

THE RELATIONSHIP OF INTEGRATION AND AUTOMATION UNDER AN UNCERTAIN ENVIRONMENT: A SEM MODEL

Qiang Tu

Saunders College of Business, Rochester Institute of Technology, Rochester, NY 14623,
USA

Tel: (001) 585-475-2314, email: jtu@cob.rit.edu

Kun Liao

College of Business, Central Washington University, Ellensburg, WA98926, USA

Tel: (001) 509- 963-1174, email: liaok@cwu.edu

Yulong Li

Gabelli School of Business, Roger Williams University, One Old Ferry Rd, Bristol, RI
02809, USA

Tel: (001) 401- 254-3836, email: yli@rwu.edu

ABSTRACT

Under an uncertain environment, two manufacturing strategies emerged: manufacturing system automation and manufacturing system integration. Existing case studies indicate that firms should adopt manufacturing integration first and then automate the manufacturing system to improve manufacturing performance. This study empirically supports this proposition using 303 responses from manufacturing managers. Analytical results also show that the combination strategy of manufacturing system integration and manufacturing system automation has more than twice the effect on manufacturing performance than using manufacturing automation strategy alone.

Key Words: Integration; Automation; Environment Uncertainty; Manufacturing Performance

1. INTRODUCTION

The global business environment is experiencing drastic changes characterized by growing global competition, changing customer demand, shorter product life cycles, increased market diversity, and advances in manufacturing and information technology (Doll and Vonderembse, 1991, Koufteros et al., 2001). In order to meet the competitive challenges resulted from these fundamental change forces, manufacturers have adopted two major manufacturing strategies: automation and integration. Implementations of manufacturing automation are mainly through the effective use of Advanced Manufacturing Technologies (AMT) (e.g. CAD/CAM, FMS, CIMS). However, evidences show that many U.S. firms are not realizing the full benefits offered by these new technologies or even forced to withdraw them from use (Chen and Small, 1994, Small 2007). A study by Mansfield (1993) on 175 Japan, Western Europe, and U.S. firms indicated that U.S. firms have been relatively slower in assimilating FMS technologies due to a lower rate of return than elsewhere. To address this issue, several studies proposed manufacturing system integration as a solution to effectively manage AMT (Duimering et al., 1993). A case study by Burcher et al. (1999) further confirmed the importance of integration for

a company to implement AMT.

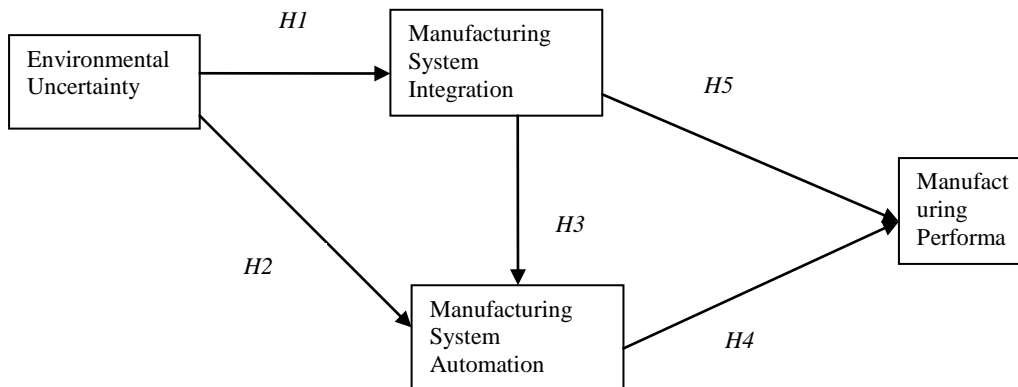
Recently, the issue of manufacturing system automation vs. integration has attracted greater attention due to the increasing level of environmental uncertainty. A case study by Vonderembse et al (1997) provided some initial empirical evidence on the role of automation vs. integration under highly uncertain environment. The study suggests that manufacturing systems must be redesigned in the post-industrial era by focusing first on integration and then automation.

The authors are very interested in two research questions: 1) What are the impacts of environmental uncertainty on manufacturing automation and integration? 2) What are the impacts of automation and integration on manufacturing performance? The next section will present the theoretical model and development of hypotheses. Research methodology is then presented along with analytical results from path analysis using structural equation modeling, followed by discussions of implications and conclusion.

2. THEORETICAL FRAMEWORK AND HYPOTHESES DEVELOPMENT

The theoretical framework under investigation in the current study can be depicted as follows (Figure 1):

Figure 1: Theoretical Framework



There are also four constructs in the above model (Table 1). There are three basic arguments in this model: 1) the environmental uncertainty drives the needs of manufacturing system automation and manufacturing system integration; 2) manufacturing system integration has a positive impact on manufacturing system automation; 3) both manufacturing system integration and manufacturing system automation have positive impacts on manufacturing performance.

Manufacturing systems automation did offer some localized benefits in terms of quality, cost and productivity. However, as the competitive environment gets much more turbulent, a highly integrated yet flexible system is required to respond to unexpected changes in order to get global optimization of the whole system. Newman, Hanna and Vonderembse, Raghunathan and Rao (1997) concluded that integration across the value chain is the first step to respond to the environmental uncertainty in their case studies. Paulraj and Chen (2007) studied the impact of in environmental uncertainty from the resource dependence perspective and found that when facing uncertainty, firms were more likely to seek external integration with trading partners and form

strategic supply chain. Thus, we have the following hypotheses:

Table 1: Construct Definitions and Literature

| Construct | Definition | Literature |
|----------------------------------|--|--|
| Environmental Uncertainty | The degree of turbulence of post-industrial environment resulted from the increasing competition, changing customer demand, shorter product life cycle, and rapidly advancing technology innovation. | Thompson, 1967; Skinner, 1985; Doll and Vonderembse, 1991; Champlin and Olson, 1994; Koufteros et al. 2001 |
| Manufacturing System Automation | Substituting labor with automatic facilities and equipment so that the system can operate with fewer labor hours per unit produced | Cooper and Zmud, 1990; Dean et al., 1992; Small and Chen, 1995; Lowe, 1995; Vonderembse et al. 1997 |
| Manufacturing System Integration | Physical connections and information flows among the manufacturing system components | Vonderembse et al., 1997; Lapalus et al., 1995; Frohlich and Westbrook, 2001; Bhatt, 2000; Giachetti, 2004; Dan et al., 2005; Deng, et al., 2002; Gao et al., 2002; Cho and Seo, 2005; Zhang et al., 2003; Cho et al., 2002; Chikan, 2001; Gimenez and Ventura, 2005 |
| Manufacturing Performance | The level of attainment of various manufacturing objectives, which are commonly considered to including Cost, Quality, Delivery, Flexibility and Innovation | Swamidass and Newell, 1987; Hayes and Wheelwright, 1984, Giffi et al., 1990; Ward et al 1998; Boyer and McDermott, 1999; Boyer and Lewis, 2002; Rosenzweig et al., 2003; Swink and Nair, 2007, Liao and Tu, 2008 |

Hypothesis 1: environmental uncertainty has positive impacts on the needs of manufacturing system integration.

Advanced Manufacturing Technologies (AMT) (e.g. CAD/CAM, FMS, CIMS) have the characteristics of using software or computer programs to control machines. This type of manufacturing systems has advantages in increasing market responsiveness while maintaining

low costs (Doll and Vonderembse, 1987). Zhang et al. (2006) empirically confirmed that in order to respond to increasing environmental uncertainty, manufacturers can utilize AMT to enhance flexible manufacturing capability as a source of competitive advantage. Therefore, we have the following hypotheses:

Hypothesis 2: environmental uncertainty has positive impacts on the needs of manufacturing system automation.

Duimering et al. (1993) proposed that the key to effective management of flexible automation is to improve manufacturing system integration before implementation. Vonderembse, Rangunathan and Rao (1997) conducted some in-depth case studies concerning the issue of automation versus integration. They found that, under the industrial paradigm of thinking, firms tend to automate specific tasks to solve local problems, which often results in “islands of automation” that are not capable of responding quickly to rapidly changing customer needs. A case study by Burcher et al. (1999) also confirmed the importance of integration in AMT implementation. Swink and Nair (2007) found similar results in their empirical study of 224 manufacturing plants which used manufacturing integration to enhance AMT usage and system automation. Therefore, we have the following hypotheses:

Hypothesis 3: manufacturing system integration has a positive impact on manufacturing automation.

The increasing use of advanced automation technologies in the U.S. manufacturing firms started in the early 1980s. During this time period, there had been many cases reporting improved quality and productivity as a result of manufacturing systems automation (Dean and Snell, 1991; Swamidass and Kotha, 1998). AMT utilization can improve product and process design, thus substantially cut down product changeover time and process variability, thereby improving manufacturing productivity and product quality (Swink and Nair, 2007). Therefore, we have the following hypothesis:

Hypothesis 4: manufacturing system automation has a positive impact on manufacturing performance.

Doll and Vonderembse (1991) has pointed out that while technology is a driving factor in the relatively stable industrial stage, technology becomes only an enabling factor when market environment gets more turbulent in the post-industrial stage. To successfully cope with the high uncertainty, manufacturers must first achieve a high level of system integration before implementing new technology (Duimering, 1993). A series of case studies by Vonderembse et al. (1997) indicated that firms operating in the post-industrial environment should focus first on integration across the value chain, and then automate those activities that add value to customers. Rondeau, Vonderembse and Ragu-Nathan (2000) empirically confirmed that high integration leads to high competitive capabilities. Therefore, we have the following hypotheses:

Hypothesis 5: manufacturing system integration has a positive impact on manufacturing performance.

3. RESEARCH METHODOLOGY AND SEM

In this section, research methods are described for the instrument development and survey administration. Among the four constructs presented in the model above, the instruments for Environmental Uncertainty (EU) and Manufacturing Performance (MP) were operationalized on five-point interval scales using multiple items developed from the strategic management and manufacturing management literature (Swamidass and Newell, 1987). The value of each variable is the mean value of the multiple items representing that variable. The EU variable was represented by 4 items in one dimension, and the MP variable was measured by 18 items in five dimensions, namely: cost, quality, delivery, innovation and flexibility. The measurements of EU and MP are verified in a previous research by Liao and Tu (2008).

The measurement items for (1) Manufacturing Automation (MA) and (2) Manufacturing System Integration (MI) are developed and validated below. The instrument development process can be roughly divided into four phases: (1) Item generation, (2) pre-pilot study, (3) pilot study, and (4) Large-scale data analysis and instrument validation. 303 responses were obtained from the Society of Manufacturing Engineers (SME).

The instrument validation processes for the two new constructs, Manufacturing System Automation (MSA) and Manufacturing System Integration (MSI), include the following steps: 1) Dimension-level corrected item-total correlation (CITC) scores and Cronbach's alpha; 2) Dimension-level exploratory factor analysis; 3) Construct-level factor analysis; 4) The final Cronbach's alpha reliability coefficients (provided only if the factor analysis result in further modification of items); and 5) The final set of measurement items for the construct (not provided if there is no change in items after instrument validation). MSA and MSI have good validity and reliability.

The AMOS algorithm provides several goodness-of-fit statistics to evaluate the hypothesized model and also suggest ways in which the model might be modified given sufficient theoretical justification.

Table 2: AMOS Structural Modeling Results

| Hypotheses | Relationship | AMOS Coefficients | t-value | p-value | Significant? |
|---|--------------|-------------------|---------|---------|--------------|
| H1 | EU → MSI | .33 | 3.85 | <0.001 | Yes |
| H2 | EU → MSA | .10 | 2.07 | <0.05 | Yes |
| H3 | MSI → MSA | .79 | 13.61 | <0.001 | Yes |
| H4 | MSA → MP | .42 | 3.84 | <0.005 | Yes |
| H5 | MSI → MP | .03 | 0.24 | 0.475 | No |
| GFI =0.975 RMSR =0.030 NFI =0.968 AGFI =0.954 | | | | | |

4. DISCUSSIONS AND CONCLUSION

Statistical significance and model fit are not the ultimate objectives of academic research. They are just the means to achieve our end, which is better understanding of the subject under investigation and discovery of new relationships. The results from the research will be of great value to practitioners in terms of assisting their business decision making processes, and to researchers in terms of providing some new instruments for further academic research.

Overall, 4 out of 5 of the hypothesized relationships (Hypotheses 1, 2, 3, and 4) were significant at or above the 0.05 level, and the final AMOS structural model displayed very good fit to the data. For the non-significant direct relationship between manufacturing system integration and manufacturing performance (Hypotheses 5), an indirect path was identified, which is the effect of integration on performance through automation.

Hypotheses 1 and 2 indicate that environmental uncertainty calls for the needs of manufacturing system integration as well as automation. The effect of Environmental Uncertainty on Manufacturing System Integration is 0.34 (H1), which is three times the effect of Environmental Uncertainty on Automation (i.e., 0.11 in H2). In the evolution process of manufacturing systems, adopting manufacturing automation is typically the first reaction of firms to cope with environmental uncertainty, but it doesn't mean manufacturing automation is the way to go (Vonderembse et al. 1997). This study shows that firms are focusing more on better integration among different components of the manufacturing system in response to increasing environmental uncertainty.

Although hypothesis 5 (the positive impact of manufacturing system integration on manufacturing performance) is supported by the Pearson correlation, it is not supported in AMOS structural equation modeling. This implies that manufacturing integration doesn't have direct effect on manufacturing performance. However, manufacturing system integration does have an indirect effect on manufacturing performance through manufacturing automation.

References available upon request