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The impact of supply chain complexity on manufacturing plant performance

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ABSTRACT

This paper puts forth a model of supply chain complexity and empirically tests it using plant-level data from 209 plants across seven countries. The results show that upstream complexity, internal manufacturing complexity, and downstream complexity all have a negative impact on manufacturing plant performance. Furthermore, supply chain characteristics that drive *dynamic* complexity are shown to have a greater impact on performance than those that drive only *detail* complexity. In addition to providing a definition and empirical test of supply chain complexity, the study serves to link the systems complexity literature to the prescriptions found in the flexibility and lean production literatures. Finally, this research establishes a base from which to extend previous work linking operations strategy to organization design [Flynn, B.B., Flynn, E.J., 1999. Information-processing alternatives for coping with manufacturing environment complexity. Decision Sciences 30 (4), 1021–1052].

1. Introduction

The last twenty years have seen a steady convergence of the traditionally distinct areas of operations management (OM), sourcing, and logistics into a single area commonly known as supply chain management (SCM). According to the SCM perspective, it is no longer adequate for businesses to run these areas as loosely linked pockets of excellence. They must also develop and manage the information flows, physical flows and relationships that link these areas together, and link these areas with upstream and downstream partners.

At the same time, the SCM perspective requires businesses to broaden the scope of business activities that must be designed and managed, and the nature of these activities has become more challenging as product life cycles shorten, product variety and customization levels increase and supply chain partners become more geographically dispersed. Managing the supply chain, therefore, is clearly a challenging mission, and most observers would agree that a supply chain is a complicated system. In this paper, however, we employ some of the concepts and terminology of the systems science literature to formally define *supply chain complexity*, clarifying the aspects of supply chains that make them truly *complex* systems. While much attention has been paid to why it is necessary for companies to expand the scope and depth of their supply chain activities (e.g., Swafford et al., 2006), only recently have researchers and practitioners begun to consider the downside of this added complexity (Hoole, 2006).

In addition to defining supply chain complexity, we also empirically explore the impact of various sources of complexity—upstream in the supply chain, internal to the manufacturing plant, and downstream from the plant—on manufacturing plant performance. Our results allow us

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to identify the sources of complexity that have a statistically significant impact on plant performance across a large data set of manufacturing plants from various industries and geographic regions of the globe. Moreover, our results resonate with the existing lean production literature in terms of the importance of certain sources of complexity in explaining poor manufacturing performance. Our research also helps to illuminate important priorities for supply chain managers in focusing on certain lean principles over others.

The remainder of this paper is organized as follows. We first review the systems complexity literature, paying particular attention to the concepts of detail complexity and dynamic complexity. Out of this, we develop a definition of supply chain complexity, and discuss its three component parts: internal manufacturing complexity, downstream complexity, and upstream complexity. In the third part of the paper, we put forth a conceptual model of supply chain complexity, which we then test using data gathered from 209 manufacturing plants in seven countries. We end the paper by discussing the parallels and differences between our results and the prescriptions found in the lean production literature, implications for managers, and directions for future research.

2. Literature review

2.1. System complexity

Complexity has been discussed in a wide range of literatures, including philosophy, the physical sciences, engineering and management (e.g., Simon, 1962; Casti, 1979; Holland, 1995; Choi et al., 2001). Despite this attention, there remains a broad range of definitions regarding what constitutes a complex system. Much of this definitional work has been used in studying, predicting, and controlling "chaotic" systems (e.g., Stewart, 2002), and has been incorporated in the organizational theory literature (e.g., Stacey, 1996; Stacey et al., 2000). This stream has also extended to the supply chain management literature, where Choi et al. (2001) have laid the groundwork for research that uses some of these ideas to model supply chains as "complex adaptive systems," along the lines of the systems-theoretic work summarized in Holland (1995).

More recently, Surana et al. (2005) and Pathak et al. (2007) have extended the theory-building work that applies complex adaptive system (CAS) concepts to SCM, the former by suggesting analytical frameworks for applying CAS principles in studying the management and performance improvement of supply chains, and the latter by providing an extensive review of CAS theory development and application in a wide array of fields. In this section, we first review some of these definitions, and then provide our own definition of supply chain complexity, which forms the basis of our conceptual model and empirical tests.

Simon (1962) offers the following, concise definition of system complexity: "Roughly, by a complex system I mean one made up of a large number of parts that interact in a nonsimple way" (p. 468). This two-pronged view of complexity—numerousness and interactions—is also found in Casti's (1979) definition, which holds that "complexity refers to two major aspects of a system: (a) the mathematical *structure of the irreducible component subsystems* of the process and (b) *the manner in which the components are connected* to form the system" (p. 41) [author's italics].

Yates (1978) defines a complex system as one that exhibits one or more of the following five attributes: (1) significant interactions, (2) high number of component parts or interactions, (3) nonlinearity, (4) broken symmetry, and (5) nonholonomic constraints. It is these last three characteristics that, according to Flood and Carson (1988), are indicative of higher-order complexity since they make a system's responses hard to predict over time. Nonlinearity arises when the response of the system to a given input is non-proportional. Highly complex systems often fail to exhibit the kind of one-to-one mapping of inputs to outputs that one might find in a simple system. Other manifestations arise when portions of the system are in some way not accessible from other portions of the system. This can be due to the asymmetry of the system, or the existence of nonholonomic constraints, which arise when one or more portions of the system are left outside the central control, allowing these portions of the system to, in the words of Flood and Carson (1988, p. 27), "go off and do their own thing." An example would be a supply chain with multiple downstream demand points that independently place orders on a centralized supply point without regard to supply constraints or the needs of other demand points. In such a case, the same "input" (placing an order based on pre-established inventory policies) can have varying effects, depending on the state of the supply chain. It is these higher-order aspects of complexity that Waldrop (1992) highlights when he points out that what makes complex systems complex is "a kind of dynamism that makes them qualitatively different from static objects such as computer chips or snowflakes, which are merely complicated" (pp. 11–12).

Based on this literature, then, we define *detail complexity* as the distinct number of components or parts that make up a system, while we use the term *dynamic complexity* to refer to the unpredictability of a system's response to a given set of inputs, driven in part by the interconnectedness of the many parts that make up the system. Perhaps the most accessible view of dynamic complexity and its distinction from detail complexity is offered by Senge (1990), who defines detail complexity as being driven by the *number* of variables embedded in a system. In contrast, Senge indicates that dynamic complexity involves "situations where cause and effect are subtle, and where the effects over time of interventions are not obvious" (p. 71). Consistent with the various definitions we present above, Senge points out further that dynamic complexity is present "when an action has one set of consequences locally and a very different set of consequences in another part of the system ... [or] when obvious interventions produce nonobvious consequences" (p. 71).