AGILITY DRIVERS, ENABLERS AND OUTCOMES: EMPIRICAL TEST OF AN INTEGRATED AGILE MANUFACTURING MODEL

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AGILITY DRIVERS, ENABLERS AND OUTCOMES: EMPIRICAL TEST OF AN INTEGRATED AGILE MANUFACTURING MODEL

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Abstract

This research paper analyses agile manufacturing in Spain and studies whether it is a critical factor for success in different industries. A conceptual model is drawn up, based on the literature and a previous case study, to relate turbulence in the environment with agile manufacturing practices and business performance. The model is tested on a large sample of Spanish manufacturers using survey methodology to obtain information and a structural equation model to analyse the data. The results obtained show that, in turbulent environments, the integrated use of agile manufacturing practices promotes manufacturing competitive strength, leading to better operational, market and financial performance.

Key words: Agile manufacturing, Operations and production management, Manufacturing strength, Competitiveness, Structural equations

JEL: M11-Production Management

1. INTRODUCTION

The industrial environment has changed radically over the last two decades. In this period of time, technology, market conditions and customer requirements have changed at an unprecedented speed and in directions that have been difficult to foresee. A number of trends have been identified that are having a significant impact on industrial firms (Jin-Hai *et al*., 2003; Ismail *et al*., 2006), making it necessary to draw up a new production paradigm (Meade and Sarkis, 1999).

Against this new competitive background, many firms have started re-orienting their distinctive competencies in order to meet the important challenges created by the new economic and industrial environment (Vokurka and Fliedner, 1998). In recent years, many manufacturers have tried to adopt practices and tools to improve their competitiveness, such as: 1) automation and flexible manufacturing systems, 2) concurrent engineering, 3) total quality management, 4) strategic and cooperative outsourcing, 5) time-based competition, 6) business process re-engineering, 7) benchmarking and 8) mass customisation. However, most of the initiatives that have been introduced since 1980 to raise competitiveness have only served as tactical responses to pressures in the industrial environment. The fact that they have been adopted in isolation within traditional production models reflects acceptance of the *status quo* and a lack of recognition of the need to face up to a new competitive situation on the basis of totally new approaches. Many firms have adopted such tactical initiatives without coordinating them with other practices (Gunasekaran, 1998), with strategic objectives and with the reality of competition and the need for new management models, thus obtaining counter-productive results. However, the academic and research community has considered adopting all these practices and tools as parts of a new manufacturing paradigm based on agility, known as 'agile manufacturing'.

Agile manufacturing is a new production model that has resulted from changes in the environment (Goldman and Nagel, 1993; Goldman *et al.*, 1995; Vokurka and Fliedner, 1998; Sharifi and Zhang, 1999; Yusuf *et al.*, 1999; Zhang and Sharifi, 2000; Yusuf and Adeleye, 2002; Ismail *et al*., 2006). It links innovations in manufacturing, information and communication technologies with radical organisational redesign and new marketing strategies (Gunasekaran, 1998).

This production model, considered by some authors to be a necessary condition or a vital element for competing in the future (Youssef, 1992; Goldman and Nagel, 1993; Sharifi and Zhang, 2001; Hormozi, 2001), is a flexible one that can adapt rapidly to changes in the business environment and can meet the needs of increasingly demanding and well-informed customers. It has been considered the ultimate requirement for 'world-class' manufacturing performance (Hormozi, 2001), or potentially the pathway to 'world-class' manufacturer status (Yusuf and Adeleye, 2002).

However, despite the fact that agile manufacturing has been frequently promoted as a means of improving business competitiveness, little empirical evidence exists in the literature validating its positive link with business performance (Vokurka and Fliedner, 1998; Gunasekaran and Yusuf, 2002). Most of the empirical research to date has focused on exploratory, descriptive or illustrative case studies. As Gunasekaran (1999a; 97) states, "theoretically derived hypotheses and empirical studies to test them are conspicuously absent from studies of the agile organisation" and "although it seems intuitive that the ability to respond to dynamic and unpredictable changes in the environment should contribute to a firm's success, this fact has not been scientifically tested".

The question as to how a manufacturer can identify tools and techniques and acquire the relevant capabilities and abilities to become agile has so far resulted in very ambiguous answers (Zhang and Sharifi, 2000). Unfortunately, agile manufacturing has been freely promoted without the necessary development of models to achieve it, generating serious risks for firms that are trying to improve their performance. As stated by Yusuf *et al*. (1999; 42) "the enablers of agility need further exploration to find out best examples of each and the underlining practices that help achieve, sustain and maintain each one over a long period of time. Along with this is the need to explore how to integrate the gamut of such 'best practices' in a single firm". Since there are important issues and questions that need to be addressed to understand how agile manufacturing might be achieved with clarity of purpose, focus and goals (Yusuf *et al*., 1999), it should be adopted with caution. Possibly for this reason, firms are starting to become aware of the importance of agility, but have not yet linked the concept to concrete actions (Katayama and Bennett, 1999).

Against this background, the contribution of this paper is twofold. Firstly, on the basis of a thorough review of the literature, a conceptual model of agile manufacturing is presented, describing and summarising the links between three basic elements of agility: drivers, enablers and outcomes. Taking this agile manufacturing conceptual model as a reference, several research hypotheses are proposed. Secondly, by means of a survey amongst the largest manufacturers in Spain, the proposed hypotheses are tested in order to empirically validate the model. This study, therefore, covers not only aspects of theoretical construction in the field of agile manufacturing but also complements these with the appropriate empirical validation.

The paper is structured as follows. Section 2 reviews and summarises the literature on agile manufacturing, analysing the concept and its basic elements. Section 3 presents a conceptual model for agile manufacturing, identifying three basic elements: drivers (environment), enablers (agility practices) and outcomes. Section 4 lays down the goals of the empirical research and presents the hypotheses. Section 5 discusses the research methodology and describes the sample profile. In Section 6, the suitability of the scales proposed for measuring the agile manufacturing conceptual model is discussed. Section 7 presents and discusses the results, and Section 8 draws the main conclusions and mentions some limitations of this study and possibilities for future research.

2. AGILE MANUFACTURING: A SUMMARY OF THE LITERATURE

The concept of agile manufacturing first appeared in the *21st Century Manufacturing Enterprise Strategy* report (Goldman and Nagel, 1991), published by the Iacocca Institute at Lehigh University (USA). This report described the results of a project financed by the US Department of Defense, which periodically brought together senior managers of the most important US firms to discuss the conditions under which firms would be operating in the future and the management principles that should be adopted. Agile manufacturing was considered in the debate on how to manage firms in a changing world, and has now been adopted by researchers, managers and consultants who consider it the latest stage in the evolution of production models or systems (Esmail and Saggu, 1996; McCarthy and Tsinopoulos, 2003).

Despite the great interest now being shown in agile manufacturing, some confusion still exists regarding the concept. There is no universally-accepted definition (Kusiak and He, 1997, 1998), nor is there unanimity amongst researchers about what it means. So, although no strategist can argue against agile manufacturing, there has been little success in distinguishing this concept from others (Richards, 1996). This is partly due to the fact that the concept of agility stems from other approaches, such as flexible manufacturing (Bolwijn *et al*., 1986), lean manufacturing (Womack *et al*., 1990), time-based competition (Stalk and Hout, 1990), and fast-cycle innovation (Tidd *et al*., 1997).

In addition, the fact that agile manufacturing is a multidimensional concept (Meade and Rogers, 1997; Vokurka and Fliedner, 1998; Vernadat, 1999; Yusuf *et al*., 1999; Jin-Hai *et al*., 2003) has led different authors to draw up their own definitions, each trying to emphasise a specific aspect (Jin-Hai *et al*., 2003). The literature therefore offers a variety of views of agile manufacturing, which has been defined with respect to the agile firm, products, workforce, capabilities and the environment (Yusuf *et al*., 1999; Gunasekaran and Yusuf, 2002; Jin-Hai *et al*., 2003).

In order to understand the concept and identify it as a new production model, all these definitions should be considered simultaneously (Yusuf *et al*., 1999; Jin-Hai *et al*., 2003). They can be taken in three main groups. Firstly, some agile manufacturing definitions are based on outcomes (i.e. flexibility, speed, responsiveness, re-configurability, dynamism, innovation, etc.). Others are expressed in terms of operation or implementation (i.e. cooperation, proactivity, virtuality, technology utilisation, market orientation, integration, etc.). Finally, there are comprehensive definitions that try to combine the two, that is, outcomes with the means by which the concept becomes operational [1].

Concerning outcomes, this new production model is not only based on flexibility and responsiveness but also considers cost, product quality and the services expected by customers (Vokurka and Fliedner, 1998; Gunasekaran, 1999a, 1999b; Gunasekaran and Yusuf, 2002). In fact, agile manufacturing aims to combine the efficiency of lean manufacturing with the operational flexibility of the flexible model whilst delivering customised solutions at the cost of mass production (Adeleye and Yusuf, 2006). For this reason, agile manufacturers are considered flexible manufacturers that can offer high-quality products at a low cost, with a better service and shorter delivery times (Goldman and Nagel, 1993; Jain and Jain, 2001). As agile manufacturing allows simultaneous development of capabilities in different manufacturing objectives (Burgess, 1994; Sheridan, 1993; Yusuf *et al*., 1999; Sahin, 2000; Yusuf and Adeleye, 2002; Adeleye and Yusuf, 2006; Fernández *et al*., 2006), it amounts to a break with the ‘trade-off’ model (Skinner, 1969), which considers the existence of incompatibilities amongst the various manufacturing objectives.

In practice, agile manufacturing can be achieved by integrating organisations, people and technology into a meaningful unit by deploying advanced information technologies and flexible organisational structures to support highly-skilled, knowledgeable and motivated people (Goldman and Nagel, 1993; Gunasekaran, 1999a). Agility will result in an organisation that has an innovative management structure with highly-skilled, motivated and empowered people who work as a team with the support of flexible, smart technology and systems for the proper management of knowledge and learning (Kidd, 1995). So an essential element of this new manufacturing model, which is inherent in all the definitions given in the literature, is that it is very different from mass production (Goldman and Nagel, 1993, Sheridan, 1993). Agile manufacturing requires an overall view of the firm (Roth, 1996) and a new strategic position with regard to operations that should be oriented towards proactive adaptation to change (Yusuf *et al*., 1999).

Several authors consider that agile manufacturing is based on elements of existing manufacturing systems, such as lean manufacturing, or on improved versions of them (Goldman and Nagel, 1993; Kidd, 1995; Richards, 1996; Parkinson, 1999; Sharp *et al*., 1999; Van Assen, 2000; Sahin, 2000; Hormozi, 2001; Maskell, 2001; McCarthy and Tsinopoulos, 2003; Jin-Hai *et al*., 2003). Goldman and Nagel (1993; 19) consider that it "assimilates the full range of flexible production technologies, along with the lessons learned from total quality management, 'just in time' production and lean production". Yusuf *et al.* (1999; 33) sustain that "the concept owes a lot to advances in communication technology and previous paradigms of manufacturing, yet it is more than an hybrid construct of technology and previous methods of production".

However, even though agility does not reject any of the preceding production paradigms and the models for agile manufacturing cannot be radically different from them (Yusuf *et al*., 1999), clear dividing lines can be identified in the literature between lean and agile manufacturing [2]. In general, researchers consider that agile manufacturing has arisen as a new production model to resolve the limitations of lean manufacturing (Yusuf and Adeleye, 2002; Adeleye and Yusuf, 2006), maintaining some similarities (Richards, 1996) but with important differences between the two models (Avella and Vázquez-Bustelo, 2005).

What is particularly innovative about agile manufacturing as a production model is that it integrates –in a compact, guided structure– the techniques, philosophies and tools that have been developed over recent years, reaching high performance levels in all the manufacturing objectives –cost, quality, flexibility, delivery, service and environment (Burgess, 1994; Sheridan, 1996; Katayama and Bennet, 1996; Gunnenson, 1997; Yusuf and Adeleye, 2002; Adeleye and Yusuf, 2006).

Agile manufacturing is identified with a more flexible approach towards inter-firm cooperation and the development of creative skills by the management and the workforce, generating an adaptable, competitive and innovative organisation. It can be achieved by integrating three resources –technology, management and workforce– into a coordinated, interdependent system (Goldman and Nagel, 1993; Meade and Sarkis, 1999). It offers huge potential for reducing production costs, increasing market share, meeting customers' needs, shortening time to market, eliminating non-value added activities and boosting manufacturing competitiveness (Gunasekaran, 1999a, 1999b). As a result, agile manufacturers offer a new form of industrial competition on a global scale for the 21st century, one that systematically applies (Meade and Sarkis, 1999) operational and management practices that aim above all to face the challenges of a new, more turbulent competitive environment.

This new form of industrial competition has four key dimensions (Goldman *et al*., 1995). The first dimension, enriching the customer, entails a quick understanding of the requirements of each individual customer and rapidly meeting them. The second dimension entails cooperation in order to enhance competitiveness, and includes better intra-organisational and inter-organisational cooperation, such as supplier partnership and perhaps emerging virtual relationships with competing organisations. The third dimension entails organising to master change and uncertainty by the utilisation of new organisational and managerial structures and technology. The fourth dimension leverages the impact of people and information and recognises the importance of employees as a key asset for the firm. It therefore places special emphasis on development of the workforce through education, teamwork, training, and empowerment.

So, basically, manufacturing agility can be defined as the capability of an organisation to (i) meet the changing market requirements, (ii) maximise customer service level and (iii) minimise the cost of goods, with the objectives of being competitive in a global market and raising the chance of long-term survival and profit potential (Gunasekaran and Yusuf, 2002). So it is a production model that integrates technology, human resources and organisation by creating an information and communication infrastructure, granting flexibility, speed, quality, service and efficiency and making it possible to respond deliberately, effectively and in a coordinated way to changes in the business environment. A positive link can therefore be expected between turbulence in the business environment, the application of agile manufacturing and the competitiveness of the firms developing this new production model.

3. AGILE MANUFACTURING CONCEPTUAL MODEL

Based on a thorough review of the literature and the analysis of several case studies, an agile manufacturing conceptual model was drawn up **(Figure 1)**. This defines three basic elements –agility drivers (business environment characteristics), agility enablers (agile manufacturing practices) and outcomes.

3.1. Agility drivers

Even though agile organisations are a relatively new research topic and there are few academic studies on them (especially in the case of Spain), there are plenty of studies and theories on organisational adaptation to the environment in the strategic and organisational literature. Research has proliferated in this field since the sixties, leading to the conclusion that organisational results are directly related to skill at adapting the organisation to changes in the environment (Duncan, 1972; Hambrick, 1982; Miller and Friesen, 1983; Dess and Beard, 1984; Miller, 1987; Daft *et al.,* 1988; Fahey and Narayanan, 1989; Wholley and Brittain, 1989).

Researchers have defined the environment as a set of external contextual elements that fall outside management control –at least in the short term–, that represent a source of opportunities and threats

(Bourgeois, 1980, 1985) and that are causally related to the results obtained by the organisation (Duncan, 1972; Swamidass and Newell, 1987; Ward *et al*., 1995). Almost three decades of empirical research support the theory that successful organisations are better adapted to their environment than those that obtain worse results. Agility has therefore been considered an essential capability for operating in turbulent business environments (Goldman *et al.*, 1995; Sharifi and Zhang, 1999; Maskell, 2001; Yusuf and Adeleye, 2002; Adeleye and Yusuf, 2006).

The concept of turbulence in the environment is subject to confusion. Some studies identify turbulence with dynamism, without specifying whether the dynamism is caused by a change in composition of the environment or in the preferences, actions or nature of those involved in it. Others take it as a multidimensional construct that includes other elements of the environment, and go so far as to define turbulence in terms of market growth. The turbulent environment can be considered to be the worst possible situation for survival. Firms that are able to operate successfully in such environments should therefore show high levels of agility because they need to adapt to: (a) relatively unpredictable changes in the environment (*high dynamism*); (b) highly-populated, competitive markets with one or more critical and scarce resources (*high hostility/competition or low munificence);* (c) close links between firms and their suppliers, distributors, customers and competitors (*high complexity*); and (d) varied products, lines, customers or businesses (*high diversity*). Not only should such conditions exist but managers must perceive them as such. In other words, it can be assumed that firms competing in environments having the above-mentioned characteristics must develop higher levels of manufacturing agility to be successful. However, of these four environmental characteristics, dynamism and competition have been stressed in the literature as the two main agile manufacturing drivers (De Vor and Mills, 1995; Cho *et al.*, 1996; Meade and Rogers, 1997; Gunasekaran, 1998, 1999a, 1999b; Sharp *et al.*, 1999; Sharifi and Zhang, 1999, 2001; Yusuf *et al.*, 1999, 2001; Gunasekaran and Yusuf, 2002; Coronado *et al.*, 2002). These factors have a direct influence on environmental stability and predictability (Dess and Beard, 1984).

It can therefore be stated that environmental turbulence, encapsulating the idea of continuous, uncertain and potentially disruptive change in a variety of factors, both internal and external, is a key driver for the development of agile manufacturing (Ismail *et al*., 2006) and forces manufacturers to adopt and develop practices linked to this new paradigm. Increasing turbulence in the business environment has made former systems, such as lean or flexible manufacturing and their associated techniques, insufficient in the way they have been managed and used. In fact, several authors (i.e. Sharifi and Zhang, 1999; Yusuf and Adeleye, 2002) have seriously questioned their viability in dealing with the changing nature of the business environment and point out that survival requires the adoption of agile practices. So, since the degree of turbulence in the environment determines the degree of agility a firm requires (Zhang and Sharifi, 2000), it is essential for it to understand its business environment, measure the degree of turbulence and know how this will impact on its organisation (Ismail *et al*., 2006).

3.2. Agility enablers or practices

In conditions of turbulence, firms must adopt agility enablers or practices, reviewing their strategies, objectives, methods and/or tools. Such enablers should promote total integration of the basic elements of the firm –people, technology and the organisation– (Vernadat, 1999), and agile manufacturing results from integration of these three resources in a coordinated, inter-dependent system (Goldman and Nagel, 1993).

Based on the list of studies on agile manufacturing in **Table I**, agility enablers can be grouped as follows: (1) human resources practices to develop highly-trained, motivated and empowered people working as a team; (2) systematic implementation and integration of advanced design, manufacturing and administrative technologies; (3) practices relating to internal organisation and external relations, including the development of mechanisms for integrating and coordinating the value chain, based on cooperation and integration of operations amongst departments in the firm and between the firm and external agents (suppliers, customers, partners, stakeholders, etc.); (4) practices relating to product development and/or design processes leading to concurrent engineering; and (5) practices relating to knowledge management and learning.

3.3. Outcomes

So far there has been little empirical study (especially in Spain) on the influence of agile manufacturing –as a holistic production model– on business performance. Apart from pioneer works (i.e. Sharifi and Zhang, 2001, Yusuf and Adeleye, 2002, and Ren *et al.*, 2003), most studies have focused on analysing the individual influence of certain agile manufacturing practices on business performance.

Manufacturing agility is associated with a firm's ability for surviving and prospering in a competitive environment that changes constantly and unpredictably (Cho *et al.*, 1996; Dove, 2001; Meade and Sarkis, 1999). But flexibility and responsiveness go together with considerations of cost, product quality, customers' needs and delivery (Dove, 1995; Gunasekaran and Yusuf, 2002). That is, being agile means offering high-quality products at low cost, with better service and delivery conditions (Jain and Jain, 2001). Yusuf *et al.* (1999; 37) state that agility is reflected in "the successful exploration of competitive bases (speed, flexibility, innovation, proactivity, quality and profitability) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide customer-driven products and services in a fast-changing market environment". In addition, agile manufacturing pays special attention to environmental protection. Legislation is the prime means of encouraging firms to adopt environment-friendly practices but other drivers are image, customers' requirements and eco-efficiency. These elements can be taken as new opportunities by agile manufacturers.

So it can be considered that the adoption of practices to promote agility leads to manufacturing strength through the development of greater capabilities in the different manufacturing objectives (cost, quality, flexibility, delivery, service and environment). Consequently, it positively affects business performance and affords greater competitiveness in turbulent environments.

4. OBJECTIVES AND HYPOTHESES

To date there has been relatively limited acceptance of agile manufacturing both in academic research and business practice. In spite of its potential, manufacturers, both internationally and in Spain, have been slow to adopt manufacturing agility practices and are still focusing on mass production (Yusuf and Adeleye, 2002). In addition, most of the literature on agile manufacturing is descriptive or theoretical, taking the form of articles in the press or for the general reader rather than being rigorous empirical studies. Therefore, having drawn up a conceptual model for the analysis of agile manufacturing, the next objective is to provide empirical evidence on the methods, practices and tools that can increase manufacturing agility, relating it with business performance or competitiveness. On the basis of the conceptual model given above, the following hypotheses are proposed:

Hypothesis 1: The adoption of agile manufacturing is reflected in the systematic integration of agile human resources and agile technologies, value chain integration, concurrent engineering and knowledge management.

This hypothesis is tested to determine the multidimensional nature of agile manufacturing.

Hypothesis 2: Turbulent environments (with high levels of dynamism and hostility) have a positive influence on the adoption of agile manufacturing practices.

This hypothesis is tested to determine the influence exerted by turbulence in the business environment on the adoption of agile manufacturing.

Hypothesis 3: The adoption of agile manufacturing positively impacts manufacturing strength (by combining strengths in cost, flexibility, quality, delivery, service and environment).

Hypothesis 4: The development of manufacturing strength (by combining strengths in cost, flexibility, quality, delivery, service and environment) leads to better business performance.

The third and fourth hypotheses are tested to determine the direct effect of agile manufacturing on manufacturing strength and, consequently, on business performance.

5. RESEARCH METHODOLOGY AND SAMPLE CHARACTERISTICS

5.1. Research design and data

In order to test the hypotheses, a database was drawn up of information provided by the largest manufacturers in Spain. The information needed for the study was obtained from a survey conducted as part of a wider research project. The target population was made up of the 1,234 manufacturers which, in 2003 (the reference date for the study), were located in Spain and employed over 100 workers, according to the SABI database. A selection was made of firms in the following industries according to ISIC classification:

chemical industry (ISIC 24), fabricated metal products (ISIC 28), machinery and equipment (ISIC 29), office, accounting and computing machinery (ISIC 30), electrical machinery and apparatus (ISIC 31), radio, television and communication equipment and apparatus (ISIC 32), medical, precision and optical instruments, watches and clocks (ISIC 33), motor vehicles, trailers and semi-trailers (ISIC 34), other transport equipment (ISIC 35) and furniture and other manufacturing industries (ISIC 36). These industries were chosen because they are the most usual in studies on manufacturing strategy. Additionally, by using a number of industries in our sample, we address the issue of whether agile manufacturing is a robust concept that is applicable across a range of industries.

The questionnaire used was designed on the basis of the existing literature and the conclusions obtained from a previous case study. In both the design and the administration of the questionnaire, the techniques highlighted by Fröhlich (2002) to improve the response rate and the rules put forward by Synodinos (2003) were taken into consideration. Before sending out the questionnaire, it was revised by experts in both operations management and survey design. With the aim of checking its validity and improving its design, a pre-test was also done on a reduced sample of firms. After contacting each of the 1,234 firms that made up the sample, it was concluded that nine of them possessed two different manufacturing strategies, and therefore two questionnaires were sent to those firms. The rest of the manufacturers –with only one plant, or with several plants having the same characteristics and implementing the same manufacturing strategy– were sent only one questionnaire. The questionnaire was sent out between January and July 2004, together with a covering letter explaining the purpose of the study, the structure of the questionnaire and the confidentiality statement. The questionnaires were addressed to the plant manager, operations manager, manufacturing manager or other similar position, and the strategic manufacturing unit was identified as the unit of analysis. Each strategic manufacturing unit corresponds to a firm, division or plant, with defined business and manufacturing strategies. As further letters, faxes and e-mails were sent and telephone calls were made, there was an increase in the number of questionnaires received.

A total of 283 valid questionnaires were returned, corresponding to 274 different firms, representing a valid response rate of 22.2%. This ratio can be considered highly satisfactory bearing in mind the length of the questionnaire and the low response rates in Spain. The most frequent causes of non-response were lack of time for managers, the large number of questionnaires they receive and consideration of some of the information requested as confidential.

Using a Student T- test, the last 25% of respondents were compared to earlier ones and no differences were found in key variables –i.e. industry representation, firm size (number of employees), belonging to a multinational group, respondent characteristics (post, number of years in the firm and in their actual responsibility/post), etc.– in the analysis at the 5% level (sig.>0.05). Based on the assumption that late respondents are similar to non-respondents (Armstrong and Overton, 1997), non-response bias does not appear to be a major problem in this research.

Table II shows the technical details of the study, with information on the target population, the geographical area, the method used for gathering information, the sample size, the valid response rate, the time frame for the field work and the respondent profile.

The questionnaires received were filled in by the manufacturing manager (39.9%), the plant manager (20.5%), the industrial or operations manager (14.5%), the CEO (4.6%) and ‘others’ (20.5%). ‘Others’ includes management positions in the areas of quality control, human resources or external relations.

Given the position and responsibility of the respondents, it was assumed they had access to the information requested in the survey so they were considered suitable respondents. Moreover, they had been in their respective firms for an average of thirteen years and in their current position for six and a half years. Their responsibility and experience in the firm and in management positions confirms the internal validity of the study, that is, that the information was obtained from reliable or appropriate sources.

5.2. Sample

Table III reflects the profile of the firms included in the sample with regard to their industry, number of employees, whether or not they belong to a multinational group, the type of manufacturing process used and the product characteristics.

The industries with the highest level of participation in the sample were those that manufacture electrical machinery and apparatus (20%), machinery and equipment (17.8%), motor vehicles, trailers and semi-trailers (16.7%) and fabricated metal products except machinery and equipment (14.9%). To evaluate any industry bias, a Chi-squared test of differences was carried out between the observed frequencies (sample) and expected frequencies (population) with respect to industry representation. Excluding electrical machinery and apparatus, which showed higher than expected participation, a Chi-squared test comparing the sample with the population of firms indicated that the sample was no different from the population at a 95% confidence level (Sig.=0.063 >0.05).

With respect to the size of the firms analysed, 78.9% employ between 100 and 499 employees. This percentage is not surprising as Spanish industry is largely made up of small and medium sized firms. However, in order to analyse possible size bias, a Chi-squared test comparing the sample with the population of firms indicated that the sample was no different from the population at a 95% confidence level (Sig.=0.057 >0.05).

55.1% of the firms in the sample belong to a multinational group. Regarding manufacturing process, the manufacturers in the sample mainly carry out assembly line production (32.2%) with the aim of efficiently manufacturing large volumes of standard products. In second and third place, respectively, are manufacturers that use discontinuous large batch production processes (22.3%) and discontinuous small batch production processes (21.8%). 21.67% carry out project-based production and 1.9% continuous flow production. With regard to type of product manufactured, the sample manufacturers produce totally standardised products

(23.2%), mainly standardised products (13.4%), standardised products with customised options (20.8%), mainly customised products (10.3%) and totally customised products (31.9%).

6. DIMENSIONALITY, RELIABILITY AND VALIDITY OF MEASUREMENT SCALES

Before testing the hypotheses, it was necessary to guarantee the suitability of the measurement scales proposed for estimating the agile manufacturing conceptual model (see **Appendix**). The dimensionality, reliability and validity were evaluated for each of the scales used for measuring concepts relating to agile manufacturing, turbulence in the environment, manufacturing strength and business performance.

Exploratory factor analysis was carried out using Varimax rotation to determine the dimensions underlying the set of variables in each scale. In all cases, the results showed factor loadings of over 0.5 and a percentage for explained accumulated variance in excess of 50%. Turbulence in the environment is reflected by two factors relating to dynamism and hostility (or competition). Agile manufacturing takes place through five dimensions: (a) agile human resources (four first-level items), (b) agile technologies (five first-level items), (c) value chain integration (three first-level items), (d) concurrent engineering and (e) knowledge management. Manufacturing strength is reflected in (a) cost, (b) flexibility, (c) quality, (d) delivery, (e) service and (f) environment. Finally, business performance is a single dimension that determines the business competitiveness.

After exploratory factor analysis, confirmatory factor analysis (CFA) was carried out by means of structural equations, using the EQS statistical package. The calculation method used was that of robust maximum likelihood in order to resolve the problem of non-normality of the data. The results of the CFA confirmed the composition of the scales identified in the previous exploratory factor analyses.

In order to analyse reliability, Cronbach’s alpha coefficient and the composite reliability coefficient were calculated. These indices reflect the degree of internal consistency of the observed variables, that is to say, to what extent they represent the common latent variable. Cronbach´s alpha coefficient in all cases was over 0.7, the criterion usually considered to identify strict internal consistency (Nunnally, 1978), exceeding the value of 0.6 recommended in exploratory studies (Hair *et al*., 1998). In all cases the composite reliability coefficient was over the minimum level of 0.6 recommended by Bagozzi and Yi (1988).

The next step was to analyse the content, convergent and discriminant validity of the measurement scales used.

Content validity indicates that the items included in the survey correctly represent the concept to be analysed. Since the scales were built on the basis of the previous literature (**Appendix**) and therefore include items used in scales that had already been validated for measuring similar concepts and assessed by case studies and the questionnaire pre-test, it was considered that each item had the necessary content validity.

Convergent validity measures the degree to which the different scales used to measure a latent factor are correlated. A measurement has convergent validity if it converges in the same model as the rest of the measurements that form part of the same concept (Lehmann *et al.*, 1999). Steenkamp and Van Trijp (1991) link the convergent validity of a concept and its corresponding scale of measurement with the significance of the coefficients of the standardised regression factor between the group of explained variables of the scale and their corresponding latent saturation variable. To test convergent validity, the lambda coefficients that measure the relation between the observed and the latent variable were analysed. All the standardised factor loadings were statistically significant at a 95% confidence level (t>1.96, weak condition) and exceeded 0.5 (strong condition).

Discriminant validity measures the degree to which the specified latent factors differ even though they are correlated (Hair *et al.,* 1998). Each construct should be sufficiently different from the others to justify its existence (Lehmann *et al*., 1999). In order to check discriminant validity, the confidence intervals of the correlation between each pair of dimensions or scales was calculated. Discriminant validity of the scales was confirmed because none of the confidence intervals contained the value 1 at a 95% confidence level.

7. ANALYSIS AND DISCUSSION

After validating the scales, the conceptual model was evaluated. A structural equation model was used to test the data and check the hypotheses [3]. This methodology allowed statistical validation of the model by means of simultaneous analysis of the complete system of variables and the links between them, determining the degree to which this is consistent with the data. So, if the goodness of fit of the model is appropriate, the plausibility of the relations between the variables can be confirmed; if not, these relations are not valid.

Figure 2 shows the global model of structural equations in the set of concepts being studied. Because of the size of the model, it was necessary to measure the variables relating to agile human resources, agile technologies and value chain integration by finding the average score of the scale attributes. In spite of this simplification, the scales used were found to maintain the recommended characteristics of reliability and validity. Moreover, we tied the errors and non-standard lambda parameters for the link between the concept of agile manufacturing and its five dimensions at the values attained when constructing the scale. The residuals of the resulting variables were also correlated.

The results for goodness of fit in the proposed model were acceptable. Except for the Chi-squared test, which did not reach the desirable significance level (*p*-value equal to or over 0.05) –as expected because of the sensitivity of this test to the number of cases in the sample– the other indices were satisfactory since they exceeded the optimal values recommended. The robust statistics BBNNFI, CFI and IFI showed values above the recommended minimum of 0.9. The GFI and AGFI statistics reached high values, close to 0.9, exceeding the generally required minimum of 0.8. SRMR and RMSEA took a value close to zero and below 0.08.

Validation of the model verified that the five sub-dimensions of agile manufacturing have a common background or, in other words, agile manufacturing is reflected in the dimensions of agile human resources, agile technologies, value chain integration, concurrent engineering and knowledge management. So, with these results, the multidimensional nature of agile manufacturing can be accepted and the first of the hypotheses corroborated: *The adoption of agile manufacturing is reflected in the systematic integration of agile human resources, agile technologies, value chain integration, concurrent engineering and knowledge management.*

The factor loadings reflected in the model (significant at a 99% confidence level) confirm the direct, positive and statistically significant influence of environmental turbulence on agile manufacturing, thus corroborating the second hypothesis: *Turbulent environments (with high levels of dynamism and hostility) have a positive influence on the adoption of agile manufacturing practices.*

Also, the estimates showed the direct, positive and statistically significant influence of agile manufacturing on manufacturing strength, thus corroborating the third hypothesis: *The adoption of agile manufacturing positively impacts manufacturing strength (by combining strengths in cost, flexibility, quality, delivery, service and environment).*

Finally, there is a positive, direct and statistically significant link between manufacturing strength developed on the basis of integrated agile manufacturing practices and each of the business performance measures analysed (in comparison with the industry average): labour productivity, customer loyalty, new product development success, sales volume, ROA and responsiveness to changes in competitive conditions. Thus the last hypothesis is corroborated: *The development of manufacturing strength (by combining strengths in cost, flexibility, quality, delivery, service and environment) leads to better business performance.*

8. CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH

This study analyses agile manufacturing (as a new production model resulting from a break with the mass production system) and its implementation in Spain. The factors behind implementation (characteristics of the environment) are studied, as are the nature and elements involved (agility practices, tools or policies) and the results. After a review of the literature, a conceptual model is presented for analysing agile manufacturing which is tested in a sample of the largest manufacturers in Spain.

The multidimensional nature of agile manufacturing was confirmed by drawing up a measurement scale based on integration of both structural and infrastructural manufacturing practices. Thus agile manufacturing is identified with a global production model that is reflected in full integration of (a) highly trained, motivated and empowered employees working in teams, (b) the use of advanced design, manufacturing and administrative technologies, (c) internal integration of operations, with suppliers and customers, (d) concurrent engineering, and (e) knowledge management.

The positive and significant influence of the environment on implementation of agile manufacturing practices was tested. Turbulence in the environment, characterised by dynamism and hostility, was identified as an important driver for agile manufacturing. It might therefore be possible to find greater application of agile manufacturing in industries that are subject to changes in customer tastes and needs, frequent innovations in products and/or processes, and high competitive pressure. However, it is now recognised that conditions of turbulence tend to exist in all industries and this suggests that the implementation and development of the agile manufacturing model might increase.

The application of agile manufacturing by the firms analysed has allowed them to boost their manufacturing strength through simultaneous improvement in various manufacturing objectives (cost, quality, flexibility, delivery, service and environment). These in turn lead to increased competitiveness (measured by indicators for labour productivity, customer loyalty, new product development success, sales volume, ROA and responsiveness to changes in competitive conditions). It was noted that, while the development of agile manufacturing improves both operational and financial performance (by developing manufacturing strength), the greatest impact is noted in market performance. That is, agile manufacturing promotes the development of greater responsiveness to change in the business environment, fosters new product development success and helps to establish stable customer relations and loyalty.

This study adopts a systematic approach to the analysis of agile manufacturing, considering various agility practices or enablers in an integrated way and relating them not only to elements in the environment but also to outcomes. This approach is especially interesting because most of the literature on agile manufacturing deals with agility strategies or techniques in an isolated way and, as stated by Gunasekaran (1999a), there have been practically no integrated studies of agile manufacturing as a system. This study also aims to fill another gap in the literature by analysing the subject not only from the theoretical point of view but also from that of empirical validation, testing the suitability of agile manufacturing in real organisations. In this case, the test is carried out –for the first time– in the Spanish context.

While it contributes to the literature on agile manufacturing, this study has two main limitations. The first is often found in studies on manufacturing strategies, namely, that it is difficult to determine the most suitable unit of analysis (firm, business unit, strategic manufacturing unit or production plant), and the most suitable management profile to be targeted (general manager, plant manager or production manager). This study considers that the necessary information affects and can basically be obtained from the strategic manufacturing unit by analysing its environment, practices and outcomes. However, some agility practices affect the firm as a whole so the plant or production manager may not have all the information.

The second limitation is that information obtained by the survey method may not be fully reliable. This problem may be resolved by obtaining information from more than one source for each unit of analysis (that is, from more than one respondent) but this was not done in this research as it would have had important negative effects on the response rate. Single respondent bias may, therefore, be considered a limitation in empirical research.

The study of agile manufacturing is in the early stages and further research is required. It would be of interest to include in the proposed agility model new practices that are currently being developed, such as virtual organisation or the creation of strategic alliances with competitors. In addition, other dimensions of the business environment could be included, such as diversity or complexity. Future research should analyse whether some combinations of agility practices are more effective than others.

Table I. Summary of agile manufacturing practices and references

STRATEGIC AREA	*AGILITY ENABLER OR PRACTICE*	*REFERENCE STUDY*
Human resources Human resources practices to develop highly trained, motivated and empowered people working as a team	Top management support and employee involvement and empowerment	[1] [2] [3] [4] [5] [6] [7] [10] [11] [13] [14] [15] [16] [17] [19] [22] [23]
	Team working, self-directed teams, cross-functional teams	[1] [2] [3] [4] [5] [7] [10] [11] [14] [15] [16] [18] [19] [22] [23]
	Job rotation, multifunctional workforce, job enrichment (responsibility on multiple tasks)	[5] [7] [13] [16] [18]
	Training and education, higher average skill levels, workforce skill upgrade, continuous training and development, cross-functional training.	[3] [7] [11] [14] [16] [18] [22] [23] [24] [25] [28] [29]
	Knowledge workers, IT-skilled workers	[7] [10] [11] [14] [18] [22]
	Decentralised decision making	[14] [22] [28]
	Entrepreneurial firm culture	[16]
	Reward schemes to encourage innovation and based on both financial and non financial measures	[10]
Technologies Systematic implementation and integration of advanced design, manufacturing and administrative technologies	Enterprise Resource Planning (ERP)	[7] [11] [18] [29]
	Material Requirement Planning (MRP)	[7] [10] [11] [23] [29]
	Robotics	[7] [9] [11] [18]
	Automated Guided Vehicle Systems (AGVSs); Automated Storage and Retrieval Systems (AS/RS)	[7] [9] [10] [11] [18]
	Computer Numerically Controlled (CNC) machines	[7] [9] [10] [11] [18] [22] [29]
	Computer-aided Design (CAD)/Computer-aided Manufacturing (CAM)	[2] [3] [7] [9] [10] [11] [18] [26] [27] [28]
	Rapid prototyping tools	[7] [9] [10] [11] [18] [21]
	Intranet, Internet and World Wide Web	[3] [7] [9] [10][11] [18] [28]
	Electronic Data Interchange (EDI)	[7] [9] [10] [11] [16] [18] [23] [29]
	Electronic Commerce	[7] [9] [10] [11] [18] [19] [24] [25]
	Visual inspection	[7] [11]
	Manufacturing cells	[7] [10] [11] [20] [22] [23]
	Virtual Reality Software	[7] [11] [18]
	Flexible Manufacturing Systems (FMS)	[7] [10] [11] [26]
	Computer-aided Process Planning (CAPP)	[7] [10] [11]
	Group Technology	[7] [10] [11] [29]
	Point-of-sales data collection (POS)	[16] [23]
	Bar codes, automatic data collection	[29]
	Real-time communication/execution systems	[23]
	Design for manufacture/assembly (DFM / A)	[10] [23]
Internal and external organisation (integration in the value chain) Practices relating to internal organisation and external relations, including the development of mechanisms for integrating and coordinating the value chain, based on cooperation and integration of operations amongst departments in the firm and between the firm and external agents (suppliers, customers, partners, stakeholders, etc.)	Strategic alliances based on core/complementary competencies	[7] [10] [11] [18] [22]
	Virtual firm/organisation	[7] [10] [11] [14] [16] [18] [19] [22] [23] [24] [25] [28]
	Rapid-partnership formation	[7] [10] 11] [14] [27]
	Integration of functions from purchasing to sales; firm-wide integration of functions	[7] [10] [11] [14] [18] [19] [22] [24] [26] [29]
	Global supply chain management	[7]
	Integrated supply chain; integrated and interactive partner relations	[7] [10] [11] [16] [25] [27]
	Customer integrated processes for designing, manufacturing, marketing, and support	[11] [14]
	Strategic relationship with customers, close relationship with suppliers; thrust-based relationship with customers/suppliers	[10] [14] [16] [18] [19] [22] [23] [26] [28]
	Internal and external cooperation	[10] [17] [18] [22] [28]
	Business Process Reengineering	[10] [23] [24] [26]
Concurrent engineering Organisational practices to develop new products and/or processes leading to concurrent engineering	Formation of cross-functional product development teams	[7] [10] [11] [15] [16] [22]
	Concurrent design of products and processes	[7] [10] 11] [12] [15] [22] [28]
	Multidisciplinary team working environment	[8] [10] [11] [30]
	Intelligent engineering design support system; groupware	[10] [7] [22]
	Collaborative work	[7] [8] [10] [11] [14] [16] [22] [28] [30]
	Customer and supplier integrated multidisciplinary teams	[10] [11] [22] [28]
	Early involvement of different agents in the product development process and concurrent execution of functions/activities	[10] [15] [16] [22] [23] [26]
Knowledge management and learning Practices relating to knowledge management and learning	Global access to databases and information, easy access to integrated data; open information/communication policy	[7] [10] [11] [14] [19] [25] [28]
	Knowledge Based Systems (KBS), knowledge management systems	[7] [11] [18] [28]
	Sensitive information protection	[7] [11]
	Organisational structure that promotes innovation and training and education; learning organisation	[11]
	Team-to-team learning	[11]

	Firm-wide integration of learning, continuous learning	[14] [15] [18]
	Knowledge acquisition from internal and external sources	[18] [28]
	Core-competence management	[1]

[1] Sharp *et al.* (1999); [2] Sharifi and Zhang (1998); [3] Zhang and Sharifi (2000); [4] Sharifi and Zhang (2001); [5] Gehani (1995); [6] Sheridan (1996); [7] Gunasekaran (1999a); [8] Medhat and Rook (1997); [9] Cho *et al*. (1996); [10] Gunasekaran (1998); [11] Gunasekaran and Yusuf (2002); [12] Kusiak and He (1997); [13] Forsythe (1997); [14] Yusuf *et al.* (1999); [15] Gehani (1995); [16] Sahin (2000); [17] Sharifi and Zhang (1999); [18] Jin-Hai *et al*. (2003); [19] Meredith and Francis (2000); [20] Ismail *et al*. (2006); [21] Onuh *et al*. (2006); [22] Goldman and Nagel (1993); [23] Fliedner and Vokurka (1997); [24] Hormozi (2001); [25] Meade and Sarkis (1999); [26] Katayama and Bennet (1999); [27] Parkinson (1999); [28] Maskell (2001); [29] Yao and Carlson (2003); [30] Vernadat (1999).

Table II. Research data

Population under study	Manufacturers with ISIC codes 24 and 28-36 with more than 100 employees
Population census	1,234 firms
Geographical area	Spain
Data collection method	Structured survey sent out to managers by mail, e-mail and website
Sample size	283 returned questionnaires
Valid response rate	22.2%
Time frame	November 2003-July 2004
Respondent profiles	Plant manager, manufacturing manager, industrial manager or similar

Table III: Characteristics of sample manufacturers

Industry (based on ISIC-Rev. 3)	**Percentage of firms**
ISIC-24: Manufacture of chemicals and chemical products	11.64%
ISIC-28: Manufacture of fabricated metal products, except machinery and equipment	14.91%
ISIC-29: Manufacture of machinery and equipment n.e.c.	17.82%
ISIC-30: Manufacture of office, accounting and computing machinery	0.73%
ISIC-31: Manufacture of electrical machinery and apparatus n.e.c.	20%
ISIC-32: Manufacture of radio, television and communication equipment and apparatus	3.64%
ISIC-33: Manufacture of medical, precision and optical instruments, watches and clocks	3.27%
ISIC-34: Manufacture of motor vehicles, trailers and semi-trailers	16.73%
ISIC-35: Manufacture of other transport equipment	3.64%
ISIC-36: Manufacture of furniture; manufacturing n.e.c.	7.64%
Firm size by number of employees	**Percentage of firms**
From 100 to 499 employees	78.9%
From 500 to 999 employees	10.9%
From 1,000 to 1,499 employees	2.55%
From 1,500 to 1,000 employees	2.18%
2,000 employees or more	5.45%
Membership of a multinational group	**Percentage of firms**
Yes	55.1%
No	44.9%
Type of manufacturing process	**Average production percentages**
Assembly line	32.25%
Discontinuous large batch production	22.33%
Discontinuous small batch production	21.80%
Project based (one-of-a-kind)	21.67%
Continuous flow	1.95%
Product type (degree of standardisation / customisation)	**Average production percentages**
Totally standardised products	23.25%
Mainly standardised products	13.48%
Standardised products with customised options	20.85%
Mainly customised products	10.39%
Totally customised products	31.94%

Figure 1. Agile manufacturing conceptual model

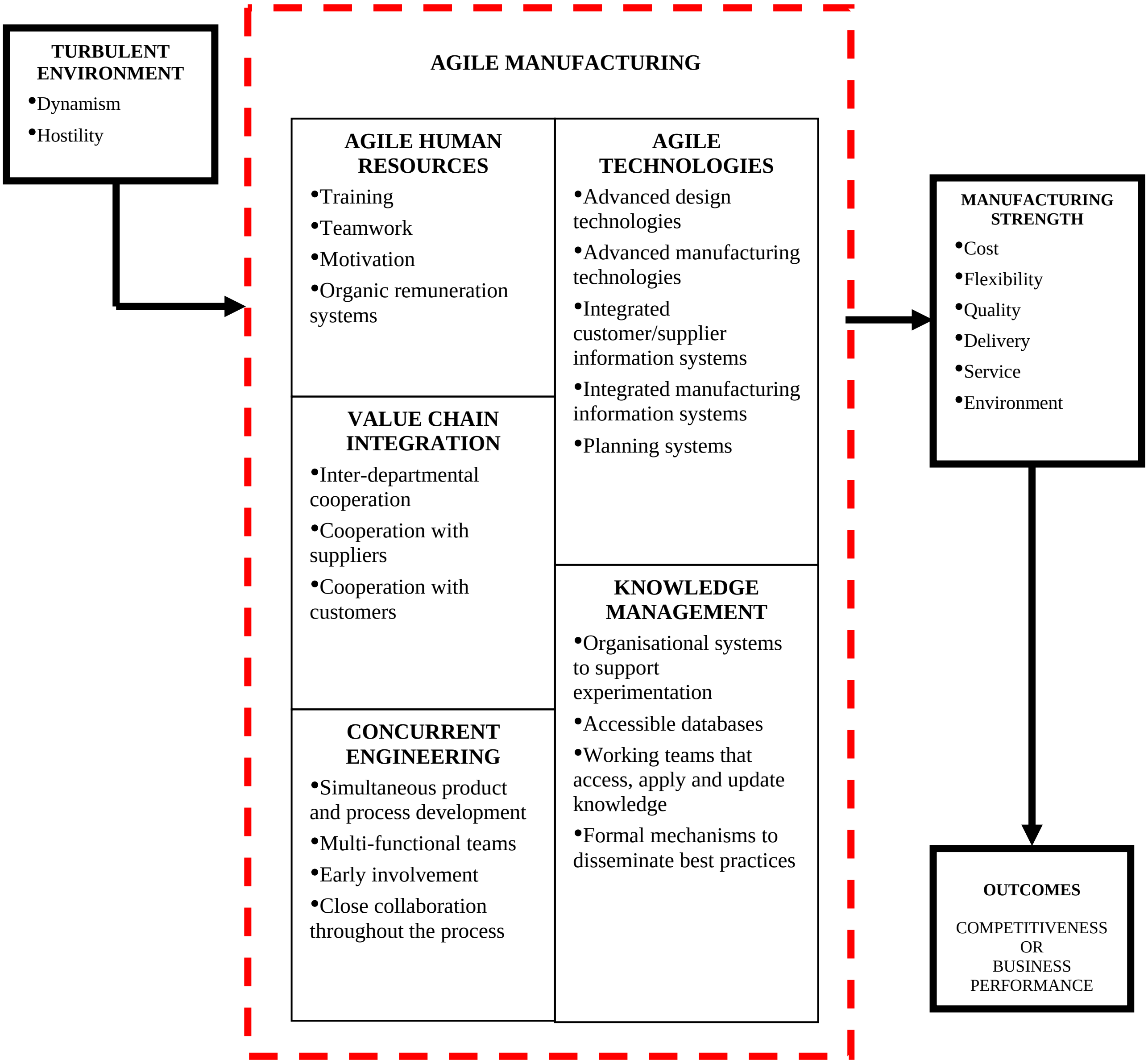
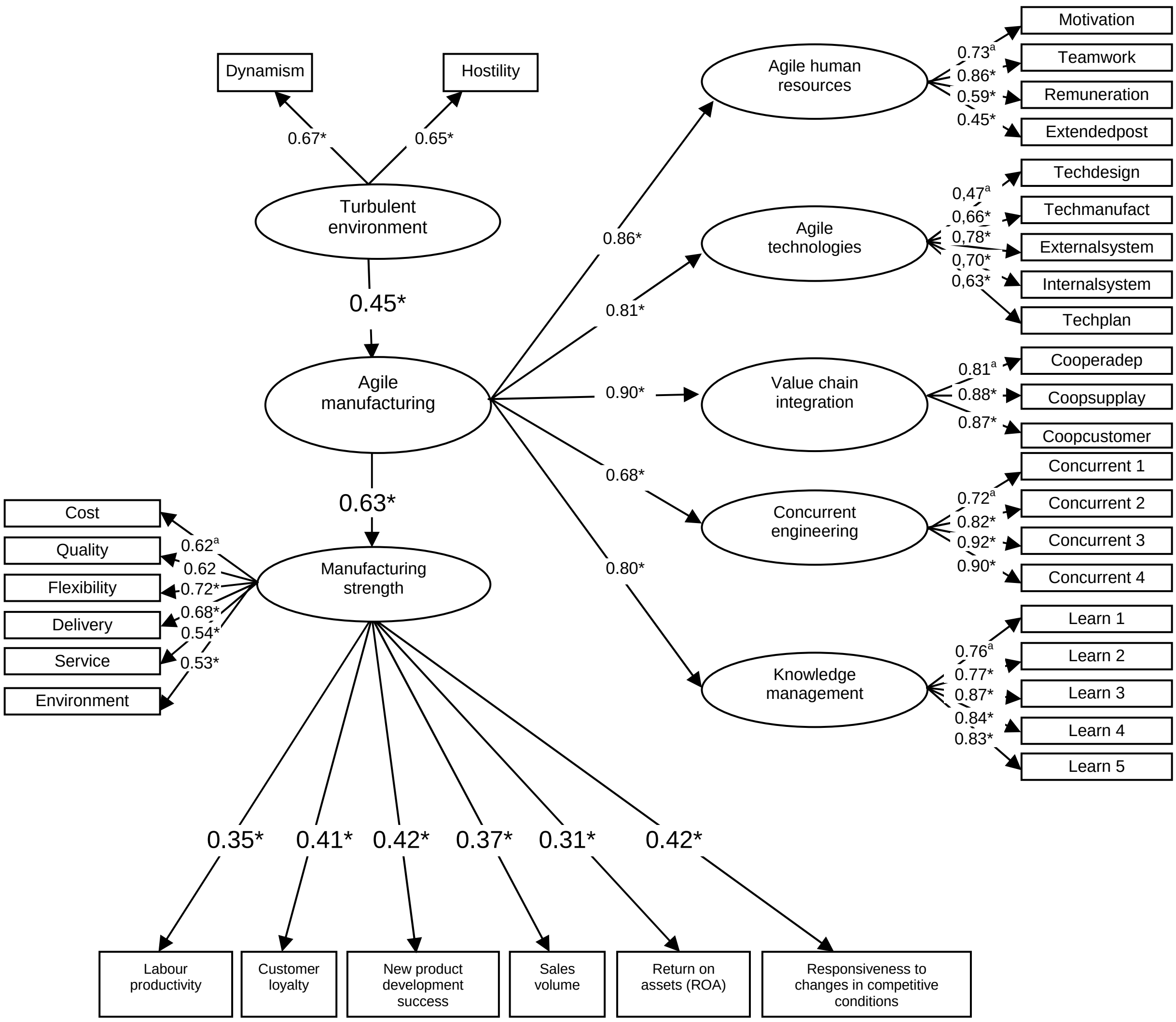


Figure 2. Agile manufacturing causal model



Measurements for goodness of fit

S-B χ^2 (687)= 1058.666	**BBNNFI**	**CFI**	**IFI**	**GFI**	**AGFI**	**SRMR**	**RMSEA**
(p= 0.000)	0.914	0.921	0.921	0.833	0.811	0.070	0.044

(*) 99% significant estimates

(a) Non-standard factor loadings fixed at1.

NOTES

[1] This research considers the latter definition to be the most correct. It was essential for drawing up and understanding the agile manufacturing model proposed.

[2] Lean manufacturing has been seen as an improvement of mass production model, whereas agile manufacturing is considered to break with mass production as it manufactures highly customised products as and when required (Sheridan, 1993; Booth and Hammer, 1995; Jin-Hai *et al*., 2003). Lean manufacturing is also identified with a production model that can operate effectively when market conditions are basically stable whereas agile manufacturing is more appropriate for turbulent situations because of its operational and strategic responsiveness. There are also differences regarding the objectives pursued by each of the models. Lean manufacturing subordinates responsiveness to maximum efficiency and productivity (by waste reduction), while agile manufacturing places the same importance on efficiency as on responsiveness (Yusuf *et al.*, 1999).

[3] This methodology was chosen because of the advantages offered by multivariate analysis in comparison with other techniques, as stated by Byrne (1994). Firstly, structural equation modelling adopts a confirmatory than an exploratory approach for data analysis. Secondly, while traditional multivariate procedures cannot measure or correct measurement errors, structural equation modelling offers explicit estimates of these parameters. Finally, while data analysis using other methods is based only on observable measurements, in structural equation modelling both observable and non-observable or latent variables can be included. This is essential because "agile manufacturing includes a number of intangible dimensions and elements that are difficult to quantify and are systematically related" (Meade and Sarkis, 1999; 244).

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APPENDIX. Measurement scales used in the study (I)

FACTOR	VARIABLE	ITEM	CODE
Agile manufacturing (1)	Agile human resources	Employee empowerment	Motivation 1
		Feedback of economic and/or strategic information to employees	Motivation 2
		Employee participation in plant decisions	Motivation 3
		Team work involving workers with different know-how and skills	Teamwork 1
		Self-managed teams with decision-making capacity	Teamwork 2
		Working teams that operate together with suppliers and customers	Teamwork 3
		Team work as an integral part of the firm culture	Teamwork 4
		Incentives for acquiring new skills and know-how	Remuneration 1
		Employee reward systems for problem-solving	Remuneration 2
		Objective-based worker remuneration	Remuneration 3
		Creation of incentives for the team, not only for individuals	Remuneration 4
		Employee rotation amongst different activities, tasks, positions or departments	Extendedpost1
		Increased variety in workers' tasks (versatility)	Extendedpost2
	Agile technologies	Computer-aided design (CAD)	Techdesign 1
		Computer-aided engineering (CAE)	Techdesign 2
		Computer-aided process planning (CAPP)	Techdesign 3
		Rapid prototyping tools	Techdesign 4
		Robots	Techmanufact 1
		Computer-aided manufacturing (CAM): Programmable automation of machines	Techmanufact 2
		Flexible manufacturing systems (FMS): Automatic multi-machine systems linked by an automatic materials handling system	Techmanufact 3
		Automatic materials storage and dispensing systems	Techmanufact 4
		Automatic identification / bar code systems	Techmanufact 5
		Electronic data interchange (EDI)	Externalsystem 1
		Supplier-integrated information systems	Externalsystem 2
		Distributor and/or end customer integrated information systems	Externalsystem 3
		Intranet	Internalsystem 1
		Information systems integrated in the production area	Internalsystem 2
		Information systems integrated amongst different departments in the plant and/or business unit	Internalsystem 3
		Manufacturing resources planning (MRP II, including capacity planning)	Techplan 1
		Enterprise resource planning (ERP)	Techplan 2

Measurement scales used in the study (II)

FACTOR	VARIABLE	ITEM	CODE
Agile manufacturing (2)	Value chain integration	Joint operating and/or strategic decision-making amongst different functions or departments	Cooperadep 1
		Formation of multi-functional teams (comprising people in different departments) to solve problems	Cooperadep 2
		Frequent organisation of project or task-based multi-functional teams	Cooperadep 3
		Use of multi-functional teams as important source of new ideas	Cooperadep 4
		Regular, important decision-making by multi-functional teams	Cooperadep 5
		Close relations with suppliers (frequent, direct contacts, mutual plant visits, collaboration agreements, etc.)	Coopsupplay 1
		Integration of plant operations with supplier operations (collaboration on logistics, mutual technical assistance, etc.)	Coopsupplay 2
		Mutual sharing of data and technical and commercial information with suppliers	Coopsupplay 3
		Joint work with suppliers on the product design and development process	Coopsupplay 4
		Joint work with suppliers on planning and market forecasting	Coopsupplay 5
		Joint work with suppliers to improve component quality	Coopsupplay 6
		Permanent interaction with suppliers using NTIC	Coopsupplay 7
		Close customer relations (frequent, direct contacts, customer visits to the firm, collaboration agreements, etc.)	Coopcustomer 1
		Integration of plant operations with customer operations (collaboration on logistics, mutual technical assistance, etc.)	Coopcustomer 2
		Inclusion of customers in new product design and development	Coopcustomer 3
		Compilation and internal dissemination of information on customer needs	Coopcustomer 4
		Permanent interaction with customers using NTIC	Coopcustomer 5
	Concurrent engineering	Simultaneous product and process design by a group of employees	Concurrent 1
		Early involvement of several departments or functions (R&D, production, sales, etc.) in new product development	Concurrent 2
		Creation of new product development teams comprising members of different departments or functions	Concurrent 3
		Close collaboration of product development team members throughout the process	Concurrent 4
	Knowledge management	Creation of organisational methods to encourage experimentation and the use of innovative ideas	Learn 1
		Databases containing organisational information accessible for all employees	Learn 2
		Work teams prepared to constantly access, apply and update knowledge	Learn 3
		Use of formal mechanisms to encourage sharing of best practices throughout the organisation	Learn 4
		Use of information systems to allow extensive dissemination of knowledge throughout the organisation	Learn 5

Measurement scales used in the study (III)

FACTOR	VARIABLE	ITEM	CODE
Turbulence in the environment	Dynamism	Fast-changing customer tastes and preferences	Dynamism 1
		Very frequent innovations in production processes	Dynamism 2
		Very frequent innovations in products and/or services	Dynamism3
	Hostility	The plant faces great competition on a global level	Hostility 1
		Very intense competition to occupy new market niches	Hostility 2
		Very intense competition to gain market share	Hostility 3
Manufacturing strength	Cost	Reduce manufacturing costs	Cost 1
		Increase labour productivity	Cost 2
		Increase equipment or capacity utilisation	Cost 3
		Reduce inventory level	Cost 4
	Flexibility	Make rapid design changes	Flexibility 1
		Introduce new products quickly	Flexibility 2
		Make rapid volume changes	Flexibility 3
		Make rapid product mix changes	Flexibility 4
		Offer a large degree of product variety (broad product line)	Flexibility 5
		Adjust product mix	Flexibility 6
	Quality	Improve conformance to design specifications	Quality 1
		Offer consistent, reliable quality	Quality 2
		Provide high performance products	Quality 3
		Offer durable, reliable products	Quality 4
		Manufacture with consistently low defect rates (reduce defect rates)	Quality 5
	Delivery	Provide fast deliveries	Delivery 1
		Meet delivery promises or commitments	Delivery 2
		Reduce manufacturing lead time	Delivery 3
	Service	Provide effective after-sales service	Service 1
		Provide effective support or complementary services	Service 2
		Wide product distribution (make product accessible)	Service 3
		Customise products and services to meet customer needs	Service 4
	Environment	Make environment-friendly products	Environment 1
		Use environment-friendly production processes	Environment 2
		Provide the firm with a positive environmental image	Environment 3
		Prevent environmental accidents	Environment 4
Outcomes		Labour productivity compared to industry average	Performance 1
		Customer loyalty compared to industry average	Performance 2
		New product development success compared to industry average	Performance 3
		Sales volume compared to industry average	Performance 4
		Return on assets (ROA) compared to industry average	Performance 5
		Adaptability to changing competitive conditions compared to industry average	Performance 6

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