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CUMULATIVE MANUFACTURING CAPABILITIES: AN EXTENDED MODEL AND NEW EMPIRICAL EVIDENCE

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Abstract

There has been intense debate in the manufacturing strategy literature on the way in which firms work on different manufacturing capabilities, with two opposing approaches considered –the *trade-off* model and the *sand cone* model. Analysis of these models has essentially been based on study of the links amongst four classic manufacturing capabilities (quality, delivery, flexibility and cost efficiency) and has obviated the need to consider environmental protection as an important manufacturing capability. This study analyses the theoretical arguments and the prior empirical evidence on the two models, and proposes and tests an extended *sand cone* model which includes the environmental protection objective alongside the four traditional ones. The research uses structural equation modelling and data from a sample of 274 manufacturers to contribute additional empirical evidence on the existence of cumulative effects amongst manufacturing capabilities. It is observed that the predominant strategic model in these firms is one of multiple, non-incompatible capabilities with cumulative effects according to the following sequence: quality, delivery, flexibility, environmental protection and cost efficiency.

Keywords: manufacturing strategy*;* manufacturing capabilities; *trade-offs*; *sand cone* model; environmental protection

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CUMULATIVE MANUFACTURING CAPABILITIES: AN EXTENDED MODEL AND NEW EMPIRICAL EVIDENCE

1. INTRODUCTION

In recent decades, there has been intense debate in the manufacturing strategy literature on the way in which firms work on different manufacturing capabilities. Generally speaking, two opposing approaches are considered – the *trade-off* model and the *sand cone* model. Analysis of these models has essentially been based on study of the links amongst the classic manufacturing objectives of quality, delivery, flexibility and cost efficiency and has led to diverging results (Rosenzweig and Easton, 2006).

This study analyses the theoretical arguments and the prior empirical evidence on the two models and offers additional evidence on the existence of cumulative links amongst the four classic manufacturing objectives of quality, delivery, flexibility and cost efficiency.

Moreover, analysis of the links amongst the objectives has generally obviated the need to consider new objectives –such as the environmental protection, that due to their increasing importance (Aragón-Correa *et al.*, 2008) should be taken into account in the analysis of manufacturing strategy.

Environmental aspects have become an essential element in the business strategy of a large number of firms (Angell, 1999) and have led many managers to consider improvements in environmental protection performance as one of their basic priorities. However, although the scientific community has called for the inclusion of the environmental protection in the set of manufacturing objectives (Angell and Klassen, 1999; De Burgos and Céspedes, 2001; Inman, 2002; Kleindorfer *et al.*, 2005), research to date has paid scarce attention to it. This research tries to fill this gap in the manufacturing strategy literature by proposing and testing an extended *sand cone* model which includes the environmental protection objective alongside the four traditional objectives. It therefore adopts an integrated perspective for environmental operations management (Angell and Klassen, 1999), considering the environmental protection as an objective for the production department and not just as an external condition imposed on the firm.

The study is structured as follows. After this introduction, there is a review of the literature on the definition of the manufacturing objectives and the models established for achieving them. On the basis of this review of the literature, the objectives of the study and the hypotheses to be tested are laid down. The research methodology is then presented and the measurement variables used are tested. Finally, after analysis of the results obtained, the main conclusions are drawn and limitations and possible future research lines are mentioned.

2. BACKGROUND

2.1. Manufacturing objectives

Since the field of manufacturing strategy was first set up, four basic manufacturing objectives have been considered: cost efficiency, quality, flexibility and delivery (Skinner, 1969, 1974; Hayes and Schmenner, 1978; Hayes and Wheelwright, 1984; amongst others).

Although the objectives of innovation (Dangayach and Deshmukh, 2001) and service were also considered, they have not been generally accepted in the literature. This is because some components of flexibility, such as change and volume, also promote innovation (De Toni and Tonchia, 1998), and because service can be considered as a component of quality (Garvin, 1983). In recent years, environmental protection has started to be included amongst manufacturing objectives, on the same terms as the four objectives mentioned above (Handfield *et al.,* 1997; Angell and Klassen, 1999).

It cannot be denied that, in the past, environmental protection matters were considered a restriction for the manufacturing area. Therefore, the only link between the environmental protection factor and manufacturing was the installation of control or end-of-process technologies –those which eliminate any waste produced– which, by their very nature, did not require the consideration of environmental protection matters as a production objective (Newman and Hanna, 1996).

But today manufacturing objectives are considered to have an effect on the environmental protection result and vice versa. So, flexibility leads to a reduction in inventories and therefore fewer products are spoilt while fewer resources are used. Also, products can be better adapted to environmental protection needs (Klassen and Angell, 1998). Improved quality stabilizes production processes, eliminating reprocessing tasks and saving energy and resources (Rosenzweig and Roth, 2004). Moreover, quality management systems have synergies with environmental protection management (Kitazawa and Sarkis, 2000). Cost reductions can also be achieved, amongst other actions, through savings in energy and by recycling products (Porter and van der Linde, 1995a, 1995b). And a reduction in delivery time not only reduces inventories but also shortens internal product transport time, eliminating the need for repeat consignments (because deliveries are reliable). This too saves energy (Koufteros *et al.*, 2002).

Environmental protection practices also affect manufacturing objectives. The use of production processes that consume fewer production inputs or less energy and make use of any waste generated helps reduce costs (Shrivastava, 1995a). Ecoefficiency or reduced costs through more efficient use of resources (Gupta and Sharma, 1996) is based on the premise that any contamination produced by the firm is a symptom of inefficiency. Moreover, environmental protection management practices affect total quality tools and this causes a move towards total quality environmental management (TQEM) (Welford, 1992), to the extent that the ISO 9000:2000 includes environmental protection aspects. Contamination prevention technologies may provide the production flexibility that firms need if they are to offer products that will not come up against environmental protection restrictions. Also, environmental protection practices can be used for adding value to products by reducing delivery time (Newman and Hanna, 1996). Therefore, Angell and Klassen (1999) suggested that, in the long term, the environmental protection objective should be included at the same level as the other manufacturing objectives thus making them endemic in the production process rather than seeing them only as external restrictions. Moreover, in the short term, they recommended that firms should reflect environmental protection aspects in tactical changes while the management should promote their inclusion in the process in the long term. However, few studies have considered the position of production departments regarding this topic and the effects of such considerations on their results.

This study therefore considers the four traditional objectives (cost efficiency, quality, flexibility and delivery) and includes the environmental protection as the fifth objective in testing the prevailing objective model in firms. These five general objectives are broken down into 22 categories (**Table 1**).

Trying to avoid terminological confusion, in this paper, for each manufacturing objective, we use the term “competitive priority” referring to priority granted or emphasis placed to each manufacturing objective (importance). Whereas, we define “manufacturing capability” as the strength or advantage developed regarding the industry average or relative to primary competitors (performance).

INSERT TABLE 1

2.2. Models for improving manufacturing objectives

Most of the literature on manufacturing strategy is based on the model of incompatibilities –or *trade-offs* to use the term devised by Skinner (1969)– amongst its different objectives. This model is based on two basic premises: a) the factory has many objectives, and b) some objectives are incompatible with others. A *trade-off* means that preference or priority is given to one manufacturing objective over others. Manufacturing only one product, a factory might pursue different manufacturing objectives but, furthermore, many objectives might arise because a single factory manufactures: a) products that are at different stages of their life cycle, and b) products that meet different market needs. In this last case, this multiplicity reflects the result of manufacturing two or more products in the same factory to meet different objectives. When products, processes, levels of skills and customer requirements are added, the production department tends to increase its size and, especially, to establish different objectives to meet different market needs (Skinner, 1974).

The traditional strategic approach is that the different objectives are incompatible (Hofer and Schendel, 1978), because they consider it is difficult and risky for a firm to try to compete by offering high performance results in all its objectives. Firms that aim to be exceptional in many objectives end up being worse than those which focus their efforts on a single objective. In the manufacturing field, Skinner (1969) proposed that each manufacturing department (factory or strategic manufacturing unit) should focus on one or, at the most, two of the various possible objectives. Skinner (1969) called this explicit, priority objective the 'manufacturing task', although the more usual term is 'competitive priority'. The manufacturing task (or competitive priority) should be maintained over time and indicates to a certain extent that achieving this objective is more important than achieving others. There is thus a synergy effect within the production department, with the actions of the various responsibility centres being oriented in the same direction (Hayes and Schmenner, 1978).

Some researchers move away from the *trade-off* model and defend achieving a balance amongst different objectives. They assume there is a link –not a conflict– between long and short term objectives (Banks and Wheelwright, 1979). Following this argument, Huge and Anderson (1988) consider that the various objectives can be improved simultaneously because they do not oppose each other and they can be reached in a concerted way. So, based on the experience of Japanese manufacturers, it has been noted that some firms tend to simultaneously achieve acceptable performance levels in the various manufacturing objectives, thus eliminating *trade-offs* (Hayes and Pisano, 1994).

Certain authors consider that balance amongst objectives can be achieved in a sequential (cumulative) way using the '*sand cone* model' developed by Ferdows and De Meyer (1990). This approach considers that every factory should focus on a single objective at any single moment in time, as there is a logical sequence that should be followed, in order to achieve substantial improvements in all of them. More specifically, the initial emphasis should be placed on obtaining quality and, once a suitable quality level has been attained, then work should be begun on improving delivery. But at the same time, work should continue on quality. When a suitable standard has been reached for delivery, work should begin on flexibility, while continuing with the two objectives already reached. Finally, having reaching the desired level of flexibility, the focus should turn to cost efficiency. The model determines that the falling sand broadens at the base while rising in height. In fact, the broadening of the base is related to continuous improvement, because it is a question of improving the objectives reached while trying to achieve the next one. Since the objectives have an accumulative nature and are based on those that have already been achieved, there is no incompatibility preventing them from being achieved. If manufacturing objectives are achieved in this sequential way, they can provide the firm with a powerful and sustainable competitive advantage because they are based on consistent management practices that are consistent over time and cannot, therefore, be replicated easily or fast by competitors.

This approach is based on an original idea by Nakane (1986), although the sequence varies: quality, dependability, cost efficiency and flexibility. However, quality management specialists introduced the idea that quality should receive priority and, until a suitable level has been reached in quality, no steps should be taken to achieve the other objectives. The competitive progression theory (Roth and Giffi, 1995; Roth, 1996) gives a theoretical explanation as well as additional empirical evidence for the *sand cone* model. This theory states that combined, sustainable manufacturing capabilities accumulate in a forward sequential progression –from quality to delivery, flexibility and cost efficiency– by means of an innovation cycle that leads towards strategic agility.

Finally, the studies that empirically test the *sand cone* model, in an explicit way, include Noble (1995), White (1996), Kathuria (2000), Corbett and Whybark (2001), Koufteros *et al (*2002), Rosenzweig and Roth (2004), Größler and Grüßner (2006), Rosenzweig and Easton (2006), Amoako-Gyampah and Meredith (2007), Wang and Tadisina (2007), Boon-itt and Wong (2008). Flynn and Flynn (2004) find empirical evidence of the link between the accumulation of some manufacturing capabilities and the production department performance, but their results do not support the *sand cone* model. Filippini *et al.* (1998) state that there is evidence of high levels of compatibility among different types of manufacturing performance but is not possible to consider that *trade-off* model has been overcome.

In spite of the theoretical arguments and the empirical evidence against the *trade-off* model, some authors consider that it can be applied in certain circumstances. They even maintain that it is possible to combine the two models (*trade-off* and *sand cone*) as they offer complementary approaches. It should be stressed in this connection that manufacturing capabilities depend on the technology used. If the factory operates below the technological frontier of its manufacturing possibilities, it can improve in all the objectives simultaneously. When it reaches the frontier, *trade-off*s occur. But if the frontier moves, there will be further room for simultaneously achieving the objectives (Clark, 1996; Schmenner and Swink, 1998). As stated by Skinner (1992), changing technology changes the *trade-offs* and the links between the design of a manufacturing system and the objectives. In other words, a factory that uses a manufacturing system that is within the technological standard for the industry (at the technological frontier) cannot expect to improve two or more objectives simultaneously (Ferdows and De Meyer, 1990). Lapré and Scudder (2004) provide empirical evidence from the airline industry that the *sand cone* model is applicable when firms are operating further away from their asset frontiers, although *trade-offs* occur when operating close to asset frontiers.

2.3. An extended sand-cone model: Research hypotheses

Based on a review of the literature, the aim of this study is to test, in a sample of manufacturers located in Spain, whether or not there are *trade-offs* amongst the manufacturing capabilities, that is, whether firms are able to achieve excellent results in several manufacturing objectives simultaneously and also whether the different manufacturing capabilities strengthen each other. Considering the literature on the environmental protection objective and the interactions between it and the four traditional manufacturing objectives (Del Brío *et al.*, 2005), in our research the sequence is completed by including the environmental protection as the fifth manufacturing objective.

De Burgos and Céspedes (2001) explain the need for including the environmental protection as an objective for the production department, and state that there are direct links between the environmental protection strategy and the production department. The authors point to the existence of synergies between environmental protection and improvement programs and activities and operating methods and practices. They also indicate that environmental protection management programs should be implemented taking into account and supporting manufacturing strategy. This means that the objectives for the operations area should be expanded to include environmental protection considerations. Angell (1999) proposes that inclusion of the environment protection as a manufacturing objective could be the first step towards achieving a sustainable environmental protection strategy. Reduction of the environmental impact should be considered, at least partially, a matter for the production department (Angell and Klassen, 1999).

Previous studies have analysed the impact of the results of environmental protection management on the production department (see, for example, Gupta and Sharma, 1996; Klassen and Angell, 1998), identifying possible synergies between environmental protection improvement and manufacturing objectives. De Burgos and Céspedes (2001) state that it would be interesting to analyse the link between this environmental protection objective and the other manufacturing objectives as well as the existence of a possible logical sequence for achieving lasting improvements in the manufacturing objectives in the long term.

Regarding this sequence and on the basis of previous studies (Noble, 1995; Ferdows and De Meyer, 1990; Rosenzweig and Roth, 2004), it can be assumed that improvements in quality serve as a basis for the improvement of the other objectives. Specifically, quality is hypothesized to have a significant positive relation with delivery. Delivery refers to a firm's ability to provide fast and dependable deliveries; therefore, it comprises two elements: a) speed, and b) reliability. Schroeder *et al.* (1996) argue that conformance quality will drive higher levels of on-time deliveries and fast deliveries. When a factory improves its quality, its processes become more stable and reliable and less time and cost are needed for re-processing tasks (Rosenzweig and Roth, 2004). When quality improves, the number of items requiring re-work becomes smaller. This allows materials to move more swiftly and consistently through a process and cycle times to become more predictable. Reductions in the lead time, set-up time and delivery time depend on the reliability of the processes and on a consistently high product quality level (Sakakibara *et al.*, 1997). Consistent with this, Wacker (1987, 1996) mathematically demonstrates that a reduction in defect rates can have a positive effect on throughput time and delivery reliability, a compatible relationship that has also been reported by other authors (Schroeder *et al.*, 1996; Vickery *et al.*, 1997; Safizadeh *et al.*, 2000). Taking this into account, it could be argued that a production process with high levels of internal quality may facilitate delivery commitments (quoted and/or forecasted) based on the process output (Sarmiento *et al.*, 2007). In other words, higher levels of quality may lead to enhanced delivery, so the following hypothesis is established:

H_1: Improving quality has a direct, positive effect on delivery.

Nevertheless, upstream in the sand-cone model, delivery is assumed to positively affect flexibility. Flexibility measures the capability for manufacturing to adapt to changing market needs. This objective involves several facets (De Toni and Tonchia, 1998): a) the possibility of changing manufacturing volume to meet fluctuations in demand without any significant effect on cost efficiency –volume flexibility; b) the skill to modify the characteristics of existing products –product flexibility; and c) the skill to place new products on the market fast – flexibility in innovation. In fact, some studies show that delivery reliability and various dimensions of flexibility (e.g. product mix and volume changes) may be compatible and are positively associated (Vickery *et al.*, 1997). High-speed manufacturing improves flexibility in that less time is needed for responding to different external influences and adjusting to changes in requirements or specifications (Milling *et al.*, 2000). Corbett and Van Wassenhove (1993) assert that if the organization is unable to meet due dates under normal circumstances, it will be unable to react flexibly to unforeseen volume fluctuations in demand. This is consistent with the comments by Wacker (1987) who argues that, as throughput time increases, a firm becomes less productive and less able to respond to changes in output mix and customer demand responsiveness. Therefore, the following hypothesis is established:

H_2: Improving delivery has a direct, positive effect on flexibility.

Manufacturing flexibility, by enabling efficient adaptation to change and uncertainty, can support environmental practices (Klassen and Angell, 1998). Improving innovation in both products and processes promotes the incorporation of more flexible, more environment-friendly technology. It also enables the development of make-to-order production systems that can operate with lower inventory levels. Such systems reduce shrinkage and limit the obsolescence of stored products which otherwise would have to be eliminated, reprocessed or recycled, and this reduces environmental impact. Moreover, production systems involving more flexible processes (such as just-in-time) may promote the adoption of more advanced environmental practices which might improve the company's overall environmental situation (Del Brío *et al.*, 2005). This argument is to some extent consistent with studies that have empirically noted synergies amongst some lean manufacturing processes and environmental practices (King and Lenox, 2001; Rothenberg *et al.*, 2001). The following hypothesis is therefore posed:

H_3: Improving flexibility has a direct, positive effect on the environmental protection objective.

Direct synergies can also be observed between environmental protection and cost reduction. For example, the development of an overall pollution prevention strategy (which only requires limited additional investments, compared with add-on equipment for an end-of-pipe strategy) may result in reduced operating costs and efficiency improvements (Wagner, 2005). Additionally, the introduction of technologies that aim to improve firms' environmental protection situation (for example, reducing energy consumption during the production process) or the re-examination of the actual production processes also help to save costs (Porter and van der Linde, 1995a, 1995b; Angel and Klassen, 1999). This was exemplified by Dorfman *et al.*, 1992, who reported annual cost savings of $740,000 at Ciba-Geigy's dyestuff plant in New Jersey as a result of re-examining its wastewater streams and operating processes and replacing some production components. Similarly, Sheridan (1992) reported how 3M implemented a new production technique that allowed it to reduce hazardous wastes by 10 tons per year at almost no cost, yielding annual savings of more than $200,000. Van Wassenhove and Corbett (1991) reported how AT&T saved US$1.4 million on recycling efforts alone, whereas the Gulf Coast Acid Team, a task force of employees at Dow Chemical, recommended installation of a state-of-the-art recycling system that resulted in an annual saving of US$20 million.

Solving environmental problems can also yield benefits in terms of lower costs due to reduced downtime. Parkinson (1990) described how installing higher quality monitoring equipment allowed DuPont to reduce production interruptions and the associated wasteful production start-ups in many chemical production processes, thus reducing waste generation as well as downtime.

The implementation of environmental initiatives aiming to substitute materials, reuse or recycle production inputs, use less packaging, reduce storage, make work conditions safer, improve monitoring and maintenance, etc., may lead to higher resource productivity (Porter and van der Linde, 1995b). Basta and Vagi (1988) reported several cases of successful waste reduction projects in the chemical industry that illustrate the positive effects of "green" initiatives on cost savings. With regard to certain ecological products, it is possible to go even further, with firms recovering waste products for re-manufacturing, thus achieving a cost reduction advantage (Ayres *et al.*, 1997). As pointed out by Porter and van der Linde (1995b), solving environmental problems by using recyclable products can lead to designs that allow valuable materials to be recovered more easily after disposal of the product; in this case, whoever takes back used products –either the customer or the manufacturer– gains greater value.

Environmental management may also improve firms' process excellence by using environmental management tools which support identification of eco-efficiency potential and successful implementation of eco-efficiency enhancing measures (Wagner and Schaltegger, 2001). In this way, as shown empirically by Carter and Carter (1998), environmental protection improvement, which in turn helps make the firm eco-efficient, leads to reduced costs (Gupta and Sharma, 1996). Or, to state this in more formal terms:

H_4: Environmental protection improvement has a direct, positive effect on cost efficiency.

The hypotheses H_1-H_4 capture the direct effects of improving a given capability on the capability succeeding it in the depicted progression. However, the literature suggests that the development of these capabilities in this successive fashion may lead to indirect and cumulative effects. As previous authors suggest (Nakane, 1986; Ferdows and De Meyer, 1990; Schmenner and Swink, 1988; Swink and Way, 1995; Flynn and Flynn, 2004), quality can be viewed as the foundation for the development of cumulative capabilities. The literature documents many cases and examples that illustrate the positive effect of quality on other manufacturing capabilities. Quality management systems have synergies with flexibility and environmental protection management (Kitazawa and Sarkis, 2000). The quality improvement stabilizes production processes, eliminating reprocessing tasks and saving energy and resources (Rosenzweig and Roth, 2004). A reduction in lead times not only reduces inventories but also shortens internal product transport time, eliminating the need for repeat consignments (because deliveries are reliable), which also saves energy (Koufteros *et al*., 2002) and reduces costs. Flexibility leads to a reduction in inventories and therefore fewer products are spoilt while fewer resources are used, which contributes to environmental protection and cost savings. Consequently, contrary to the theory that *trade-offs* exist among manufacturing capabilities, cost efficiency in production can be achieved more easily through improvements in other capabilities. Therefore, considering the shared (or common) process variance between enhancement in one capability and improvement in the others, it is possible to assume the existence of positive indirect effects amongst them (Rosenzweig and Roth, 2004). This leads to the following hypotheses:

H_{5a}: Improving quality has an indirect, positive effect on flexibility by improving delivery.

H_{5b}: Improving quality has an indirect, positive effect on environmental protection by improving delivery and flexibility.

H_{5c}: Improving quality has an indirect, positive effect on cost efficiency by improving delivery, flexibility and environmental protection.

H_{6a}: Improving delivery has an indirect, positive effect on environmental protection by improving flexibility.

H_{6b}: Improving delivery has an indirect, positive effect on cost efficiency by improving flexibility and environmental protection.

H_7: Improving flexibility has an indirect, positive effect on cost efficiency by improving environmental protection.

The theoretical reasoning presented above leads us to consider a cumulative manufacturing capabilities model, depicted in **Figure 1**, showing a progression in the achievement of quality, delivery, flexibility, environmental protection and cost efficiency capabilities. By empirically testing this model, we try to answer the following research question: *Do firms accumulate manufacturing capabilities by following the sequence of quality, delivery, flexibility, environmental protection, and cost efficiency, in such a way that the performance achieved in each objective allows improvements in the others?*

INSERT FIGURE 1

3. METHODOLOGY

3.1. Research design and sample characteristics

The information needed for the study was obtained from a survey conducted on 1,234 manufacturers that in 2003 were located in Spain and employed over 100 workers, according to the Amadeus-SABI database. The selection of firms was based on two-digit ISIC codes, including codes 24 and 28 to 36. A detailed description of the research instrument and the sample analysed can be seen at Vázquez-Bustelo *et al.*, 2007.

The questionnaire used was designed on the basis of the existing literature and the conclusions obtained from a previous case study (Vázquez-Bustelo and Avella, 2006). It was revised by four experts in operations management and two experts in survey design. With the aim of checking its validity and improving its design, a pre-test was also done on a small sample of firms drawn from the population.

The information needed for the study relates to the production function in firms, so the questionnaire was addressed to the plant/operations/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, or a division or plant within a firm, with defined business and manufacturing strategies. A total of 283 valid questionnaires were returned corresponding to 274 different firms and representing a valid response rate of 22.2%. Using a Student T-test, the last 25% of respondents were compared to earlier ones and no statistically significant differences were found in key variables at the 5% level. Based on the assumption that late respondents are similar to non-respondents (Armstrong and Overton, 1977), non-response bias does not appear to be a major problem in this research.

3.2. Measurement of variables

For each of the 22 items of the five manufacturing objectives considered in this research (**Table 1**), managers were asked to indicate on a five-point scale (1 = poor/lower; 3 = average; 5 = excellent/higher), the strength or advantage developed in comparison to its competitors. In this way we measure manufacturing capability in each dimension of the five manufacturing objectives considered in this research.

Before testing the hypotheses, the metric properties of the scales for the five manufacturing capabilities were evaluated, that is, the unidimensionality, reliability and validity.

Exploratory factor analysis was carried out using Varimax rotation to determine the dimensions underlying the set of variables in each scale (**Table 2**). The 22 variables were grouped in five factors relating to cost efficiency (4 items), flexibility (6 items), quality (5 items), delivery (3 items) and environmental protection (4 items) with factor loadings above 0.5 and a percentage of total accumulated explained variance of over 50%.

INSERT TABLE 2

After exploratory factor analysis, confirmatory factor analysis (CFA) was carried out by means of structural equations, using the EQS statistical package, which confirmed the composition of the scales identified in the previous exploratory factor analyses for the manufacturing capabilities –strength developed in each of the manufacturing objectives– (**Table 3)**.

INSERT TABLE 3

In order to analyse reliability, Cronbach's alpha coefficient and the composite reliability coefficient were calculated (**Table 3**). Cronbach's alpha coefficient in all cases was over 0.7, the criterion usually considered to identify strict internal consistency. In all cases the composite reliability coefficient was over the minimum level of 0.6 recommended by Bagozzi and Yi (1988).

After studying the unidimensionality and testing for reliability, the content, convergent and discriminant validity were analysed. Content validity indicates that the items considered are suitable for representing the concepts to be analysed. The 18 measures used for the four traditional manufacturing objectives (cost efficiency, quality, flexibility and delivery) are an adaptation of those used in the Global Manufacturing Futures Survey Project-GMFSP (Miller *et al.*, 1992) and are consistent with the measures used in other empirical studies on manufacturing strategy (Roth, 1996; Corbett, 1996; Avella *et al.*, 1998; Gilgeous, 2001, among others**)**. The items used for measuring the environmental protection objective are also based on the extant literature (Porter and van der Linde, 1995a; Shrivastava, 1995a, 1995b; Gupta and Sharma, 1996; Newman and Hanna, 1996; Ayres *et al*., 1997; Klassen and Angell, 1998; Angell and Klassen, 1999; Kitazawa and Sarkis, 2000**)**. Only those categories in which the manufacturing area is directly responsible are included.

Since the scales were built on the basis of the previous literature 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. It can be assessed from the measurement model by determining whether each indicator's estimated pattern coefficient on its posited underlying construct factor is significant (Anderson and Gerbing, 1988). Following Anderson and Gerbing's method, the lambda coefficients that measure the relation between the observed and the latent variable were analysed observing that all the standardized factor loadings were statistically significant at a 95% confidence level (t>1.96, weak condition) and exceeded 0.5 (strong condition) (**Table 3**).

The discriminant validity measures the degree to which the specified latent factors differ even though they are correlated. It was tested by calculating and examining the confidence interval of the paired correlations among the latent variables (i.e., +/- two standard errors; Marcoulides, 1998). As shown in **Table 3**, the discriminant validity of the scales can be confirmed because none of these confidence intervals contains the value 1.0 at 95% confidence (Bagozzi and Phillips, 1982; Anderson and Gerbing, 1988; Torkzadeh *et al.*, 2003). However, the idea of the existence of synergies or reinforcements amongst the various objectives suggests that the factors that measure the objectives should have a certain degree of correlation. Table 4 shows the correlation matrix amongst the various objectives. The results presented indicate that the correlations between the objectives are moderate, in no case above 0.7. This allows us to conclude that the factors measure different concepts and can be treated as different statistical objects.

INSERT TABLE 4

4. RESULTS

In order to analyse the data and test the hypotheses, a structural equation model was used. This methodology allowed us to carry out statistical validation of the model proposed by means of simultaneous analysis of the whole system of variables involved and their links, determining the degree to which the analysis is consistent with the data. Use of this technique allows the researcher to simultaneously compare many equations and explore both the direct and indirect effects of the variables, offering a more precise measure of the overall effect of one variable on another.

If the chi-square test is considered in isolation, the model does not reach the recommended criterion for good fit. However, the possibility of using the chi-square test is limited and has been questioned in the literature (Bagozzi and Yi, 1988) because it does not take into account the complexity of the model tested.

To solve this limitation, its value should be divided by the degrees of freedom. This quotient should be 3 or below, a criterion which is achieved in this model (S–B χ^2 / df = 1.95 < 3). The values reached by other robust indices (BBNNFI = 0.921 > 0.9) (CFI = 0.930 > 0.9) (IFI = 0.931 > 0.9) (RMSEA = 0.058 < 0.08) also support the model's goodness of fit and allow us to confirm the plausibility of the links proposed between the variables involved.

The estimated value and the sign of the links (direct and indirect effects) between the five manufacturing objectives are shown in **Table 5**.

INSERT TABLE 5

The results of testing the model support the hypothesis that improved manufacturing objectives can be achieved progressively and without incompatibility or direct *trade-offs* between them. The results of the multi-variant analysis offer evidence that backs up the theory of the sequential or *sand cone* model (**Figure 2**).

INSERT FIGURE 2

The specific link between quality and delivery (H_1) is backed by the empirical evidence that points to the existence of a direct, positive, significant link at 99% confidence between the former and the latter (*t* value = 9.040). Similar results can be observed for the other hypotheses that indicate direct effects amongst the remaining manufacturing objectives. They show that greater delivery speed and dependability has a positive effect on flexibility ($p < 0.01$), thus supporting hypothesis H_2. The data also support hypothesis H_3, noting a direct, positive, significant effect (t value = 5.543) of flexibility on environmental protection. Finally, the t value of the non-standard coefficient 0.348 illustrates the existence of a direct, positive, and significant effect ($p < 0.01$) of environmental protection on cost efficiency, which supports hypothesis H_4.

Table 5 shows that a higher level in quality has an indirect effect on cost efficiency ($p < 0.01$) through an improvement in the delivery, flexibility and environmental protection. These results support hypotheses H_{5a}, H_{5b}, H_{5c}. With regard to H_{6a}, H_{6b}, the results indicate that improved delivery have an indirect, positive effect on cost efficiency (t value = 3.219), through increased flexibility and environmental protection improvement ($p < 0.01$). Finally, the results support the last of the hypotheses (H_7), indicating that flexibility has an indirect effect on cost efficiency ($p < 0.01$) as a result of greater environmental protection.

5. DISCUSSION

Our results point out that not only can *trade-offs* be avoided altogether, but in fact one capability would enhance another. Specifically, our findings provide empirical evidence supporting an extended *sand cone* model which includes the environmental protection objective alongside the four traditional manufacturing capabilities –quality, delivery, flexibility and cost efficiency. Our data show the system of simultaneous dependence that exists in the process of improving these five manufacturing capabilities and suggest that it is possible to reject the existence of *trade-offs* or incompatibilities among them, thus providing empirical support for the cumulative aspects of the manufacturing capabilities analysed.

Nowadays, compared to their competitors, excellent manufacturers seem to achieve better quality, to be more dependable, more flexible, and more environment conscious and, in spite of all that, to achieve cost efficiency. Maybe the pursuit of intelligent production-competition strategies that try to overcome the traditional duality of cost leadership or differentiation (Bullinger and Schweizer, 2006), the generalized implementation of advanced manufacturing technologies (AMT) and other world-class practices and organisational improvements (New, 1992) have helped such firms to concurrently develop multiple capabilities avoiding *trade-offs* between them. These findings are in line with the arguments of previous authors (Ferdows and De Meyer, 1990; Swink and Way, 1995; Schmenner and Swink, 1998) and also support the idea that addressing capabilities in a particular sequence enables improvements to be made in other capabilities.

The relationship among capabilities suggested in our model and our results would appear to have some theoretical and practical implications.

From a theoretical point of view, this paper highlights the need to adopt an integrated perspective for environmental operations management, and justify the need to include environmental protection as a dimension of operations performance in manufacturing strategy studies. The paper contributes to the field of operations management by exploring the direct and indirect connections between capabilities for a large sample of manufacturers. Our findings on the relationship among manufacturing capabilities and their sequence may offer a way of better understanding manufacturing competence, which determine manufacturing's contribution to the success of a firm.

Since our findings suggest that improvement in certain manufacturing capabilities can amplify certain other capabilities, managers can conclude that developing multiple capabilities simultaneously is possible and desirable. Our model also suggest to practitioners that an efficient development path to overall improvement in manufacturing capabilities exist, and it can be used as a guide when constructing manufacturing strategies and designing programmes to improve performance of manufacturing systems. The sequence, strength and direction of the tested relationships between the five manufacturing capabilities considered in our paper may play a major role conducting firm's resource allocation and leading the emphasis placed by managers on the improvement of different capabilities. Particularly, our findings suggest that improvements on the quality dimension have a strong positive impact on improvements on delivery capabilities and, by supporting delivery, capabilities on a higher level (e.g. flexibility, environmental protection and cost efficiency) jointly benefit from achievements on quality. Thus, as the other capabilities benefit from quality, management attention should first be directed toward achieving and then expanding it. Quality management (control, assurance and improvement) may serve a primary building block for gaining cumulative capabilities. This assertion is consistent with previous studies that observe quality management to form a strong foundation for cumulative capabilities (Flynn and Flynn, 2004). Quality-related principles, initiatives, practices and action programmes (e.g. Process Statistical Control, ISO 9000, *kaizen*, six sigma, TQM, quality circles, QFD, etc.) may function as drivers to enhance supportive links between the manufacturing capabilities. One explanation may be related to the fact that the work processes associated with quality management may also have interdependent properties, or "process commonalities" that overlap with other management practices related with the enhancement of different capabilities. Thus, the improvement of one capability maybe acts synergistically to automatically modify other capabilities with which it shares common processes (Rosenzweig and Roth, 2004). This argument can be a plausible explanation of the indirect links and cumulative effects observed in the structure of capabilities presented in our paper. After achieving the quality-related objective and while quality efforts are further expanded, attention should be directed toward the improvement of delivery capabilities. Delivery (dependability and speed) is closely related to organisational integration, supply chain management and lean manufacturing (Flynn and Flynn, 2004). In this second layer, management should focus their strategic initiatives on developing effective supplier relationships and incorporating external supply chain management practices internally. Relationship-building initiatives such as just-in-time (JIT) manufacturing, supplier certification and customer integration, for example, can clearly change delivery reliability and speed, and synergistically amplify other capabilities on a higher level, such as flexibility, environmental protection or cost efficiency. Once significant performance has been achieved in quality and delivery and while pursuing these objectives further, resources may be directed toward improving manufacturing flexibility by proper product-process integration and close coordination between manufacturing activities and suppliers and/or customers. In this third layer, the activities initiated during the previous stages of the improvement progression facilitate the possibility of changing manufacturing volume to meet fluctuations in demand without incurring high penalties, and enhance skills in both modifying the characteristics of existing products or processes, and placing new products on the market fast. A close coordination with suppliers that provide slack capacity, absorb demand fluctuations or exchange technological expertise, and the information sharing and degree of process integration with customers may be key for directly acquiring flexibility capability and affecting the remaining capabilities indirectly. While efforts continue toward achieving and expanding quality, delivery and flexibility, attention can then be directed toward improving environmental protection. Since environmental protection as strategic capability is supported by other capabilities and reinforce each other (De Burgos and Céspedes, 2001), managers should develop policies and implement environmental management programmes with similarities and synergies with the strategic operations initiatives already in place. Proactive environmental strategies (e.g. Design for environment (DfE), total quality environment management (TQEM), life cycle assessment (LCA), total recycling, source reduction/pollution-prevention (SR/P2), or zero emissions) would have a positive affect on cost cutting via waste reduction and other factors that reflect an eco-efficient approach.

6. CONCLUSIONS

The purpose of this study was to determine which model for improving manufacturing objectives prevails in firms. Are there incompatibilities (*trade-offs)* among the different manufacturing capabilities? Or, on the contrary, are firms able to obtain high scores in several manufacturing objectives simultaneously and do the various manufacturing capabilities strengthen each other?

The study began with a review of the literature and the design of a model structuring the links among the five key manufacturing objectives –quality, delivery, flexibility, environmental protection and cost efficiency. After drawing up a precise definition of these objectives, the measurement scales for the constructs were validated, and the set of links proposed was tested using structural equation modelling. The results of the multi-variant analysis showed that the predominant model in these firms is one of multiple, non-incompatible capabilities with cumulative effects according to the following sequence: quality, delivery, flexibility, environmental protection and cost efficiency. It was noted that the five manufacturing objectives considered in the research not only are not incompatible with each other but that improvements in quality have a positive effect on delivery, flexibility, environmental protection and cost efficiency as do each of the objectives on the others, so they strengthen each other and produce cumulative effects.

Thus, this study makes a dual contribution. On the one hand, it offers additional empirical evidence on the existence of cumulative links amongst the four classic manufacturing objectives: quality, delivery, flexibility and cost efficiency, as suggested both by the *sand cone* model (Ferdows and De Meyer, 1990) and the competitive progression theory (Roth, 1996; Rosenzweig and Roth, 2004). On the other, it adopts an integrated perspective for environmental operations management, validating an extended *sand cone* model which considers environmental protection management alongside the four traditional objectives.

In spite of its contribution, the study has certain limitations that represent challenges for further research. On the theoretical side, the absence of *trade-offs* among the capabilities may be explained by the fact that the manufacturing units studied are positioned further from their performance, technological or assets frontier (Schmenner and Swink, 1998; Rosenzweig and Roth, 2004). However, our research does not consider the viewpoint of performance frontiers, an aspect that should be addressed in future research. Since we did not include the consideration of contingencies as Swink and Way (1995) suggest, and did not compare the influence of different structures of capabilities on business performance (measured, for example by market share, ROI or other indices) one has to be careful to interpret the specific structure of operations-based capabilities presented in this paper as the “one best way” to firm’s competitiveness and success. This paper also uses a conceptualization of environmental protection mainly focused on internal issues, although an internal perspective to environmental protection may be insufficient to actually improve a firm’s environmental objective.

On the methodological side, obtaining information by means of a survey may generate doubts about the validity of the information provided by respondents. This problem may be solved by obtaining information from more than one source for each unit of analysis (that is to say, from more than one respondent), but this research did not consider this possibility, as it would have had important negative effects on the response rate. For this reason, single respondent bias can be considered a limitation for this empirical research. This study also uses managerial perceptions to measure the manufacturing capabilities. Perceptual measures of performance have often been used to measure operational performance because of the difficulty associated with obtaining comparable, objective measures for large samples. Objective measures are not normally available at the manufacturing level, or firms are reluctant to facilitate such information. Although this approach is a common procedure in management research, objective measures might improve the validity of our results. The lack of objective measures to complement the subjective/perceptual measures used can be considered a limitation. Also, this research adopts a cross-cutting approach when it considers the manufacturing strengths achieved by the firms analysed at a specific moment in time, which limits the discussion of causality. Although plausible theoretical inter-relationships among capabilities have been drawn from the literature, and prior research (Noble, 1995; Rosenzweig and Roth, 2004) has stated that the path dependency of manufacturing capabilities generally holds over time, our inferences on a time sequence with respect to capability development should be interpreted with caution. Future research should carry out a longitudinal analysis of the link between the various manufacturing objectives, including environmental protection, in order to offer stronger empirical support for the time process-model of capabilities development. It should also adopt a contingent approach (Noble, 1995; Schaltegger and Synnestvedt, 2002; Flynn and Flynn, 2004; Sousa and Voss, 2008), evaluating the robustness of the results when considering context factors such as firm size and age, industry, type of production process, customer behaviour, business environment or national context and culture.

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Figure 1. Manufacturing capabilities cumulative model

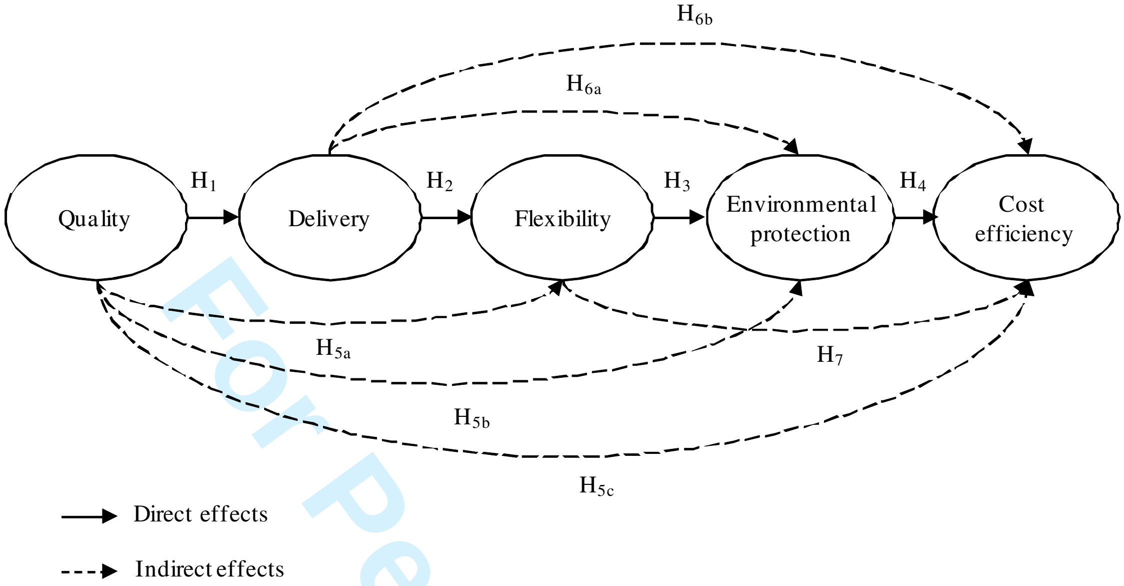

Figure 2. Estimated cumulative model

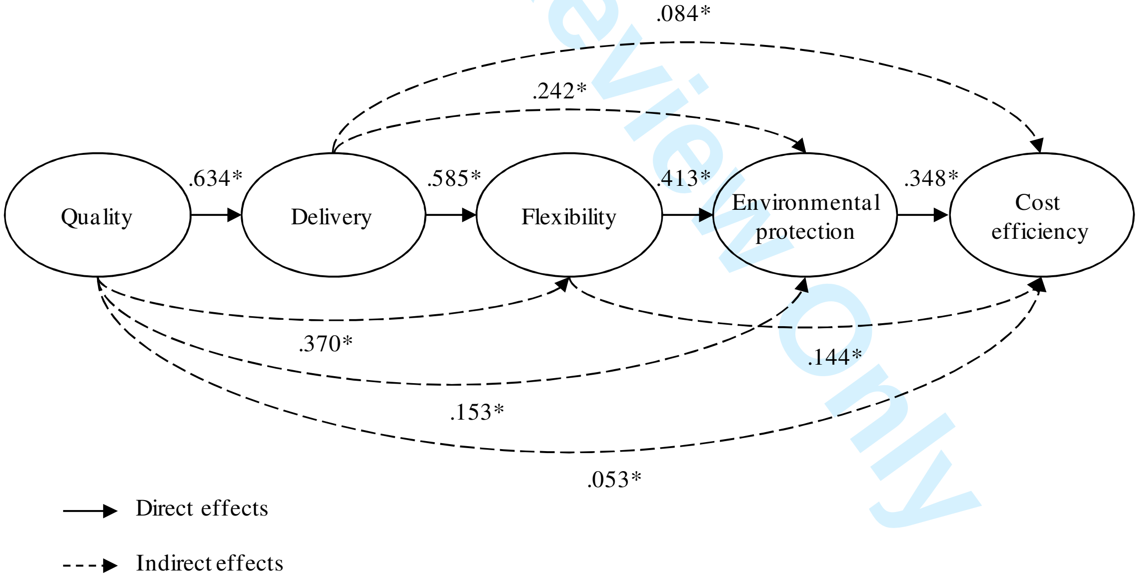

Table 1. Competitive manufacturing objectives

Factor	Variables	Code	Description of item
Competitive manufacturing objectives	Cost efficiency	Cost1	Reduce manufacturing cost
		Cost2	Increase labour productivity
		Cost3	Increase equipment or capacity utilization
		Cost4	Reduce inventory level
	Flexibility	Flex1	Make rapid design changes
		Flex2	Introduce new products quickly
		Flex3	Make rapid volume changes
		Flex4	Make rapid product mix changes
		Flex5	Offer a large degree of product variety (broad product line)
		Flex6	Adjust product mix
	Quality	Quali1	Improve conformance to design specifications
		Quali2	Offer consistent, reliable quality
		Quali3	Provide high-performance products
		Quali4	Offer durable, reliable products
		Quali5	Manufacture with consistently low-defect rates (reduce defect rates)
	Delivery	Deliver1	Provide fast deliveries
		Deliver2	Meet delivery promises or commitments
		Deliver3	Reduce manufacturing lead time
	Environmental protection	Enviro1	Make environmental-friendly products
		Enviro2	Use environment-friendly production processes
		Enviro3	Provide the firm with a positive environmental image
		Enviro4	Prevent environmental incidents

Table 2. Exploratory factor analysis

Items	Manufacturing objectives				
	Factors				
	1	2	3	4	5
Cost efficiency1	.083	.128	.077	**.784**	.151
Cost efficiency2	-.028	.077	.111	**.758**	.162
Cost efficiency3	.162	.136	.119	**.643**	.087
Cost efficiency4	.216	.093	.149	**.583**	.133
Flex1	.114	**.684**	.211	.276	-.017
Flex2	.117	**.590**	.340	.214	-.072
Flex3	.098	**.536**	.212	.325	.229
Flex4	.109	**.777**	.125	.127	.140
Flex5	.059	**.708**	.129	-.087	.155
Flex6	.086	**.701**	-.157	.030	.235
Quali1	.162	.038	**.703**	.294	.323
Quali2	.139	.083	**.656**	.333	.316
Quali3	.136	.283	**.749**	.030	.058
Quali4	.159	.136	**.819**	.028	.033
Quali5	.131	.110	**.557**	.471	.181
Deliver1	.160	.212	.116	.148	**.807**
Deliver2	.144	.120	.153	.213	**.793**
Deliver3	.140	.190	.223	.235	**.702**
Enviro1	**.874**	.118	.164	.084	.131
Enviro2	**.906**	.105	.124	.067	.115
Enviro3	**.879**	.150	.132	.180	.110
Enviro4	**.881**	.101	.154	.160	.128
Explained variance (66.049%)	15.660%	13.737%	13.420%	12.759%	10.472%
Extraction method: main components Varimax Rotation with Kaiser					
Kaiser–Meyer–Olkin Measure of Sampling Adequacy 0.875					
Bartlett 's test of Sphericity Approx. Chi-Square: 3304.53 d.f. 231 (Sig. 0.000)					

Table 3. Confirmatory factor analysis

Factor (Latent Variable)	Item	Mean	Std. Dev.	Standard lambda parameters (t–value)	Reliability: Cronbach's alpha	Reliability: Composite reliability index	Discriminant validity: Factor	Discriminant validity: Correlation coefficient (confidence interval)
Cost efficiency (F1)	Cost1	3.471	0.624	0.775 (14.187)	0.738	0.750		
	Cost2			0.715 (11.731)				
	Cost3			0.56 (8.536)				
	Cost4			0.556 (8.963)				
Flexibility (F2)	Flex1	3.485	0.672	0.639 (9.702)	0.805	0.805		
	Flex2			0.567 (8.708)				
	Flex3			0.652 (10.385)			F1–F2	(0.321 – 0.609)
	Flex4			0.787 (13.935)			F1–F3	(0.508 – 0.704)
	Flex5			0.604 (9.272)			F1–F4	(0.433 – 0.681)
	Flex6			0.574 (10.012)			F1–F5	(0.217 – 0.477)
Quality (F3)	Quali1	4.011	0.629	0.851 (19.041)	0.844	0.836	F2–F3	(0.360 – 0.600)
	Quali2			0.844 (20.249)			F2–F4	(0.421 – 0.641)
	Quali3			0.553 (9.516)			F2–F5	(0.242 – 0.498)
	Quali4			0.581 (10.342)			F3–F4	(0.504 – 0.720)
	Quali5			0.698 (14.190)			F3–F5	(0.319 – 0.555)
Delivery (F4)	Deliver1	3.999	0.738	0.79 (14.420)	0.819	0.820	F4–F5	(0.294 – 0.542)
	Deliver2			0.78 (12.973)				
	Deliver3			0.759 (13.575)				
Environmental protection (F5)	Enviro1	3.846	0.801	0.867 (19.574)	0.941	0.941		
	Enviro2			0.899 (20.291)				
	Enviro3			0.905 (22.396)				
	Enviro4			0.906 (19.543)				

Measures of the model's goodness of fit (Robust Method)

S–B χ^2 = 303.58 (d.f. 197) *p*= 0.000 **BBNNFI =** 0.955 **CFI =** 0.962 **IFI =** 0.962 **RMSEA =** 0.044

Table 4. Correlation matrix between objectives

	Delivery	Flexibility	Environmental protection	Cost efficiency
Quality	0.612	0.480	0.437	0.606
Delivery	1.00	0.531	0.418	0.557
Flexibility		1.00	0.370	0.465
Environmental protection			1.00	0.347
Cost efficiency				1.00

Note: All the correlations are significant at 99% ($p<0.01$)

Measures of the model's goodness of fit (Robust Method)

S–B χ^2 = 303.58 (d.f. 197) *p* = 0.000 **BBNNFI =** 0.955 **CFI =** 0.962 **IFI =** 0.962 **RMSEA =** 0.044

Table 5. Breakdown of effects: direct and indirect effects. Standard coefficients and goodness of fit (robust statistics)

EFFECT OF…	ON…							
	Delivery		Flexibility		Environmental protection		Cost efficiency	
	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
Quality	0.634 (9.040) $R^2 = 0.402$	-----	-----	0.370 (4.489)	-----	0.153 (4.157)	-----	0.053 (3.057)
Delivery	-----	-----	0.585 (5.925) $R^2 = 0.342$	-----	-----	0.242 (5.000)	-----	0.084 (3.219)
Flexibility	-----	-----	-----	-----	0.413 (5.543) $R^2 = 0.171$	-----	-----	0.144 (3.448)
Environmental protection	-----	-----	-----	-----	-----	-----	0.348 (4.661) $R^2 = 0.121$	-----

t values between brackets
All estimates are significant at 99% ($p<0.01$)

Measures of the model's goodness of fit (Robust Method)

S–B χ^2=397.33 (d.f. 203) ***p*** = 0.000 **BBNNFI =** 0.921 **CFI =** 0.930 **IFI =** 0.931 **RMSEA =** 0.058