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THE RELATIONSHIP BETWEEN MANUFACTURING FLEXIBILITY AND PERFORMANCE: A META ANALYTICAL STUDY

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Abstract

Today, manufacturing industries are trying to maintain and increase their competitiveness in an environment where constantly changing uncertainty prevails. The industry is increasingly searching for new technology to respond quickly and at low cost to fluctuating customer demands in the market. Manufacturing flexibility has become one of the prime areas of research in manufacturing technology. In the literature studies investigating the relationship between manufacturing flexibility and different aspect of performance are seen to yield differing results, and we are forced to consider that there might be other factors influencing this relationship. In this study an attempt was made to reveal the relationship between manufacturing flexibility and performance by means of a meta-analysis of the combined results of separate studies carried out between 1990 and 2017 using an analytical technique. The resulting meta-analytical results are in line with the results of previous individual studies.

The meta-analysis findings have revealed a positive relationship between Advanced Manufacturing Technologies (AMT), Engineering Technologies (ET) and types of Administration Technologies (AT) on one side and production and overall performance on the other. Evaluations of the findings obtained in the study are presented.

Keywords: Manufacturing Flexibility, Performance, Meta-Analysis

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Introduction

Manufacturers are confronted with increasing uncertainty due to changes in customer expectations, the intensity of global competition, and the effects of radical technological developments (Germain et al., 2001, Doll and Vonderembse, 1991). When we examine manufacturing systems, we see that the development of manufacturing systems is based on different concepts. Chief among these concepts is efficiency. During the period before the Second World War manufacturers had no problems in selling all their products, but this period ended with the war and manufacturers started to feel the pressure of international competition. It is here that efficiency has become an important concept for manufacturers for the design and operation of systems. Twenty years after the Second World War, international competition became more intense, product prices declined in an unprecedented manner, and consumer purchasing power went up. This situation led to focus shifting from manufacture to the consumer and to consumers demanding higher quality goods. Efficiency and quality have become basic criteria for manufacturing enterprises. Since the 1970s manufacturers have encountered another problem, the need to meet the rapid changes in consumer needs, a need that mass production cannot respond to efficiently. It is here that the concept manufacturers focus on is flexibility (Maleki, 1991, Güler, 2008). Researchers and manufacturing managers argue that flexibility is a strategic imperative that allows firms to cope with uncertainty in consumer demand (Sethi and Sethi, 1990).Flexibility has begun to be seen as a fundamental feature of manufacturing systems (Grubbström and Olhager, 1997).There are many studies on the relationship between manufacturing flexibility and performance in the literature. Many different models have been developed in these studies and it has been shown that in the majority of studies there is a close relationship between manufacturing flexibility and many aspects of performance (Cost, Delivery Speed, Sales, Growth, Market Share, Customer Satisfaction and so on). However, while findings from the individual studies on Manufacturing Flexibility and Performance point to the existence of a positive relationship, it is not possible to come to a holistic or unifying conclusion when sample inadequacies are taken into account. In this context there is a clear need for a holistic meta-analysis of the findings of studies made at the individual level. According to Glass (1976), it is possible to integrate the findings of individual studies with meta-analysis, which is defined as a statistical analysis of a large number of analyzes resulting from individual studies in order to integrate findings. The aim of this study is to integrate the findings of individual level studies into Manufacturing Flexibility and Performance using meta-analysis. That way, the degree to which the findings of individual studies reflect the truth will become clear.

Conceptual Framework

Manufacturing flexibility is the ability of an operator to manage manufacturing resources and uncertainty to meet various customer demands. Frazelle (1986) defines manufacturing flexibility as the ability to adapt to market conditions in terms of such options as the variety, quantity, price difference and quality of manufactured goods. Upton (1994) defines manufacturing flexibility as the ability to respond to environmental changes with less time and cost. However, one of the most comprehensive definitions was put forward by Swamidass (2000), who defines a manufacturing system as "the capacity to adapt successfully to changing environmental conditions and to changing product and process requirements".

Manufacturing flexibility emerges as a complex, multidimensional concept evolving over the years. When the topic of manufacturing flexibility began to develop people considered combining a series of small, functional machines in different arrangements in order to make different products. Diebold (1952) accepts manufacturing flexibility as a necessity for producing different parts effectively and efficiently. Achieving flexibility in large volume manufacturing without compromising efficiency begins with the development of manufacturing cells and flexible manufacturing systems. According to Schonberger (1986), Efficiency and flexibility can only be achieved by reducing the time and cost of manufacturing preparation, switching to product-oriented layout arrangements, increasing equipment reliability and increasing quality.

The acquisition of manufacturing flexibility is not solely a matter of technology. Previous studies have shown that the factors that determine manufacturing flexibility are related to strategy, environmental factors and organizational qualities in addition to technology (Vokurka, RJ et al., 2000, Akyol and Güler, 2010). The concept of flexibility is closely linked to the overall strategic plan in addition to individual production factors at the operational level. Some of the factors making flexibility in manufacturing strategy a priority for management include an urgent need for a broader product range and scope plus shorter product life cycles (Noori, 1990).

The concept of manufacturing flexibility does not, in fact, represent a single variable; rather manufacturing flexibility is generated by a set of variables. In the literature we see different approaches in studies made about the definition and grouping of manufacturing flexibility. (Koste and Malhotra 1999) have identified ten aspects of flexibility and a hierarchy of flexibility ranging from individual sources to the workshop floor, factory, functional and business units. Carlsson (1989) defines three main types of flexibility: operational (short-term), tactical (medium-term) and strategic (long-term). Gupta and Somers (1992), Sethi and Sethi (1990), Parthasarthy and Sethi (1993), Oke's (2005), Slack (1983), Dixon (1990) and Suarez et al. (1995, 1996) demonstrated the aspects of flexibility listed in Table 1 for manufacturing flexibility in their work.

Table 1: Types and Definitions of Flexibility

Flexibility Types	**Description of Flexibility Types**
Machine flexibility	Range of operations that a piece of equipment can perform without involving a major setup
Labor flexibility	Range of tasks that an operator can perform within the manufacturing process
Volume flexibility	Range of output levels at which a firm can economically produce products
Production flexibility	Range of products the system can produce without adding new equipment
Product flexibility	Time it takes to add new or substitute parts into the system
Routing flexibility	Number of alternative paths a part can take through the system in order to be completed
Process flexibility	Number of different parts that can be produced without involving a major setup
Operations flexibility	Number of alternative processes or ways in which a part can be produced within the system

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Delivery flexibility	Ability of the system to respond to changes in delivery requests
Material handling flexibility	Ability of a material handling process to move different parts throughout the manufacturing system
Automation flexibility	Extent to which flexibility is housed in the automation (computerization) of manufacturing technologies
New design flexibility	Speed at which products can be designed and introduced into the system
Expansion flexibility	Ease at which capacity may be added to the system
Program flexibility	Length of time the system can operate unattended
Market flexibility	Ability of the manufacturing system to adapt to changes in the market environment
Mix flexibility	system flexibility type that depends on other factors including changeover times, product modularity, labor skills, process technology, supply chains and information technology.

Performance

Some authors have stressed the importance of the concept of performance and have prepared prescriptions for improving organizational performance (Nash, 1983). Discussions about terminology, analysis levels and conceptual fundamentals when evaluating performance continue to be held in academic circles. Yavuz (2010) states that organizational performance expresses a whole as an indicator of success determined by different factors, and when an organization refers to periodic or integrated performance it means that all of the factors contributing to or affecting this performance should be presented simultaneously. Company performance refers to organizational effectiveness in terms of financial and production performance (Venkatraman and Ramanujam, 1986; Saraf et al., 2007). Literature research shows that manufacturing performance is viewed as a multi-dimensional structure and that the suitability of the performance scale to be used depends on the operating conditions. Cost, quality and delivery have traditionally been seen as three important aspects of manufacturing performance. In many studies the growth criterion was used as a frequently used performance criterion. Growth criterion is treated as total growth, growth in sales, return on assets and return on sales. The following performance criteria are used in studies investigating the relationship between Manufacturing Flexibility and Performance:

- Operational performance
- Manufacturing performance
- Growth performance
- Financial performance
- Market share
- Sales
- Return on assets
- Cost
- Delivery time
- Speed
- Product innovation
- Process innovation
- Quality

Relationship between Manufacturing Flexibility and Performance

Even though there are many variables affecting operational performance, it is clear that manufacturing flexibility has an important effect on operational performance. Kekre and Srinivasan (1990) empirically examined the relationship between product diversity (process flexibility and mix flexibility) and market success. They saw that larger product groups resulted in greater market share and profitability and did not seem to be associated with higher costs. Swamidass and Newell (1987) have shown that manufacturing flexibility is significantly related to performance and that mix flexibility and new product innovation have a positive effect on sales growth and net profit margins. Gerwin (1993) and Suarez (1995) find that volume flexibility has a positive effect on sales growth and net profit. Tombak (1988) also shows that flexibility affects strategic business unit performance positively. Similarly, Vickery et al. (1997) found that manufacturing flexibility is significantly related to performance. In the literature we encounter studies on the direct relationship between manufacturing flexibility and performance as well as studies showing the moderate effects of operational and manufacturing strategies and organizational qualities on manufacturing flexibility (Patel et al. 2012).

In contrast to the studies noted above showing a positive relationship between manufacturing flexibility and performance some studies (Gupta and Somer (1996), Upton (1995), Pagell and Krause (1999) have shown that there is no direct relationship between flexibility and performance, but in spite of this we have established a significant and positive relationship between manufacturing flexibility and performance at an aggregate level. The rapid developments in manufacturing technology and the intense climate of global environment plus the increase in the number of studies investigating the effects of manufacturing flexibility on performance are an indication of the importance given to this topic. However, there is a need for more scientific work involving new approaches and methods that will enable the relationship between manufacturing flexibility performance to be seen more clearly. To this end, the Meta Analysis method, which is mentioned very little in the literature, has been applied in this study.

In the light of the above explanations, the following hypotheses have been established in order to be tested in this meta-analytic study:

H1: There is a positive relationship between Manufacturing Flexibility and Performance.

H2: There is a positive relationship between Manufacturing Flexibility and the aspects of Manufacturing performance.

Methodology

The Criteria for Which Studies to Include in/Exclude From Analysis

In order to determine the studies dealing with the relationship between manufacturing flexibility and performance in the domestic and foreign literature that will be included in the meta-analysis, we used Web of Science, Science Direct, Jstor, AOS, EBSCO and Google Academic, which possess a broad database, for international texts, and the Dergipark and National Thesis Center national databases given their ease of access. The criteria for including studies in the analysis are as follows:

1. Being a study in the specified databases,
2. The study includes the concepts of Manufacturing (production) Flexibility, Volume Flexibility, Flexible Production Systems - Manufacturing (production) Flexibility, Volume Flexibility, Flexible Manufacturing Systems and Performance, Benefits (usefulness), Success - Performance, outcomes,
3. It includes correlation coefficients or calculable data for correlation coefficients and sample size finding,
4. It must have been published between 1991 and 2017.

As a result of all these scans a total of 75 studies were identified; those that did not meet the selection criteria of the study (e.g. having no correlation coefficient) were excluded and 15 studies were included in the meta-analysis while a total of 57 sets of data suitable for analysis were obtained based on the dimensions of the variables.

Coding of Variables

For the purpose of the research, a suitable form was created and the studies were classified according to all variables and sizes, and correlation values and sample sizes were coded. Flexible Manufacturing and Performance variables are coded as shown in Table 2.

Table 2: Flexible Manufacturing and Performance Variables:

Manufacturing flexibility	**Performance**
Manufacturing flexibility	Firm performance
Product flexibility	Manufacturing performance
Volume flexibility	Growth performance
Mix flexibility	Delivery
Routing flexibility	Cost
Machine flexibility	Product innovation
Range flexibility	Customer satisfaction
Process flexibility	

Statistical Analysis Processes

The combined correlation coefficients for each study's meta-analysis results are calculated and converted to the values that appear in the Z table. A meta-analysis was made according to the random effects

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model for values of <0.05 because they formed a heterogeneous body, while the meta-analysis of the homogeneous body (p>0.05) was made according to the fixed effects model. In addition, Begg and Mazumdar's rank correlation test was performed to test the bias, and the Classic fail-safe N test was performed to test the power of the meta-analysis.

The CMA 3.0 (Comprehensive Meta-Analysis) package program was used to make all the analyses. In this study, attention was paid to the existence of independent correlation values for each conceptual structure and no transformation process was performed.

Findings

Meta-analysis results on the relationship between manufacturing flexibility and overall performance are given in Table 3. According to the findings, the Q values of the heterogeneity test indicate that the meta-analysis should be done according to the fixed effect model (p <0.05). Since the Z values of the meta-analysis correlation values are significant at p <0.05, a positive relationship is found between the variables. This finding is consistent with the results of individual studies and confirms a positive relationship between Manufacturing Flexibility and Performance. The Relationship between Manufacturing Flexibility and Performance - Based on the findings of the Classic fail-safe N test, it is understood that a further 714 studies are needed in order to invalidate the results of the meta-analysis study.

Table 3: Manufacturing Flexibility-Performance Relationship: Meta-Analysis Results

	Confidence Interval							Heterogeneity		
Variable	k	r	Lower Limit	Upper limit	Z	P	Q	Df (Q)	P	I Square
Manufacturing Flexibility	15	0.144	0.117	0.171	10.24	0.000	189.134	34	0.000	82.023

As can be seen in Table 4, meta-analytical results are presented that generally show the relationship between manufacturing flexibility and manufacturing performance. These results show there is a correlation (r=0.159) between performance and the aspects of manufacturing flexibility such as cost, delivery speed, process innovation, quality, efficiency, product innovation and speed. According to the Classic fail-safe N test results, there is a need for a further 202 studies into manufacturing flexibility in order to invalidate the results of the meta-analysis study. On the other hand, according to Kendall's rank correlation findings, it is clear from the tau b values being p>0.05 that the study sample included in the meta-analysis is not bias.

Table 4: Manufacturing Flexibility-Manufacturing Performance Relationship: Meta-Analysis Results

	Confidence Interval							Heterogeneity		
Variable	k	r	Lower Limit	Upper limit	Z	P	Q	Df (Q)	P	I Square
Manufacturing flexibility	19	0.159	0.116	0.201	7.243	0.000	100.594	18	0.000	82.106

Conclusion

This study aimed to examine the relationship between manufacturing flexibility and performance within a meta-analytical framework at this time when businesses are increasingly turning towards manufacturing flexibility in the operation strategies that they are developing in order to succeed in the global competitive environment. Working off individual studies, the findings of the study show that holistically there is a positive, meaningful relationship between overall performance and manufacturing flexibility as a whole. In addition, given the meta-analytical results, a higher positive correlation has been found between the aspects of manufacturing flexibility and manufacturing performance. In other words, it can be said that the results of individual studies subjected to meta-analysis using a larger sample group than individual studies made with small sample groups reflect the true state. Acting on this, businesses will be able to achieve performance expectations having various different aspects provided they incorporate flexibility into their strategies.

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