# Chapter 11
# Analyzing the Lead Time and Shipping Lot-Size in a Chaotic Supply Network

**Mohammad J. Tarokh**
*K. N. Toosi University of Technology, Iran*

**Sina Golara**
*K. N. Toosi University of Technology, Iran*

## ABSTRACT

*Supply network issues recently have attracted a lot of attention from industrial practitioners and academics worldwide. Supply networks are highly complex systems. The oscillations in demand and inventory as orders pass through the system have been widely studied in literature. Studies have shown that supply networks can display some of the key characteristics of chaotic systems. Chaos theory is the study of complex, nonlinear, dynamic systems; therefore it can be useful for studying the dynamics of supply networks. In this paper the authors implemented a system dynamic approach and simulated a chaotic multi-level supply network. The authors analyzed the effects of decision parameters, delivery lead time and shipping lot-size on chaotic behavior of the whole supply network. The simulation revealed that an increment in lead times or shipping lot-size has a similar impact on chaotic behavior of the system and reduces the chance of chaotic behavior occurrence.*

## INTRODUCTION

A supply chain is a complex system that involves multiple entities encompassing activities of moving products and adding value from raw material stage to final delivery stage. There are various types of uncertainties along the chain such as demand uncertainty, production uncertainty, and delivery uncertainty. Making decisions about to how much and when to replenish, often needs a feedback process to trigger interaction between partners, which may result in nonlinearity of the system. We usually observe a time delay between when a decision is made and when we feel its effect, which further complicates the interaction between partners. Feedback, interaction, and time

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delay exist in many supply chain processes. This makes the supply chain a complex dynamic system (Hwarng & Xie, 2008).

By increasing the partners of supply chain in each level, 'supply network' is introduced in the literature. In a supply network, for a given product and speed required by the customer, handling of logistics operations become more and more complex when vertical, horizontal, spatial and relational complexities grow (Romano, 2009).

The introduction of chaos theory goes back to the study by Lorenz (1963) on weather forecasting systems. Feigenbaum (1978) and Mandelbrot (1982) contributed to this field. One of the significant achievements of chaos theory is its ability to demonstrate how simple deterministic relationships can produce patterned yet unpredictable behavior. The key features of chaos are listed in Williams (1997) and Wilding (1998):

1. **Sensitivity to initial conditions (the butterfly effect):** Small changes multiply over time due to nonlinearity and the dynamic, repetitive behavior of the system;
2. **Irregular and random-like behavior:** The system behavior seems to be random;
3. **Non-randomness:** Chaos only happens in deterministic systems;
4. **Strange attractor:** A specific pattern is observed in the phase space;
5. **Bounds:** Variables are bounded.

Because of butterfly effect long-term planning and forecasting are very difficult in chaotic systems. Chaos theory has attracted a lot of interest in many fields. This might be because chaos theory suggests we can find order and structure beneath complex behaviors (Levy, 1994). There has been a lot of interest in utilizing chaos theory implications in financial, economical and management studies but there are limited studies in the fields of inventory management and supply chain management (Hwarng & Xie, 2008).

Hwarng and Xie (2008) considered chaos in a multi-level supply chain, classical beer distribution model with some modifications. They offered viewpoints about how to manage interrelated supply chain factors in order to eliminate or reduce system chaos. They considered various supply chain factors, i.e., demand pattern, ordering policy, demand-information sharing, and lead time, and studied the dynamics of the system under their influence.

Romano (2009) investigated the appropriate configuration of supply chains and business processes in the time-sensitive casual wear industry in order to achieve time performance. He explained the relations among the supply network configuration, business process structure and time performance using fluid dynamics. He described the relation between time performance and configuration decisions.

Wilding (1998) considered the management and design of supply networks from the viewpoint of chaos theory. He suggested that chaos theory can partly explain the failure of traditional approaches to significantly reduce uncertainty. He suggested that supply networks can exhibit some of the key characteristics of chaotic systems, e.g., sensitivity to initial conditions that undermines computer accuracy; exhibiting temporary stability; generating patterns while being highly complex and invalidating the reductionist view.

Levy (1994) suggested that chaos theory can provide an appropriate theoretical framework through which we can better understand the dynamics of industries and the complex relations among industry entities. He demonstrated that industries are complex, nonlinear, dynamic systems that exhibit both unpredictability and underlying order. He suggested the use of chaos theory for strategy and management.

Xu et al. (2009) designed a Prediction model of supply chain demand which has been built by fuzzy neural network based on a chaotic time series to enhance the prediction accuracy of supply chain demand.

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