Chapter 8

Fuzzy System Dynamics:
An Application to Supply Chain Management

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ABSTRACT

In the presence of fuzzy or linguistic and dynamic variables, dynamic modeling of real-world systems is a challenge to many decision makers. In such environments with fuzzy time-dependent variables, the right decisions and the impacts of possible actions are not precisely known. The presence of linguistic variables in a dynamic environment is a serious cause for concern to most practicing decision makers. For instance, in a demand-driven supply chain, demand information is inherently imprecise, leading to unwanted fluctuations throughout the supply chain. This chapter integrates, from a systems perspective, fuzzy logic and system dynamics paradigms to model a typical supply chain in a fuzzy environment. Based on a set of performance indices defined to evaluate supply chain behavior, results from comparative simulation experiments show the utility of the fuzzy system dynamics paradigm: (1) the approach provides a real-world picture of a fuzzy dynamic supply chain, (2) expert opinion can be captured into a dynamic simulation model with ease, (3) the fuzzy dynamic policies yield better supply chain performance, and (4) "what-if analysis" show the robustness of the fuzzy dynamic policies even in turbulent demand situations. Managerial insights and practical evaluations are provided.

INTRODUCTION

Due to the presence of fuzzy or linguistic and dynamic variables, the modeling of dynamic real-world systems such as social or humanistic systems is a challenge to many decision makers. Decision makers, including economists, politicians or supply chain managers often face difficulties when addressing real-world dynamic systems. Under such conditions characterized by linguistic time-dependent variables, it is difficult to make precise decisions and anticipate the im-

pacts of possible actions. As such, the presence of linguistic variables in a dynamic environment is a serious cause for concern. As stated by Tessem and Davidsen (1994) "we need qualitative techniques because we are often unable or unwilling to describe system structure, state, and behavior with exact numerical precision." In other words, there is need to circumvent numerical quantification because our conceptions are often vague or uncertain. A typical fuzzy dynamic system is a manufacturing supply chain system with fuzzy demand behavior.

In a demand-driven supply chain, demand information is often inherently imprecise, leading to unwanted fluctuations throughout the supply chain. Real-world supply chain systems have imprecise, linguistic, and dynamic variables that play a significant role in the overall behaviors of the supply chain systems (Houlihan, 1987; Tessem & Davidisen, 1994, Retortillo et al., 2008; Campuzano & Mula, 2010). As such, when a supply chain system is characterized by fuzzy data and ambiguous variable relationships, developing robust supply chain strategies is a complex task that requires reliable decision support tools. Under these situations, it is often difficult to precisely determine future demand, creating further serious challenges to the supply chain policy makers. Demand-related uncertainties usually arise from a number of possible causes and sources. Some of these causes are as follows:

1. Turbulent external market conditions.
2. Unpredictable demand patterns in a fast growing economic environment.
3. New innovative business ventures where demand patterns are not known precisely.
4. Insufficient or outdated past information.

Turbulent external market conditions are a common cause for concern among supply chain decision makers (Petrovic, 2001; Giannoccaro, Pontrandolfo, Scozzi, 2003). In modern business environments, local and global economic crises have resulted in numerous unprecedented shifts in

business operations for economic survival. Supply chain players take innovative decisions to expand or specialize, or to diversify or shrink their business operations. In response to these turbulent changes, the marketplace tends to cautiously adjust their buying behavior so as to minimize the impact of the drastic changes in demand-supply situations. Since the marketplace is inundated with future uncertainties in supply, their buying behavior tends to be uncertain, which ultimately affects the overall demand pattern in the marketplace. In such turbulent environments, it is difficult to anticipate and estimate the future demand pattern in a dynamic and turbulent environment (Campuzano, Mula, Peidro, 2010), let alone predict the performance of the supply chain system (Ganga and Carpinetti, 2011). Therefore, there is need for more robust systems simulation methodologies that take into account the turbulent dynamics in real-world complex systems.

Unpredictable demand patterns are common in most fast growing economic environments. Though it may be worthwhile estimating demand patterns using historical data of similar systems which may have gone through similar situations, it is not always the case that historical patterns will repeat themselves due to change of prevailing conditions. Coupled with turbulent global market situations, and the heavily networked supply chain systems, a slight shift at one point in the business network will create a chaotic response behavior in the entire system (Sinha & Sarmah, 2008). Supply chain management is quite complex due to the presence of various sources of uncertainty and complex interrelationships between various entities in the supply chain system (Giannoccaro, Pontrandolfo & Scozzi, 2003; Wang & Shu, 2005). Consequently, every single dynamic change has a ripple effect on the whole supply chain system. As modern supply chain systems become more and more closed loop, estimating future demand behavior continues to be more and more challenging, especially in an uncertain environment (Mukhopadhyay & Ma, 2009; Wei & Zhao, 2013). To make appropriate decisions, the decision maker

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