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Manufacturing strategy and technology operations practices: An empirical study of machinery plants

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We show results of an ongoing study examining links between a manufacturing strategy set and a technology set of operations practices. The link between them is tested by selection/congruency fit using data from machinery plants in ten countries. We do not expect to find a significant fit between these sets, which is contrary to the selection fit found between manufacturing strategy and technology practice sets in the auto supplier sector presented in a separate paper. Due to industry differences, the machinery sector may present a state of disequilibrium for the manufacturing strategy set of practices, which may have a large deviation from the optimum for the technology set and cause variations in performance which cannot be measured by this method. This does not necessarily mean there is no relationship between these practice sets, but that another fit method, such as interaction, would be required to test closeness between performance deviations.

Keywords: Manufacturing Strategy, Technology, Empirical Research

1. Introduction

The strength of competition in production sectors has grown from the nineteen-seventies onwards. Once the importance of relating manufacturing strategy to a company's strategic planning had been established (Skinner 1969; Hayes and Wheelwright 1984, Kim and Lee 1993) companies sought to implement new operating practices in the manufacturing area with the aim of being more efficient, faster and more flexible (Prahalad and Hamel 1990). Production technology is an obvious example of this as it is a pivotal part of manufacturing (Leong et al. 1990; Marucheck et al. 1990). Technology therefore has to be taken into account if production strategy is to be used effectively.

Most of the studies in the literature have basically dealt with the two one-way perspectives of the strategy-technology relationship in isolation. Authors such as Hofer and Schendel (1978); Porter (1983); Hayes (1985); Maidique and Patch (1988); Itami and Numagami (1992); Parthasarthy and Sethi (1992); Dean and Snell (1996), and Parker (2000) present a unidirectional perspective in which the causal relationship goes from technology to strategy and not vice versa, arguing that existing technological capacities should guide the formulation of strategy.

Meanwhile, advances in information and communication technologies have changed the way companies as a whole and, as might be expected, manufacturing, are managed, as the sources of competitive advantages might derive from consolidating technologies and production skills in the basic competences rather than from generating products that the competition do not anticipate (see Chandler 1962; Prahalad and Hamel 1990).

Ortega (2008) combines the two perspectives (manufacturing strategy and technology) fitting the relationship in both directions by using a congruency model to demonstrate the degree of association between the two practices. For this the international HPM Project database was used, focusing on the automotive suppliers sector.

Taking the manufacturing strategy-technology relationship and its impact on company performance as its basis, this study analyzes congruency between manufacturing strategy and technology for the machinery plant sector. Selection fit is used to examine whether technology and manufacturing strategy are in a state of equilibrium in order to test the degree to which they are related. Two vital research aspects are proposed for this possible relationship:

1) Congruency between manufacturing strategy and technology in machinery plants.

2) Interaction between manufacturing strategy and technology, as well as the effect on performance in the machinery plant sector, testing to see whether this is produced mutually, by supplementary fit or by reinforcement/complementarity (synergy).

The following sections are organized as follows. First, a review of the literature on manufacturing strategy and technology. This is followed by this paper's propositions on manufacturing strategy and technology and a description of the model that will be used to test the propositions. The methodology used is then described, followed by an analysis of the results. Finally, the conclusions to the research are set out.

2. Literature Review

There are numerous international projects analyzing the interrelationship between some given manufacturing practices and company performance and competitiveness. Of these, the following can be highlighted: the "Global Manufacturing Futures Project", which analyzes the competitive priorities of companies in North America, Europe and Asia (Roth et al. 1989; De Meyer et al. 1989), the "Global Manufacturing Research Consortium", which focuses on the impact of world class manufacturing and supply chain strategies on company competitiveness on the international scale (Vastag and Whybark 1993, 1994) and the *High Performance Manufacturing* (HPM) Project, a dynamic production model which includes the best advanced production practices (APP) on the international level to see whether they can be included in manufacturing processes depending on a plant's given circumstances (Schroeder and Flynn, 2001). The last of these international models, which focuses on new production management practices –manufacturing strategy, total quality management, Just in Time (JIT) and the theory of constraints (TOC), human resources, information systems, technology, new product development, total productive maintenance and supply chain management- has been taken as a reference framework for this study. One of the HPM study's propositions is due in part to a lack of correlation between practices and a number of studies have been done to relate advanced production practices (APP) with company performance, for example (Bates 1995; Flynn et al. 1995;Sakakibara et al. 1997; Cua et al. 2001; Morita et al. 2001; Ahmad and Schroeder 2002; Schroeder et al. 2002; Deverag et al. 2004; Ketokivi and Schroeder 2004). However, only four HPM project studies have looked at the relationship between manufacturing strategy and technology. Matsui (2002) examined the relationship between a range of practices (including manufacturing strategy) in technology development and found that the involvement of

APP in technology development has an important impact on plant competitiveness. McKone and Schroeder (2002) investigated what kinds of plants make use of process and product technology from the plant context and considering aspects of manufacturing strategy. Meanwhile, part of the Ketokivi and Schroeder (2004) study included aspects of manufacturing strategy for adopting and implementing manufacturing processes and included one technology dimension. Finally, Ortega, 2008 looked at the relationship between manufacturing strategy and technology and its impact on operations performance in auto supplier plants, proving that there is a two-way relationship between the two practices.

Outside the HPM project we find that most research studies explore the relationship between technology and business strategy rather than manufacturing strategy (Zahra and Covin 1993; Maidique and Patch 1998; Parker 2000; Croteau and Bergeron 2001). These studies propose integration models that describe the fit between various dimensions of technology and business strategy, but do not empirically show whether there is any relationship with manufacturing strategy given their business strategy focus. Parker (2000) evaluates the current and future dynamic interaction between business strategy and technology and the effect on plant performance, for example. Other empirical studies have analyzed the effect of manufacturing strategy on company performance without considering technology, including Vickery et al. (1993); Kim and Arnold (1992); Williams et al. (1995).

Parthasarthy and Sethi (1992) mention that competitiveness in a company's production technology is required if a manufacturing strategy is to develop that reflects the production capacities and technology initiatives. This means that technology is a factor that limits the strategy in two ways: 1) existing technology determines the strategy that an organization can pursue (Itami and Numagami 1992); 2) any company that wants to pursue a different strategy must expand its technology base (Hofer and Schendel 1978; Maidique and Patch 1988; Porter 1983; Parker 2000).

Meanwhile, other researchers maintain that strategy should guide technology selection (Skinner 1969; Stobaugh and Telesio 1983; Dean and Snell 1996). In this way technological development can afford the plant both a set of competitive weaponry and a more solid technology base. This is also applicable to other products/markets (Itami and Numagami 1992; Zahra and Covin 1993).

The studies that were found focus on the relationship between technology and business strategy and do not relate in any way to either manufacturing strategy or studies on manufacturing strategy and technology and/or they have only focused on a unidirectional impact between the practices. Only one author (Ortega 2008) has examined the interrelationship between both sectors, but only in the auto supplier industry. Our research focuses on ascertaining the interrelationship between manufacturing strategy and technology for machine tool companies with different characteristics to the auto supplier industry; machine tool companies usually have to handle a variety of low-volume products, for example, unlike auto supplier companies, which seek to control the variety of products with high volumes.

2.1. Manufacturing strategy and its constructors

Skinner was the first author to propose that manufacturing strategy is connected with the rest of the functional areas and corporate strategy, being the link between long-term planning and shop floor operations. Leong (1990) highlighted two important elements that define manufacturing strategy: 1) competitive priorities or capacities and 2) strategic decision categories.

Meanwhile Hayes & Wheelwright (1988) highlighted certain manufacturing decision categories: structural and structure-infrastructure, where structural decisions require hefty investment and have a long-term impact, such as an increase/decrease in capacity, investment in technology, vertical, integration etc. On the other hand, infrastructure decisions are more tactical as they do not require large capital investments to be made and are related to work force, quality, production/materials control planning, organization, new product process development, performance measuring and compensation systems.

Manufacturing strategy is therefore characterized by a pattern of decisions that affect company performance with respect to its objectives being met in both the short and long term, and traditionally it was not thought that manufacturing activities could contribute to competitive advantages as they were considered to be operational and not maximum-efficiency based (Avella 1999). The dimensions proposed by the international HPM project will be used to measure any impact that manufacturing strategy has on the production function and, specifically, on technology. These are:

- Forecast for new technologies
- Formal strategic planning

- The link between manufacturing strategy and company strategy

These dimensions will be used in the study to evaluate the interrelationship between manufacturing strategy and technology using the congruency model.

2.2. Technology and its constructors

Technology "refers to the sum total of knowledge that we have of the way that things are done, including events, techniques, design, production, processes and tasks" (Koontz 2004). Studies by contingent theoreticians show that this variable has a direct effect on a company's operational base, division of work, shaping of hierarchies and functional processes, which vary depending on the type of organization.

Technology can be split into product technology (also called new product development), production and process technology and Information and Communications Technology (ICT). When these technologies are integrated into a company's practices they impact on its competitiveness (Maier and Schroeder 2001). For international HPM research, technology comprises not only hardware systems, but also the human and organizational aspects of the company's operations. The dimensions of technology as defined in the HPM and as will be used here for testing against the manufacturing strategy dimensions are:

1. Effective process implementation
2. Interfunctional design effort
3. Supplier participation

3. Theoretical Model and Propositions

The fit model that will be used to test the interrelationship between the two practices (manufacturing strategy and technology) is based on contingency theory. This study will focus on the machinery sector, which is characterized by intense global competition and the high number of plants in Canada/U.S.A., Asia and Europe, the three areas of the world focused on by research into international *High Performance Manufacturing* (HPM).

The intention is to test whether machinery plants on the international level behave in a similar way to the international automotive supplier sector using similar management focuses as far as technology and manufacturing strategy are concerned. The relationships between the two advanced production practices will therefore be examined using the bivariate selection fit model. Our research will focus on two types of relationship:

1. That an independent variable, in this case either manufacturing strategy or technology, has an impact on the operational performance variable.
2. That the two independent variables, manufacturing strategy and technology, are in congruence.

The congruence model that will be used is described below.

3.1. Bivariate fit/selection model

It has been the norm for organizations to use structuralist theories to explain how a company, seen as an open system, interacts with its environment. Other practical theories have arisen out of this, such as the contingency theory used in Management Operations research which focuses on the equilibrium of a company's external environment and the internal elements of the organizational structure to achieve the greatest profit. Donaldson (1994) states that the concept of fit between structural and conceptual features is at the core of contingency theory and that any failure in achieving this fit would lead to substandard results.

Following the same research perspective used in the study by Ortega (2008) on the relationship between manufacturing strategy and technology in the auto supplier sector, the same model of reductionist bivariate selection or congruency (Van de Ven and Drazin 1985; Venkatraman 1989) will be used. This allows the bivariate fit to be conceptualized for the two variables, manufacturing strategy and technology, in order for their interrelationship to be ascertained. By using the same research parameters, the propositions in Ortega (2008) can be tested against the results found in this study.

The selection fit model has frequently been used in the empirical contingency literature (Galunic and Eisenhardt 1994; Meilich 2006). The model starts from the idea that for any given manufacturing practice to be controlled or improved, its levels have to be regulated or adjusted taking into consideration the level of some other manufacturing practice, and vice versa. It is therefore assumed that weak manufacturing-technology element combinations tend to disappear (through extinction or adaptation). For this, surviving measures and all their combinations should display suitable congruency. In line with this, the way in which technology factors are related to manufacturing strategy aspects will be examined without attempting to measure whether the association has any links with performance (Merchant 1984; Chenhall & Morris 1986; Chenhall 2003). The study of this relationship will focus on identifying specific technology profiles associated with different manufacturing strategy dimensions. This focus does not contemplate determining the direction of causality, but presents a path for a cross-section study that allows it to be established whether any congruency exists between manufacturing strategy and technology. In other words, the connection between the two practices is two-way indicating the effect that exists between manufacturing strategy and technology and vice versa. This reinforces what was stated above, that the model does not examine the cause-effect relationship but the correlation of the two practices.

The following hypotheses regarding the bidirectional link between manufacturing strategy and technology are therefore defined to demonstrate some kind of contingency.

H1: Congruency exists by way of a unidirectional relationship between manufacturing strategy and technology.

H2: Congruency exists by way of a unidirectional relationship between technology and manufacturing strategy.

A third hypothesis arises out of any possible unidirectional relationship between the two practices:

H3: Congruency exists by way of a bidirectional relationship between manufacturing strategy and technology.

Multiple linear regression and Umanath and Kim's (1992) and Umanath's (2003) conclusions on contingency will be used to test these hypotheses. For this, the following two equations have been defined:

$$\mathbf{T_i = \beta_0 + \beta_1 S_1 + \beta_2 S_2 + \beta_3 S_3 + \varepsilon_i} \quad \textbf{[1]}$$

$$\mathbf{S_i = \beta_0 + \beta_1 T_1 + \beta_2 T_2 + \beta_3 T_3 + \varepsilon_i} \quad \textbf{[2]}$$

Where T represents technology and S operations strategy, the βs are the coefficients associated with each of the variables, the 1, 2 and 3 sub indexes are the respective dimensions of the two manufacturing practices and ε is the error.

Dimension	Variable
Anticipation of new technologies	S1
Formal strategic planning	S2
Manufacturing strategy-company strategy link	S3
Effective process implementation	T1
Interfunctional design effort	T2
Supplier participation	T3

Table 1: Manufacturing strategy and technology dimensions (Ortega, 2008)

4. Methodology

This study uses the intercontinental database (America, Asia and Europe) generated by the international HPM research project. The research methodology used in this project is the survey, with twelve questionnaires targeted at different positions in the company, from plant manager to shop-floor workers. The questionnaires include scales and measures for the various advanced production practices with hundreds of different items addressing performance- and plant characteristic-related data, and a range of exogenous variables.

The items and scales as used in the international HPM study measuring instruments have been tested using confidence, validity and internal consistency analyses (Flynn, et al. 1995; Sakakibara et al. 1997; McKone et al. 1999; Cua et al. 2002; Ahmad and Schroeder 2003; Ortega 2008).

Current HPM research is on its third round in ten countries[1] with around 270 companies in three industrial sectors (auto suppliers, machinery and electronics) with the objective of empirically evaluating the critical factors in production management. The HPM also distinguishes between high performance and standard performance plants.

Only information on manufacturing strategy and technology in machine tool companies was taken for our study. It should be mentioned that each of the scales is included in at least two different questionnaires so that information can be triangulated to achieve a higher level of confidence in the instrument. As for the sample, the analysis unit used was the individual machine tool manufacturing plant with an average sample of eighty plants.

5. Discussion - Analysis and Results

This research focuses on a possible manufacturing strategy-technology fit in machinery plants. These are some of the essential aspects of the international HPM empirical research model. The research uses the latest HPM database, now on its third round, which includes a survey of some 270 companies throughout three continents. The selection or congruency model supported by multiple linear regression with its various adjustments has been used to ascertain whether there is a positive or negative relationship between manufacturing strategy and technology.

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[1] The ten countries are: Germany, Austria, Korea, the USA/Canada, Spain, Finland, Italy, Japan and Sweden.

5.1 Results of the congruency model

Multiple regression was used to test hypotheses H1 and H2, with six regression models corresponding to six scales, three for manufacturing strategy and three for technology. Each model included one of the two practices as an independent variable and the three scales from the remaining practice as an independent variable (see equations 2 and 3).

In the first test, where the three manufacturing strategy dimensions acted as independent variables and the technology scales as dependent variables (see Table 2), one technology scale was found to be related with two manufacturing strategy scales, i.e. effective process implementation (T1) was related to the manufacturing strategy-company strategy link (S3) with a level of significance of 0.01, and with anticipation of new technologies (S1) with a level of significance of 0.05. Interfunctional design effort (T2) was also related to anticipation of new technologies (S1) with a level of significance of 0.05. These were the only relationships that were found between technology and manufacturing strategy.

		Technology		
		T1	T2	T3
Manufacturing Strategy	S1	0.055	0.035	0.697
	S2	0.305	0.582	0.513
	S3	0.000	0.353	0.840

Table 2: Levels of significance, Manufacturing Strategy related to Technology[2].

Consequently, it can be concluded that the aggregate form of Manufacturing Strategy has a very weak link with technology and so H1 is rejected. Therefore, the effect of manufacturing strategy does not impact on technology. This might be due to the environment of the manufacturing process under study. In general terms, machine tool companies deal with jobshop or project type processes. This means they work with a wide range of small volume products and the investment made in process technology might be lower than for companies with a continuous process (Boyer et al. 1996).

In the second round, where the technology dimensions were used as independent variables and the manufacturing strategy dimensions as dependent variables, the T3 technology scale, supplier participation, is not related to any of the manufacturing strategy scales, and all the remaining scales have relationships with levels of significance of under 0.05 (see Table 3).

[2] The referenced scales are listed under the codes S1, S2, S3, T1, T2 and T3 in Table 1.

		Manufacturing Strategy		
		S1	S2	S3
Technology	T1	**0.000**	**0.004**	**0.000**
	T2	**0.003**	**0.031**	**0.032**
	T3	0.601	0.289	0.512

Table 3: Levels of significance, Technology related to Manufacturing Strategy [3]

The relationships between the scales can therefore be summarized as follows:

1. Effective process implementation → Manufacturing strategy scales

2. Interfunctional design effort → Manufacturing strategy scales

It can be concluded that technology influences manufacturing strategy. H2 is thus confirmed despite the fact that supplier participation is not associated with manufacturing strategy. This is consistent with what Matsui (2002) states regarding the existence of a relationship between the development of technology and manufacturing strategy and it is also behind the reason why some Japanese manufacturing companies have gained competitive advantages in the international market. Das and Narasimhan found that manufacturing technology impacts on manufacturing strategy, which is consistent with the results of this second round.

In general terms, it can be stated that a bidirectional relationship does not exist between the two advanced manufacturing processes, only a unidirectional relationship from Technology to Manufacturing Strategy on the scale level. H3 is therefore rejected as the relationship between the two practices is weak according to the congruency model used.

To summarize, on the dimensions level of the two practices three scale relationships have been found in both directions: S1←→T1; S1←→T2 and S3←→T1, and three scale relationships in only one direction T1 →S2, T2→S2 and T2→S3. The "Supplier participation" technology dimension has no relationship with the manufacturing strategy dimensions in either direction.

6. Conclusions

This research is grounded in the international HPM project and is a continuation of the Ortega 2008 study. This study tested for an interconnection between manufacturing strategy and technology taking the machine tools industry as its reference and using a selection congruency model for the analysis. The findings show that there is a unidirectional relationship from technology to manufacturing strategy and not vice versa in two dimensions. Despite the fact that there are some strategy dimensions that

[3] The referenced scales are listed under the codes S1, S2, S3, T1, T2 and T3 in Table 1.

have a positive effect on technology, the impact is not great enough for there to be a close relationship in the manufacturing strategy-technology direction, as there is a certain lack of fit. When the dimensions of the two practices are analyzed, it is found that Anticipation of New Technology (S1) is related bidirectionally to both Effective Process Implementation (T1) and Interfunctional Design Effort (T2). This is in keeping with Trecey et al. (1999), who state that an improvement in the understanding of technology and increased participation in the formulation of strategy have helped manufacturing managers to successfully implement technology in manufacturing.

There is also an interrelationship between the manufacturing strategy-company strategy link (S3) and effective process implementation (T1)

The analysis brought to light a number of misfits between some of the manufacturing strategy and technology scales in the machine tool sector which might be due to the fact different processing environments have different manufacturing goals and that this affects technology development (Markland et al. 1998; Boyler et al. 1996; Das and Narasimhan 2001).

As far as future research is concerned, it is recommended that the degree of fit between manufacturing strategy and technology values in a state of disequilibrium be ascertained using two perspective models, difference and multiplicative, with the objective of taking a close look at the coexistence of these two practices and their possible effect on manufacturing performance.

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