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# Complementarities in the implementation of advanced manufacturing technologies

Jennifer C. Percival *, Brian P. Cozzarin

[a] Faculty of Business and Information Technology, University of Ontario Institute of Technology, Canada
[b] Department of Management Sciences, Faculty of Engineering, University of Waterloo, Canada

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ABSTRACT

The purpose of this analysis is to use complementarity analysis to explain why some implementations of advanced manufacturing technology (AMT) provide a high return on investment while others do not. By analysing the engineering environment, as well as the technology used in the manufacturing process, we hope to provide further insight into the necessary environmental conditions for high returns on investments in AMT. This paper aims to advance current understanding of the impact of organizational fit through complementarity analysis of 26 AMT and 12 engineering management practices. The results reveal that analysis on the dependencies of implementation of AMT must be conducted at the industry and plant size levels, otherwise the environmental differences may lead to inconclusive or misleading results for the majority of senior managers engaging in strategic AMT investment decision making.



## 1. Introduction

In today's economic climate, there is an increasing emphasis on cost reduction and increased efficiency in manufacturing that is driving the adoption of advanced manufacturing technologies (AMT) (Udo and Ehie, 1996; Sohal, Burcher, Millen and Lee, 1999). AMT are a group of computer-based technologies including: computer-aided design, robotics, group technology, flexible manufacturing systems, automated material handling systems, storage and retrieval systems, computer numerically controlled machine tools, and bar-coding or other automated identification techniques. Unfortunately, Chung (1996) found in his review of over 15 studies that the balance of AMT implementations result in failure (no substantial increase in process flexibility, responsiveness, reliability, or quality) 50 to 75 percent of the time. This represents a large number of firms that invested millions of dollars only to obtain minimal returns; in some cases, organizations had a negative return on their investment.

Given the correct organizational fit, AMT have given some adopters a strong competitive advantage in their industry. The debate over the value of AMT continues (Swink and Nair, 2007). DeRuntz and Turner (2003) found that careful selection of management practices was conducive to AMT success. Given the high cost of AMT and the importance that such investments have on firm performance (Da Silveira, 2005), it is vital to understand the impact that management practices have on success. The literature on the nature of technology implementation uses two primary modes of analysis — technology adoption/diffusion and complementarities between technologies. Technology adoption/diffusion research focuses on exogenous factors affecting implementation. Bocquet, Brossard and Sabatier (2007) and Hollenstein (2004) are examples of this stream of research applied to information and communication technologies and Astebro et al. (2005) and Battisti et al. (2004) investigate CAD/CAM. There has also been some research using a diffusion approach to the organizational and environmental factor impacting electronic data interchange (EDI) implementations (Chau and Hui, 2001; Chau and Tam, 2000; Premkumar, Ramamurthy and Nilakanta, 1994).

* Corresponding author. Faculty of Business and Information Technology, University of Ontario Institute of Technology, 2000 Simcoe Street North, Oshawa, Ontario, Canada L1H 4K7. Tel.:+1 905 721 8668x2833.
*E-mail address:* Jennifer.Percival@uoit.ca (J.C. Percival).

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These studies consider internal aspects of the organization such as infrastructure and prior experience, as well as external variables such as the market conditions and support networks (Kuan and Chau, 2001). These studies do not consider specific organizational practices which significantly influence the value the can be derived from the technologies due to their impact on technology usage. The studies also focus on a specific system or technology and do not consider the interaction between the various systems in the organization.

By using the complementarity approach as conducted in this study, it is easier to measure the impact of AMT adoption and organizational changes together. Fundamentally, the impact of complementarity means that there is a marked benefit for making simultaneous changes involving AMT and organizational practices together. When AMT and practices are not complementary the implication is that a new "cost saving" measure may result in the opposite effect. This type of study identifies the interaction effects between the various forms of AMT and engineering management practices in order to identify the optimal technology-organizational fit. Complementarity analysis does not focus on longitudinal diffusion of the technologies but on the impact these technologies and their interaction with other variables has on a value measure such as productivity or profitability. By better understanding the AMT-engineering management practice fit, senior managers will be able to make more informed AMT investment decisions to better match their technology investments, engineering management practices, and strategic goals (Goodhue and Thompson, 1995).

The purpose of this study is to aid senior managers in making strategic AMT investment decisions by identifying complementarities between installed advanced manufacturing technologies and engineering management practices in order to obtain an improved AMT-organizational fit. If AMT and engineering management practices were standard inputs into the manufacturing process (i.e. continuous variables such as labor, energy and materials) we could simply use standard economic techniques such as the elasticity of substitution, to measure interaction effects. Since AMT adoption and management practice adoption are binary variables another technique has to be used. We apply the theory of complementarity (Milgrom and Roberts, 1990, 1995) to a performance function. This study advances current knowledge on the impact of technology-organizational fit by analyzing 26 forms of AMT and 12 engineering management practices while previous research has been restricted to only one or two forms of AMT and one or two internal organizational variables.

The paper is organized as follows. In Section 2 we discuss the theory behind complementarity and summarize previous research. In Section 3 we propose hypotheses about the complementarities that we expect to find in this research. Section 4 discusses the data and in Section 5 the econometric model is presented. Section 6 presents the results. Finally, Section 7 draws conclusions and gives recommendations for future research.

## 2. Complementarities: measurement and practice

### 2.1. Measurement of complementarities

For a succinct definition of complementarities in this journal, the reader is directed to Cassiman and Veugelers (2006), as a consequence the discussion here will be brief. To measure complementarity between binary variables discrete comparisons are a necessity. Traditional economic techniques (e.g. elasticity of substitution C.f. Blackorby and Russel, 1989) cannot be used for discrete variables and so lattice theory is employed instead. Lattice theory enables the optimization of functions over a partially ordered set to identify complementarities (Milgrom and Roberts, 1990; Topkis, 1978). Two elements are complementary in the objective function if they satisfy the supermodularity restrictions, meaning that increasing both values at once has a greater return than increasing each variable one at a time (Milgrom and Roberts, 1995). This technique is important as it permits us to obtain clear comparative statics results in order to interpret observed changes in firm practices (Milgrom and Roberts, 1995). That is the underlying approach that we use in this study.

### 2.2. Complementarities in the literature

Identifying complementary AMT increases the benefit of implementing technologies in groups e.g., the introduction of CAD/CAM technology makes it cheaper to improve products and design new ones. Existing literature on technology diffusion virtually ignores the impact of organizational design and practices on the adoption of technology (Bocquet et al., 2007). Kuan and Chau (2001) presented a perception-based model using a technology-organization-environment framework for understanding EDI adoption were they included two variables to represent each element of technology, organization, and environment. This study was focused on the adoption decision and although the framework has also been applied to open systems (Chau and Tam, 2000) it has never been applied to implementation in order to determine if it is effective in selecting technologies which derive high investment returns on implementation.

The lack of understanding on the impact of internal management practices and technology fit gives rise to the purpose of studying complementarities between AMT and organizational practices. The evolution of organizational practices and technology form the primary determinant of the types and quantity of AMT implemented throughout a plant. Schlie and Goldhar (1995) showed that implementation of computer-integrated manufacturing must be accompanied by a complementary change of competitive strategy in order for the organization to derive the maximum benefit. Athey and Schmutzler (1995) found that product and process flexibility were complementary. In particular, they found that implementing an innovation was complementary to increasing a firm's research capabilities which in turn increased the return to both process and product flexibility.