtual relations are very useful, as well, to allow medium-to-small sized companies to enter in GMVNs and participate in projects or products they could never afford to accomplish independently.

Anyhow, the RR case studied has mostly analysed the strategy network feature of RR included in Figure 2. The different strategy positions of RR over time will have a strong impact on other network features like its structure, its information systems and its culture that could be extensively studied in future research works to complete the findings of this work.

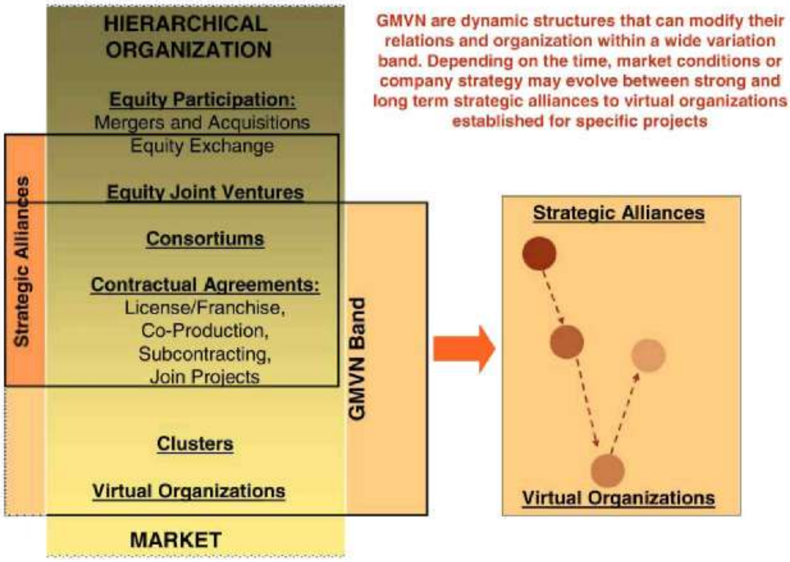

Figure 6. GMVN band.

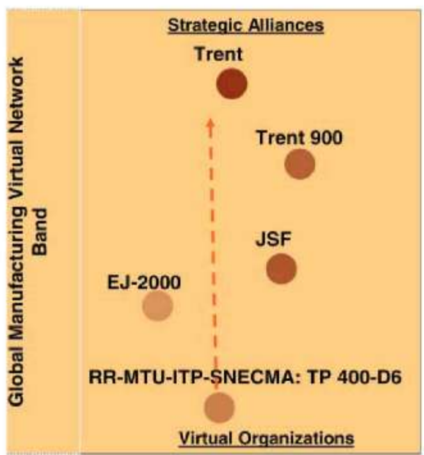

Figure 7. GMVN positioning depending on each project.

6. Future evolution of global manufacturing virtual networks in the aeronautical industry: mass customisation and 'network virtualisation'

The challenge now is to forecast what the next step will be, how the manufacturing systems will evolve in the coming years with regard to these GMVNs and what the determining factors behind the development of this industry will be. Basically, there are two clear trends in the production strategies of these networks in the aeronautical industry: (1) the convergence between this type of network and mass customisation systems; and (2) a greater 'virtualisation' of the networks leading to the decapitalisation of a large part of the companies' manufacturing resources in favour of a greater specialisation in one or more aircraft engine components.

6.1. *Mass customisation in the GMVN of the aeronautical industry*

The Society of Manufacturing Engineers (Christman 2003) has referred to mass customisation and to the collaboration of manufacturing networks as two of the most important trends in production strategies for the 21st century. Meixell, Wu, and Kamrani (2004) and Kamrani and Chandra (2004) have also mentioned the importance of mass customisation in the context of global manufacturing networks, highlighting the importance and difficulty of supply chain management in these environments.

Although it is not at all simple to consider all the possibilities of this convergence, it is possible to estimate the feasibility of the process and the profits that would be obtained. GMVNs are based on a dispersed manufacturing process which, in most cases, implies the manufacturing of the product by modules or independent subunits or in completely separate stages of the product chain. As a result, the application of mass customisation techniques, such as the modularisation of products (Ulrich 1995) or the customisation during the latter stages of production is possible.

According to Bugos (2001), customisation in this industry began with the introduction in 1970 of the Boeing 747. When this plane was supplied to the airlines of each country, it was discovered that each one had slightly different requirements, which forced Boeing, McDonnell Douglas and Airbus to implement new mass customisation methods through the application of small final adaptations in their mass production processes, such as that implemented by Boeing in its wing production process. However, mass customisation will be implemented on a large scale in the aeronautical industry as a natural process resulting from GMVNs and the varied requirements of an increasingly demanding market that seeks differentiation through customised aircraft that satisfy the particularities of clients or their strategic positioning on the market without increases in the price of the aircraft in question.

Within GMVNs, mass customisation becomes a feasible model that was almost unthinkable in the past. The dispersion of the manufacturing process requires greater specialisation in one or more specific components in comparison with the all-round solutions that were supplied previously. As a result, in this context, mass customisation systems will be based on two fundamental trends: product modularity and superficial changes in the final stages of the value chain:

(1) *Product modularity.* This will be one of the fundamental factors behind the effective implementation of mass customisation in the aeronautical industry. Product modularity refers to a design of the product that allows for the combination of different components or subunits in such a way that the client can choose from several options for each module. This feature can be implemented seamlessly in GMVNs, since the network involves the dispersion of manufacturing processes and, for the said processes to be efficient, some kind of product modularity is necessary so that its manufacture can be broken down into similar subunits for later assembly. By dispersing the manufacturing process over a network, the modularity of the product design is almost a fundamental requirement for the efficiency of the GMVN. When manufacturing products based on GMVNs, modular design is a must to be efficient. Thus GMVNs might smooth the way of mass customisation products in the network. This approach could be efficiently applied to structural subsystems of the aircraft like engines or fuselage.

(2) *'Superficial' changes.* Mass customisation through changes in the final stages of the value chain will be one of the most effective techniques to be implemented in the aeronautical

industry. Many manufacturers have uncovered the market's need for changes to the variety and specifications of the aircraft and at structural subsystem level (wings, engines, fuselage, cabin, etc.); however, at the same time, they have found that the existing processes can satisfy these changes in the demand. In other words, new market requirements focus on 'superficial' changes to the aircraft, which, in most cases, do not require substantial changes to either the manufacturing networks or the internal production processes. The new Airbus A380 has already implemented this option by offering various internal configurations of the inhabitable area of the aircraft and, in the coming years, the concept will be applied to other subunits with no substantial effect on the manufacturing processes. The origin of this trend lies in the requirements of a market that is becoming more and more demanding and versatile and seeks to provide its clients with a differentiated service.

6.2. *'Virtualisation' of the network in the aeronautical industry*

Another trend that will gain in significance in the production strategy of these networks in the aeronautical industry is the increase in virtual collaborations between external companies for specific projects. The benefits of this type of collaboration will mean that companies will not need to maintain internal manufacturing resources, since they will be able to use the network resources and assume greater flexibility to satisfy unpredictable variations to the demand. The manufacturing systems of the future will be based on relations with the various components of a virtual network that enable the company to design a specific supply chain in accordance with each engine type or client. In short, this type of network will not be based on the possession of specific resources, but on managing and sharing the resources available on the network.

Consequently, as with other manufacturing companies, RR shall tend more towards specialisation. Participation in every stage of an engine's value chain will no longer be profitable and companies will have to specialise in a number of main competences, such as design or a specific structural subunit (e.g. a compressor), leaving the responsibility for other structural subunits or specific technologies to other companies on the network.

7. Conclusions

GMVNs are based on three basic vectors: the globalisation of internal manufacturing processes; the supply and value chains of all the centres involved; and strategic alliances with companies outside the organisation. Although this type of intercompany collaboration is becoming more and more common, especially in the aeronautical industry, the car industry and the electronics sector, there are currently no models that describe how the networks operate or how they should be managed or designed. Their future growth potential is huge, since, on the one hand, they are more efficient at meeting the requirements of a market that is becoming increasingly varied and variable in its search for customised solutions at very competitive prices and, on the other, they allow manufacturers to reduce their financial risk by disinvesting heavy internal manufacturing resources, access new markets and seamlessly incorporate technological improvements to their products. In addition, the future evolution of this type of network will be based on a greater 'virtualisation' of the network and a convergence with mass customisation systems.

The conceptual framework proposed in Figure 2 permits a sequential analysis of all the characteristics that affect the design of a GMVN, such as its strategy, structure, communication systems and network culture as well as taking into consideration the mutual dependence and influence of these four network features. The three-dimensional model of Figure 5 applied to the production strategy of RR over time has provided a better understanding of the evolution of its strategic positioning since its beginning and has permitted the estimatation of its evolution for the next years. This powerful tool may allow us to compare the strategic positioning of different companies and estimate a better strategy for the future. Figures 6 and 7 have provided a good understanding about of the dynamic and fluent nature of the virtual relations in a GMVN as well as the flexibility that can be adopted depending on each engine or project. Anyway, since this work has been focused mostly on the strategy network feature of RR, future research works could extend the analysis to other network features such as its structure, its communication systems or its culture that have evidently been affected by the different strategy positions of RR over time. This approach should both confirm and complete the findings of this work in the future.

Other further investigation fields could be based on additional case studies within the aeronautical industry or extensive analysis of other industrial sectors where GMVNs are starting to grow rapidly (e.g. automotive or electronics industries). The future evolution of GMVNs such as by a greater 'virtualisation' resulting from higher specialisation among the member companies should be also taken into consideration.

Notes on contributors

Carlos Rodríguez Monroy is professor of Corporate Strategy and Business Administration at Madrid Technical University (UPM). He coordinates doctoral programmes in collaboration with Latin American universities. He holds a degree in Industrial Engineering (1973) and a PhD degree in Industrial Organisation (1991) from UPM. He has coordinated two Erasmus-Mundus Master Programmes and is an active member of LACCEI (Latin American and Caribbean Consortium of Engineering Institutions).

José Ramón Vilana holds a MSc degree in Industrial Engineering from the University Pontificia de Comillas (ICAI), an MBA from Madrid Technical University (UPM), Executive MBA at Instituto de Empresa and is a PhD candidate in Industrial Organization at UPM. During last 8 years, he carried out the position of European Turbine Manager at Sulzer Metco. At present, he is Managing Director at Bystronic Ibérica.

References

Arntzen, B.C., G. Brown, T.P. Harrison, and L.L. Trafton. 1995. Global supply chain management at Digital Equipment Corporation. *Interfaces* 25, no. 1: 69–93.

Ayers, J. 2002. Supply chain management and the manufacturing enterprise wheel. Published by the Computer and Autom Systems Association of the Society of Manufacturing Engineers, (CASA/SME). Blue book series. Dearborn, Michigan. ISBN 0895-5085.

Bugos, G. 2001. History of the aerospace industry. EH.Net Encyclopedia, available at: http://eh.net/encyclopedia/article/bugos.aerospace.industry.history (accessed 13 August 2005).

Camm, J.D., Chorman, T.R., Dill, F.A., Dennis, J.R., Sweeney, J., and Glenn Wegryn, W. 1997. Blending OR/MS, judgement, and GIS: Restructuring P&G's supply chain. *Interfaces* 27, no. 1: 128–442.

Chen, B., Y. Shi, and M. Gregory. 2003. The aerospace system integration business: Context, content and implementation. Paper presented at the Joint International Conference of the European Operations Management Association and the Production and Operations Management Society, 16–18 June, Cernobbio, Italy.

Christman, A. 2003. CAD/CAM outlook: Some thoughts on world-class manufacturing. *Modern Machine Shop*, available at: http://www.mmsonline.com/articles/1003cad.html (accessed 10 July 2005).

Colotla, I. 2002. Global manufacturing strategy process: A proposal for a process approach integrating factory and network perspectives. Paper presented at 7th Annual Cambridge International Manufacturing Symposium Proceedings, 19–20 September, Cambridge, UK.

Du Bois, F.L., Toyne, B., and Oliff, M.D. 1993. International manufacturing strategies of US multinationals: A conceptual framework based on a four-industry study. *Journal of International Business Studies* 24, no.2: 307–33.

Elmuti, D., and Y. Kathawala. 2001. An overview of strategic alliances. *Management Decision* 39: 205–17.

Ferdows, K. 1997. Making the most of foreign factories. *Harvard Business Review* 75, no. 2: 73–88.

Ferdows, K., and K. Ferdons. 1989. *Mapping international factory networks.* Amsterdam: Elsevier Science.
Flaherty, M.T. 1996. *Global operations management.* New York: McGraw-Hill.
Gailbraith, C.S. 1990. Transferring core manufacturing technologies in high-technology/RMS. *California Management Review* 32, no. 4: 56–70.
Jiao, R., Y. Xiao, and A. Kumar. 2006. An agent-based framework for collaborative negotiation in the global manufacturing supply chain. *Network Robotics and Computer-Integrated Manufacturing* 22: 239–55.
Johansen, K., and M. Comstock. 2005. Coordination in collaborative manufacturing mega-networks: A case study. *Journal of Engineering and Technology Management* 22, no. 3: 226-44.
Kamrani, A.K., and C. Chandra. 2004. *Mass customization: A supply chain approach.* New York: Kluwer Academic.
Khurana, A., and B. Talbot. 1999. Plant missions in global manufacturing networks: A resource-based view with evidence from the global color picture tube industry. Working Paper 99-0005. University of Michigan Business School, Ann Arbor, MI.
Lee, H.L., and Billington, C. 1995. The evolution of supply-chain management models and practices at Hewlett-Packard. *Interfaces* 25, no. 5: 42–63.
Li, R., T. Yu, and M. Fang. 2004. The reliability management of manufacturing grid. Paper presented at 14th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM 2004, 12–14 July, Toronto, Canada.
Li, X., Y. Shi, and M.J. Gregory. 2000. Global manufacturing virtual network (GMVN) and its position in the spectrum of strategic alliance. Paper presented at the 7th International Annual Conference EurOMA, 4–7 June, Ghent, Belgium.
Mathews, J.A., and C.S. Snow. 1998. A conversation with the Acer Group's Stan Shih on global strategy and management. *Organizational Dynamics* 27, no. 1: 65–74.
Meixell, M.J., S.D. Wu, and A.K. Kamrani. 2004. *Collaborative manufacturing for mass customization.* Boston: Kluwer Academic.
Rudberg, M., and J. Olhager. 2003a. Manufacturing networks and supply chains: An operations strategy perspective. *OMEGA* 31, no. 1: 29–39.
Rudberg, M., and J. Olhager. 2003b. Manufacturing strategy and e-business: An exploratory study. *Integrated Manufacturing Systems* 14, no. 4: 334–45.
Rudberg, M., and J. Olhager. 2008. Global operations strategy: Coordinating manufacturing networks. *Omega* 36: 91–106.
Schmenner, R.W. 1982. Multiplant manufacturing strategies among the fortune 500. *Journal of Operations Management* 2, no. 2: 77–86.
Shi, Y., and M.J. Gregory. 1998. International manufacturing networks to develop global competitive capabilities. *Journal of Operations Management* 16, no. 2: 195–214.
Shi, Y., and M.J. Gregory. 2001. Global manufacturing virtual network (GMVN): A new manufacturing system for market agility and global mobility. Paper presented at the International Working Conference on Strategic Manufacturing, 26–29 August, Aalborg, Denmark.
Shi, Y., and M.J. Gregory. 2003. From original equipment manufacturers to total solution providers: An emergence of global manufacturing virtual network in electronics industry. *International Journal of Service Technology and Management* 4, no. 4–6: 331–46.
Shi, Y., D. Fleet, and M. Gregory. 2005. Global manufacturing virtual network and its position in manufacturing systems. Paper presented at 7th Annual Cambridge International Manufacturing Symposium Proceedings, 19–20 September, Cambridge, UK.
Sturgeon, T. 1999. Turn-key production networks: industrial organization, economic development, and the globalization of the electronics manufacturing supply-base. PhD dissertation, University of California.
Sturgeon, T. 2002. Modular production networks: A new American model of industrial organization. *Industrial and Corporate Change* 11, no. 3: 451–96.
Sturgeon, T., and R. Florida. 1999. Globalization and jobs in the automotive industry. Final report to the Alfred P. Sloan Foundation, Massachusetts Institute of Technology, Cambridge, MA.
Ulrich, K. 1995. The role of product architecture in the manufacturing. *Research Policy* 24, 419–40.
Vereecke, A., and R. Van Dierdonck. 1999. *Design and management of international plant networks: Research report.* Ghent: Academia Press.
Williams, T., B. Ellis, R. Maull, and M. Gregory. 2001. Offset strategies in the global aerospace sector. Paper presented at Paper presented at the 6th Research Symposium on International Manufacturing, 23–25 September, Cambridge, UK.
Yin, R.K. 1994. *Case study research: Design and methods.* Thousand Oaks, CA: Sage.
Zhao, D., Y. Shi, and M. Gregory. 2001. Manufacturing virtual network system. Paper presented at the 6th Research Symposium on International Manufacturing, 23–25 September, Cambridge, UK.

Appendix 1: Data collection methodology

Data collected for this research work has been through interviews, literature review, documentation studies and on-site observations to achieve a relatively high construct validity. Methodology used based on the research terminology of Yin (1994) has been exploratory and descriptive based on a case study with qualitative approach. This qualitative approach has been based on a case study to the engine manufacturer Rolls-Royce.

Data were obtained through a number of visits, during six years (1999–2005), to the most relevant engine manufacturing plants within the aeronautical industry in Europe: Volvo Aero (Trollhättan, Sweden), SNECMA (Evry-Corbeil, France), MTU (Munich and Hannover, Germany), GE Aero (Caledonian, UK; Eskiseir, Turkey), ITP (Zamudio and Ajalvir, Spain), IAI (Israel) and Rolls-Royce (Hillington, UK; Oberursel, Germany). These companies and locations were chosen because of their high level of participation in international cooperative projects manufacturing a large number of aero engines.

Data collection for the case study was based on:

(1) *Open interviews*. This approach is well suited for data collection in situations where the qualitative method is used (Yin 1994). In total, 21 people were interviewed from the above-mentioned manufacturing sites. These interviews were conducted with experienced top, middle and front line managers and the main objective was to gain background information about how manufacturing networks work from a practical point of view and the problems they face in these collaborative projects. The interviews were open with a few main questions for each theme but with room to further explore relevant issues arising during the interviews with each participant. The main advantage of conducting open interviews was that we could present additional questions to interviewees in order to gain more in-depth comprehension.

The interviews were focused on obtaining a better understanding on GMVNs by approaching the following topics: (a) Reasons to join a GMVN?; (b) Network structure; (c) Coordination among network actors and how resources, material and information flow is planned; (d) Formal and informal relations within the network.

Because of the open character of the interview, the questions addressed to approach these topics were very varied as well as conditioned by the interviewee profile and the issues that arose in each interview. Some of the open questions addressed during most of the interviews were: (i) What are the major reasons to join a GMVN? (ii) What benefits, in your opinion, has your company obtained through such collaboration? (iii) What is the evolution of these types of organizations? (iv) How do network actors interact with external partners such as suppliers or final customers? (v) How is your GMVN organised (structured)? (vi) Do you have any IT platform to coordinate the information and material flow? (vii) Do you apply any collaborative manufacturing standard for production or design at network level (e.g. manufacturing grid, RosettaNet)? (viii) What are the reasons to select a specific network actor in a project? (ix) Do you have any network validation system to approve new products, subsystems or components? (x) Is there any homologation process to approve new network actors in the GMVN?

(2) *On-site observations*. Direct observations on the different locations, including the manufacturing plants, were used to complement information obtained through interviews and to gain an understanding of the nature of customer activities.

(3) *Documentation*. Additional methods of data collection were used to triangulate the data obtained from the interviews and on-site observation. These sources of data were a review of company documentation (annual reports, key financial data, shareholders information, catalogues and company web page), professional market reviews, specialised internet sites and literature reviews.